Assessing, Capturing and Utilising Methane from Expired and Non-operational landfills

An EU LIFE+ project for 2012-2015

ACUMEN project report - Managing landfill gas at closed and historic sites






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The ACUMEN Project

The project partnership

The ACUMEN project is a partnership between the Environment Agency, Norfolk County Council, Ground Gas Solutions Ltd, Biogas Technology Ltd, the UK Department of Energy and Climate Change, the UK Department for Environment Food and Rural Affairs and Warsaw University of Technology.

All the partners contributed resources towards the project which was supported by the European Union EU LIFE+ Programme.

The project started in September 2012 and completed in August 2015.

Project goal

The goal of the ACUMEN project was to demonstrate approaches to managing methane gas and reducing methane emissions at closed landfills.

The project:

- Demonstrated a range of approaches for assessing methane production at closed landfill sites.
- Investigated the technical and economic viability of capturing, utilising and mitigating methane from closed landfills by monitoring and assessing the results from the project.
- Communicated the lessons learnt from ACUMEN and shared the guidance and tools to help encourage others to manage methane from closed landfill sites.

Driver for the project

The project was initiated as there are currently economic and technical uncertainties hampering wide take up of new technologies to manage methane emissions from closed and historic landfill sites.

Our aim was to explore these uncertainties through a number field scale demonstrations of methodologies, technologies and techniques for assessing, mitigating and utilising the methane at closed landfill sites.

This report presents the findings from our ACUMEN project. We have tried to present this in a way that we hope will allow others to benefit from what the project team learned during the course of the work.

Introduction to this report

Objective and intended audience

The objective of this report is to provide advice to people who are responsible for managing the gas at closed and historic landfills.

The advice is based on our learning and experience during the ACUMEN project and is presented to help closed landfill site owners identify the most suitable approaches to managing the landfill gas at their site, or sites.

The intended audience for the report are people who are involved in managing closed landfills. That could range from people who wish to assess their portfolio of closed landfills through to people who are looking to possibly generate some electricity or income from the closed landfills that they are currently managing.

Whilst writing this, the team were acutely conscious that there is a lot of technical guidance already available about managing landfills, and equally that we have only worked at a small number of closed landfills which we chose to allow us to demonstrate a range of techniques which we believe are typical of older closed sites.

This report is not exhaustive or a detailed 'how to' guide for managing closed landfills, but rather focuses on the key areas of new learning we encountered during the ACUMEN project. For this reason, the report includes more detail on some aspects of managing closed landfills than others.

A typical closed landfill and gas management system in the UK

Why has ACUMEN focused on closed landfills?

Background

The UK and Europe has a large closed landfill legacy. There are approximately 20,000 closed landfill sites in the UK[1] and many more within the EU. Additionally, there are in excess of 6,000 (as of 2012)[2] operational landfills in the EU, many of which will close during the coming decade.

Legislative context

The EU Landfill Directive (1999/31/EC) provides regulatory direction to member states in operating permitted landfills[i], with gas control in particular, a key area requiring stringent operating conditions to minimise emissions and the risks to human health and the environment.

Many closed sites precede the need for regulation in this context and are therefore not subject to the same level of regulatory control. Furthermore, the quality and quantity of landfill gas tails off over time which can make investment in managing landfill gas from closed sites a challenge.

Issues such as contaminants in the gas, variations in flow and methane concentration, difficulty of exporting electricity to the grid and financial incentive schemes can be a barrier to public bodies and businesses investing in projects to utilise this source of methane. Our aim has been to explore these issues and attempt to reduce the financial and technical uncertainty that exists.

Demonstrating new options

When we started the ACUMEN project, it was not clear how best to manage landfill gas from older sites and the costs and value from doing so were not well understood.

However, the project team were aware that there are a range of new technologies and techniques emerging that address the challenges in assessing, mitigating and utilising lower quality gas from closed landfill sites. The ACUMEN project has allowed us to demonstrate a number of promising technologies and viable approaches to managing gas at closed sites and stimulated further development and interest in this emerging area.

We hope that the lessons from the project will give people increased confidence in the options that we have demonstrated for managing landfill gas at both permitted and non-permitted closed landfill sites.

[1] Categories of landfill for methane emissions; Jacobs 2010
[2] Eurostat - Product code: *env_wasfac*, updated on *25-Mar-2015*

The landfill gas management hierarchy

Overview

Some European member states have provided detailed guidance on landfill gas (for example, Environment Agency; 2009), including the setting out of a clear landfill gas 'treatment hierarchy' based on gas volume and quality. The key principle underpinning this hierarchy is that wherever possible, landfill gas should be put to beneficial use.

Our work on the ACUMEN project focused on older closed landfills. We have adapted the traditional landfill gas hierarchy and the diagram below illustrates the range of gas conditions that we have focused on.

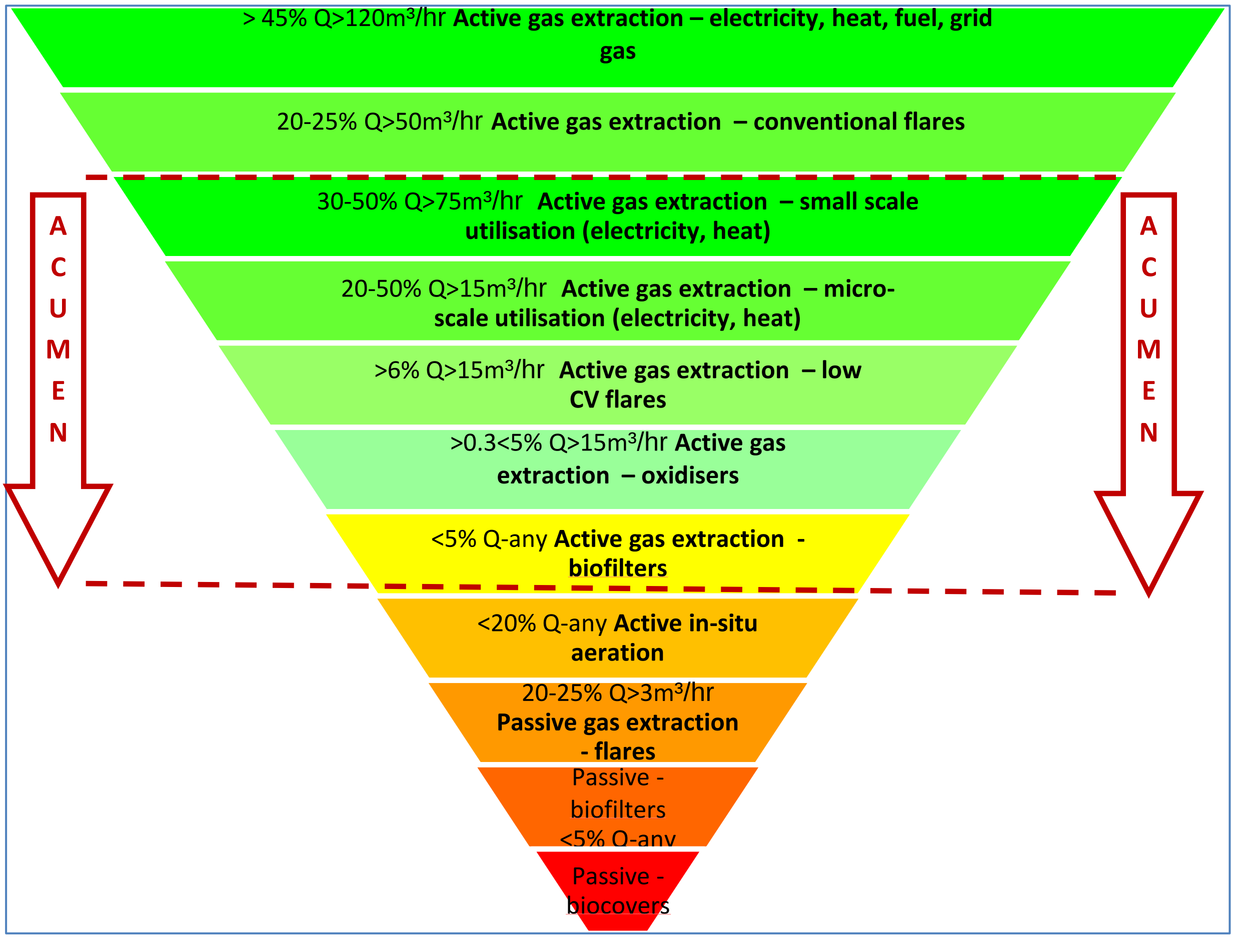
During the ACUMEN project we have demonstrated that power generation at lower gas flows and methane concentrations is technically viable at some of these older closed landfills which have previously only flared their gas.

This adapted hierarchy appears throughout this report to illustrate what the project team feel are appropriate gas management techniques for a range of gas conditions typically found at older closed landfills.

An adapted LFG management hierarchy

The adapted diagram below illustrates the range of options available for landfill gas management, with the options ACUMEN has considered highlighted.

Highest methane concentration & flow



Lowest methane concentration & flow

Structure of this report

Report structure

Broadly speaking, our work focused on *assessing the site* and approaches to *managing* gas at closed landfills and the chapters in this report reflect this.

In addition to the chapters, we have also compiled a series of technical summaries of the practical field-scale demonstrations that we carried out during the ACUMEN project – These are presented in chapter 7.

A brief overview of the chapters in this report is presented below.

A S S E S S I N G

Generally speaking, the first stage in any study to investigate changes to the way you manage gas at a closed landfill is to 'assess' your portfolio of sites, and the current gas conditions at them. Based on our ACUMEN experience, some of the questions you may need to consider are set out below.

Question 1

Q. I am responsible for a portfolio of closed landfills and would like to get a feel for the likely gas management and whether any of my sites might have the potential for power generation.

A. Review the **Portfolio Screening Tool chapter (Chapter 1**) to help you to better understand your sites. This spreadsheet-based tool allows you to quickly screen your portfolio to identify the sites with potential for some form of gas utilisation or mitigation scheme. *If you already have a good knowledge of your sites, skip forward to question 2.*

Question 2

Q. I think one of my closed landfills may be suitable to support some form of power generation. What do I do next?

A. Review **Chapter 2 and use the Gas Estimation Tool (GET)**. This spreadsheet-based tool allows you to quickly estimate how much gas your closed landfill may be generating. If you already have good quality information about the gas regime at your site, skip forward to question 3.

Question 3

Q. Now that I have better information about my site, I think that some form of methane utilisation scheme may be viable. However, I'd like to do some monitoring to confirm my understanding of the amount of gas being generated and surface emissions at my site. What techniques could I consider?

A. *Go to **chapter 3 on Monitoring** to learn more about* the innovative techniques that are available to help improve your understanding of the gas generation and surface emissions at your sites. This chapter highlights some of the new techniques developed by the ACUMEN project team.

Having considered the questions above, and obtained a better understanding of the gas regime at your site you could now start to consider the options for managing the gas. The questions in the next section will help you with this.

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G

Gas conditions at a landfill change over time, and so the most appropriate option for managing the gas will also vary. Assuming you have a good understanding of the gas conditions at your site, the following questions could help you identify the most appropriate option, and how to progress it.

Question 4

Q. I am managing an older closed landfill with decreasing gas volumes and methane concentrations – What are my options?

A. Review **Chapter 4 on Available technologies to** learn more about the options which ACUMEN demonstrated and may be suitable for your site. When considering your options, it may also be helpful to consider **Chapter 7 on our demonstration sites** and ask yourself 'Could this work at my site?' If you have already chosen a technology, skip forward to question 5 to consider the costs and benefits.

Question 5

Q. Changing the way I manage gas at my site will have financial implications. What costs, benefits, risks and issues might I need to consider when developing a business case for changing my current gas management approach?

A. Review **Chapter 5 on Assessing the costs and benefits** to understand some of the issues when considering developing an economic case for changing the way you manage the gas at your site. If you have already worked through your business case, skip forward to question 6.

Question 6

Q. I'm thinking about changing the way I manage gas at my site. What are the regulatory issues I need to consider?

A. Review **Chapter 6 on Regulation and grid connection**. This will help you understand the planning and environmental permitting regulations that may apply. If your chosen gas management option involves electricity generation for export, the section of chapter 6 on grid connection will also be relevant to you.

Having considered these questions, you should be well placed to decide on the most appropriate gas management option for your site. We've deliberately presented these chapters as discrete topics. However, we recognise that the process of assessing your options often isn't simple, and in reality you may need to consider several of the chapters at the same time. This is illustrated in chapter 7 which presents examples of our demonstration site work, and highlights some of the complexities involved in planning and implementing changes to the gas management systems at closed and historic landfills.

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Chapter 1 - Screening your landfill portfolio

This chapter provides an overview of the ACUMEN Portfolio Screening Tool (PST). This has been developed to enable owners of multiple closed landfills to quickly screen and prioritise their sites based on their potential to support a power generation scheme.

The ACUMEN Portfolio Screening Tool

Background

When developing the PST we recognised that many people will not have access to all of the data about their closed landfill sites - Therefore, the PST only requires a very limited amount of data about a site. If you already have access to data about the gas quality and flow at your site then this will give you a far better indication of the potential for the site to support a power generation scheme than the ACUMEN PST.

You can access the ACUMEN PST online.

What's the ACUMEN PST intended for?

The tool is intended to help closed landfill site owners carry out an initial review of their sites to identify those that might warrant further investigation of the landfill gas as a potential source for power generation.

How does the tool work?

The tool asks you to provide a value from one to five for a set of simple parameters and then sums these values to provide an overall score. The higher the score, the greater the potential for power generation at your closed landfill site.

To help people make initial estimates on the scores for each parameter, the ACUMEN Team have made suggestions about what scores to use for the parameters. These are presented in this chapter as well as being included in the PST spreadsheet.

What should the tool be used for?

The tool is intended to provide a quick and simple first step for anyone wishing to assess the portfolio of closed landfills that they either own or manage and help them identify those that offer the greatest potential for a power generation scheme.

What should the tool not be used for?

The tool should not be the sole basis for decision making and is no substitute for practical experience of the site.

Selecting our ACUMEN demonstration sites

At the start of the ACUMEN Project we drew up a list of closed landfill sites that would have made ideal demonstration sites. This was reduced to a short list which we then refined down to the five demonstration sites described in chapter 7. Whilst going through this process we considered similar criteria to those described below. However, within a time limited project, there had to be a degree of pragmatism about choosing our demonstration sites – particularly in relation to being able to rapidly obtain the site owners' permission to work at the site.

Introduction

The PST is an Excel spreadsheet based tool built using Microsoft Excel 2007. The section below provides an overview of the parameters used by the PST. To get the maximum benefit from these sections of this chapter, it would be helpful to have a copy of the tool available to use.

Data inputs for the PST

The PST tool is intended to be a very quick and simple tool to use. As a result, it requires only subjective assessments to produce an answer. In order to use the PST in a meaningful way, you should be sufficiently familiar with the site's details to provide scores against each parameter in the tool's scoring system. These are the:

- waste type accepted
- size of site
- leachate conditions
- site engineering
- current gas collection infrastructure
- presence of an electricity grid connection

Waste type

The type of waste that was deposited at a landfill site during its operational period will have a significant impact on the gas generation potential of the site. Broadly speaking, the higher the percentage of biodegradable waste a site took, the greater its potential to generate methane as a result of the breakdown of the waste.

Previous work on the gas generation curve[3] shows that gas is still being produced decades after the site stopped receiving waste, albeit at lower quantities and calorific values. However, sites that accepted mainly inert waste are likely to have a very low probability of producing enough methane to support a small-scale power generation scheme.

ACUMEN suggested scores:

- 1 - If the site only accepted inert waste.
- 2 - If the site only accepted construction and demolition waste.
- 3 - If the site accepted mixed waste.
- 5 - If the site accepted municipal waste.

Surface area of the site

As a general rule, the larger the landfill, the greater the potential for gas generation, as the site is likely to have accepted greater volumes of waste.

Conversely, smaller sites are likely to have less waste and hence less potential to produce gas as a result of the waste decomposing.

ACUMEN suggested scores:

- 1 - If the surface area of the site is < 1 hectare.
- 2 - If the surface area of the site is >1 and <2 hectares.
- 3 - If the surface area of the site is >2 and <5 hectares.
- 4 - If the surface area of the site is >5 and <10 hectares.
- 5 - If the surface area of the site is >10 hectares.

[3] Environment Agency, 2004; LFTGN03, Section 6.3, page 56

Leachate conditions

High leachate levels may be an indicator of raised water levels within the waste mass and this can have the effect of suppressing gas generation. Whilst a certain amount of moisture is needed to assist the process of waste break down, too much liquid within the waste mass is likely to lead to significant reduction in the rate of gas production. Additionally, if the waste mass is fully saturated it can mean that it is difficult to extract the gas.

ACUMEN recognises that many people carrying out screening assessments may not have sufficient knowledge of their site to be able to identify which of the categories presented below their site falls within - We have therefore provided some suggestions below based on three categories.

ACUMEN suggested scores:

- 1 - If the waste mass can be categorised as 'fully saturated'
- 3 - If the waste mass can be categorised as 'dry'
- 5 - If the waste mass can be categorised as 'damp '

Site liners and capping layers

Broadly speaking, sites that benefit from containment engineering (lining and capping layers) are more likely to successfully support a power generation project than uncontained sites. We recognise that the impact of site lining and capping layers on gas collection and utilisation is complex, however for the purpose of this tool we have tried to simplify this topic.

ACUMEN suggested scores:

- 1 - If there is no engineered liner or capping layer.
- 3 - If the site only has a capping layer.
- 5 - If the site has both a liner and capping layer.

Gas collection infrastructure

Sites that currently have a gas collection system (wells, pipework, blowers etc) in place are likely to offer the greatest potential for economically viable power generation. However, an important first step is to consider how effectively the existing infrastructure is working.

Generally speaking, the installation of a new gas collection system would be a significant cost. Therefore, only sites that currently have a working gas collection system in place are likely to offer any realistic potential for economically viable power generation.

ACUMEN suggested scores:

- 1 - If there is no gas collection infrastructure in place.
- 3 - If there is gas collection system in place, but its condition is unknown.
- 5 - If there is an effective gas collection system.

Grid connection

An electricity grid connection is required if you wish to export electricity and receive payment for it. Installing a new grid connection can be a significant expense.

If your intended power generation is below 50Kw, you may not need to upgrade/install a grid connection. This is because you can use the electricity supply connection for your gas extraction systems/site offices/weighbridges to export your generated power.

If your intended power generation is above 50 kW, you will need a suitably sized grid connection. Sites that have previously run large scale power generation schemes may well still have a grid connection in place that will allow you to support a power generation scheme exporting greater than 50kW.

ACUMEN suggested scores:

- 1 - If there is no grid connection at the site.
- 5 - If there is an operational grid connection in place that has the capacity to allow power export.

Screening multiple sites

The ACUMEN PST will provide a qualitative indication of the suitability of a single site for power generation. However, the tool is at its most useful if used to screen a number of closed landfills, allowing you to compile a prioritised list of those sites most likely to prove viable, and therefore those deserving of earliest attention.

Understanding the results

Power generation

The PST will return a score of between 6 and 30 for your site. Broadly speaking, we would suggest that if your site scored more than 20 it may be worth taking further steps to investigate the gas generation potential and potential economic viability of a power generation scheme. For example, this could involve using the ACUMEN Gas Estimation Tool described in chapter 2 (or other gas modelling tools) and then assessing the possible costs and benefits as described in chapter 5.

LFG mitigation options

If your site scored less than 20, then it is unlikely that your site will offer the potential for a viable power generation scheme. However, it may well be suited to some of the other available techniques for residual landfill gas management, such as those described in chapter 4.

Monitoring required?

Should these initial investigations prove positive then you may need to carry out some monitoring to verify the amount of gas available, possibly including some of the techniques discussed in chapter 3. These techniques may give you further data with which to refine the most appropriate mitigation or utilisation option.

PST examples

We have run the PST for some of the ACUMEN demonstration sites and the results are presented as examples within the PST tool itself.

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Chapter 2 - Estimating landfill gas generation

This chapter provides an overview of the ACUMEN Gas Estimation Tool (GET). This tool has been developed to enable owners of closed landfills to quickly estimate the rate of landfill gas generation at their sites without the need for detailed data or modelling. You can use this information to help inform your choice of gas management option. If you already have gas flow data from a flare or engine, then you do not need to use the GET for your site as you already have more useful data than the GET can provide.

Introduction

Background

Estimating rates of landfill gas generation can be difficult and require detailed information on the landfill in question and the waste deposited. These difficulties are particularly acute on closed and historic landfills where data availability is often very limited. One recent report stated: *'Factors influencing the rate and quantity of methane produced in landfilled waste, and the migration of methane emissions, are site specific.' (Jacobs 2010, p1)*

These factors vary in number and significance, and include: waste type, quantity and age; landfill dimensions (area, depth, total volume); the degree of engineering present (for example, engineered capping or lining) and the underlying geology. In addition, hydrogeology and the local (micro-) climate, with moisture in particular, are other significant factors in determining waste degradation rates, and therefore gas generation rates.

Older closed landfills, due to a wide variation of size, age and disposal practices, often exhibit apparent variation in landfill gas generation within the waste mass with 'pockets' of landfill gas often reported where differential rates of waste degradation are evident.

All of this makes accurately estimating methane generation from older closed landfills a very difficult process.

LFG modelling

A range of tools and software is available to model landfill gas generation rates. However, these tools often require large amounts of data and experienced users to generate accurate landfill gas models.

ACUMEN felt a quicker and simpler tool was required to allow landfill operators to quickly gain an indication of likely landfill gas generation rates, without requiring extensive data or experience. As a result, the project developed the ACUMEN Gas Estimation Tool to fill this gap.

For more information on other available modelling tools, please see Further modelling below.

ACUMEN GET purpose

The purpose of the ACUMEN GET is to provide a quick indication of how much gas your site may be generating, and therefore, which type of technology or intervention might be appropriate for your site.

You can access the ACUMEN GET online.

The ACUMEN Gas Estimation Tool

ACUMEN GET	The ACUMEN Gas Estimation Tool (GET) was developed to provide quick estimates of likely gas generation at closed UK landfills, without requiring large amounts of data, experienced staff or detailed modelling work.
What's the ACUMEN GET intended for?	The tool is intended to indicate approximate landfill gas generation rates during the post-closure period at typical UK landfills, based on very limited data inputs. The tool also approximates the potential greenhouse gas emission at such sites if no methane recovery is in place (for example, at a site that employs passive landfill gas venting).
How does the tool work?	The approximations are based on simplified modelling of typical late-1990s UK waste data derived using Gassim (Version 2.05). The tool works by using the data inputted to match a landfill's operational parameters (operational period, years since closure and total waste deposited) against a set of pre-populated data tables. The tool then presents a series of simple graphical and numerical results.
What should the tool be used for?	The tool is intended to provide a quick and simple **first step** to anyone wishing to develop or improve gas management and utilisation at a UK landfill, particularly those with no history of active gas management.
What should the tool not be used for?	This tool **must not** be used as the sole basis to intervene, or not, in the current gas management regime at any particular landfill.
Important!	The ACUMEN GET is calibrated for closed UK non-inert landfills, particularly those which closed between 1990 – 2005. The GET tool can easily be recalibrated for other countries or categories of landfill. Instructions on how to do this will be contained in the ACUMEN technical report (due for publishing Autumn 2015).

How to use the tool

Introduction

The GET tool is intended to be a very quick and simple tool to use, as a result, it requires very little data to work. This section details how to use the GET tool to establish an estimated gas generation rate or greenhouse gas potential.

Data inputs

The GET tool requires three pieces of data to work successfully. They are as follows:

- The year your landfill began accepting waste*
- The year your site ceased accepting waste**
- How much waste your site accepted***

* Many closed UK landfills have long waste management histories. For the purposes of the GET tool, it is suggested that users enter the year when the site in question first had a modern (post-1974) waste management licence or equivalent.

** In order to generate the most representative gas generation curve, it is suggested that users enter the year when large scale waste deposits ended, rather than the year of final deposit or formal closure.

*** This value can be calculated, estimated or completed from your records. The value should be entered in kilotonnes. That is '100' would equal 100,000 tonnes, and '1000' would equal 1 million tonnes and so on.

Results

The GET tool presents four distinct results based on the data you input. They are as follows:

Result 1 – Operational period

- This confirms your site's operational period based on the 'opening' and 'closing' year you entered.

Result 2 – Operational gas generation estimate

- This estimates the current rate of gas generation at your site, expressed in cubic meters of landfill gas per hour ($m^3 hr^{-1}$) at 50% methane content.

Result 3 – Current greenhouse gas potential

- This converts result 2 into an equivalent greenhouse gas potential, expressed in tonnes of carbon dioxide equivalent per year ($t\ CO_2\ y^{-1}$)

Result 4 – Remaining greenhouse gas potential

- This indicates the projected greenhouse gas potential of your site for the fifty years after its closure.

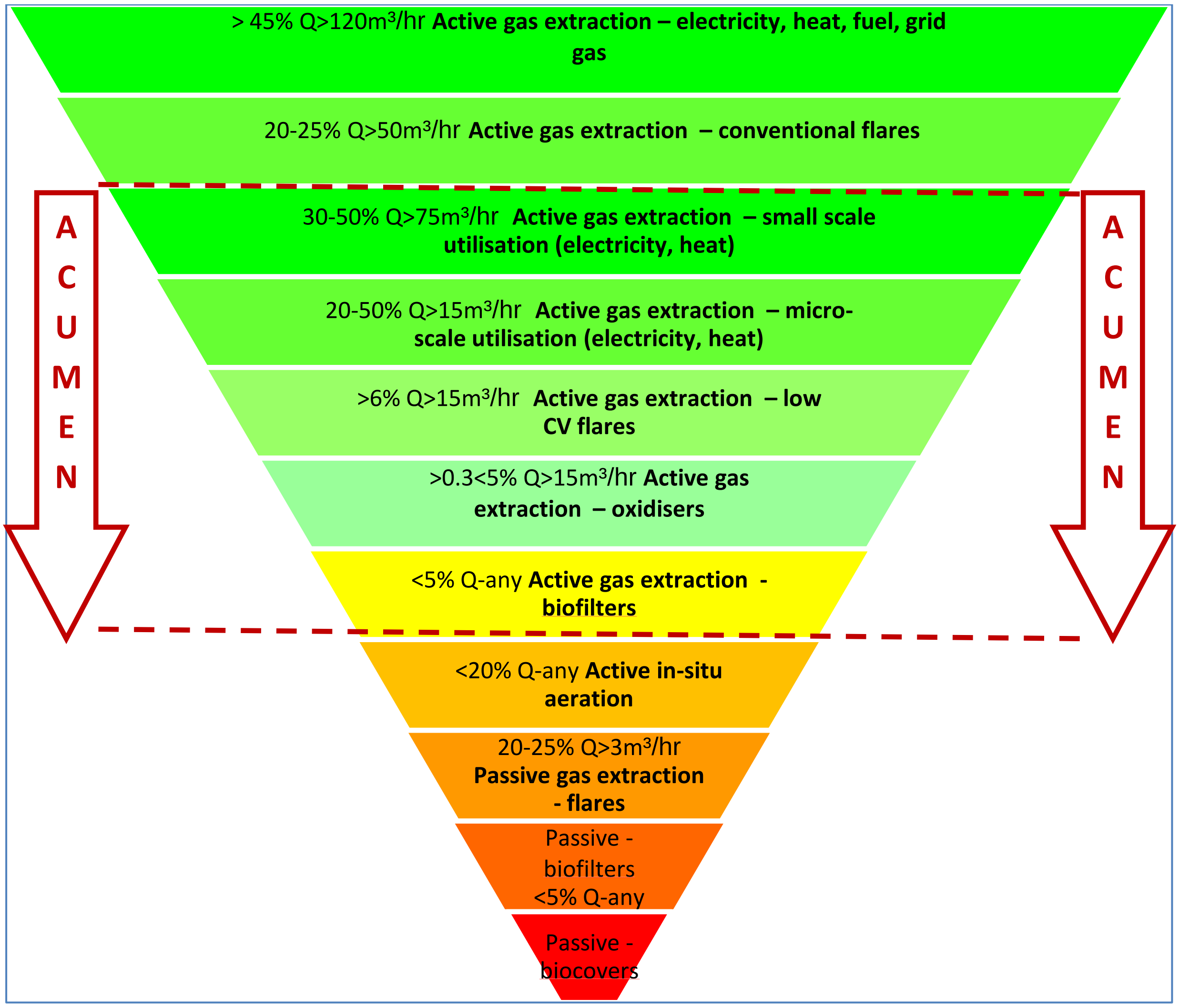
Screening multiple sites

If you're responsible for a number of closed landfills, you can also use the ACUMEN GET to screen and prioritise your sites to identify those sites most likely to support some form of beneficial gas utilisation.

Understanding the results

LFG management options

The LFG hierarchy outlined below gives an indication of the possible gas management techniques that could be applied to a range of possible gas generation values suggested by the GET tool. You can find more detailed information on several of these techniques in chapter 4, and examples of their use in chapter 7.



It is important to remember that the ACUMEN GET tool is targeted primarily at those sites with no verifiable measure of gas generation (such as by having an existing flare or engine). The absence of such a measure is suggestive of a landfill with minimal gas collection infrastructure. It must be borne in mind that significant costs may be required to install sufficient gas collection wells, pipework and associated infrastructure to realise the gas generation estimates suggested by the GET tool.

For this reason, the ACUMEN GET is intended to be a first step in assessing the gas potential at a closed landfill. A sensible next step would be to consider assessing the costs and benefits of seeking to capture and utilise such a gas resource. Further guidance on cost benefit analysis of landfill gas utilisation is contained in chapter 5.

Uncertainty	As has earlier been stated, the ACUMEN GET is a deliberately simple model in order to make it quick and simple to use. An inevitable trade off of this simplicity is the accuracy and precision of the resulting estimates. The following section highlights some of the uncertainties you should bear in mind when considering the results of the GET tool.
Waste composition	The waste composition used by the GET to derive its estimates is based on the average waste composition accepted by English and Welsh landfills in the late 1990s. If the waste accepted at your site differs significantly from this average, you may well find more or less gas at your site depending on the nature of the wastes you accepted.
Modelling uncertainty	Even if your site accepted precisely the same mixture of wastes as the UK national average, the inherent uncertainty in any model means you may still observe differences in the rates of gas generation, although these would be expected to be relatively small differences.
Operational variability	The way a landfill is operated, both now and in the past, can have an effect on how much gas is generated and collected. The presence of engineering containment can also affect how gas is generated and collected. For this reason, it is suggested you consider the results of the ACUMEN GET tool along with plus or minus 33%, as shown in the 'Operational LFG estimate' graph. This range is likely to encompass the true value, and therefore give a useful indication of the site's scale of gas generation, rather than a precise value. **Note:** The GET (and other models) estimates how much gas will be generated. It should be borne in mind that the amount which is realistically collectible is smaller (typically 60 – 80% is collectible).
Environmental variability	Environmental parameters such as rainfall levels and groundwater/leachate levels, and also seasonal (or even daily) climatic variation can significantly affect the rate of gas generation and collection efficiency at a closed landfill.
For more information	For more detail on how the ACUMEN GET works, and the assumptions behind it, please refer to the ACUMEN technical report (due for publishing Autumn 2015).

Further modelling

A range of well established alternative landfill gas models exist. Generally speaking, these models require more experienced users and more site-specific data than the ACUMEN GET tool.

- Gassim 2 – A sophisticated payware model used for regulatory purposes in the UK and elsewhere.
- Gassim Lite – A freeware basic version of an earlier iteration of the Gassim model.
- EPA LandGEM – A freely available spreadsheet-based tool, well suited for use in the USA.
- Afvalzorg simple landfill gas generation and emission model – A freely available and detailed spreadsheet-based tool based on IPCC default values.
- Global Methane Initiative country-specific models – A selection of spreadsheet-based tools for a small number of countries worldwide.

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Chapter 3 - Monitoring landfill gas emissions

This chapter provides an overview of some innovative monitoring techniques, which are largely focused around continuous in-ground gas monitoring. We developed these techniques during the ACUMEN project. You can use these alongside more established traditional landfill gas monitoring techniques to help verify the findings of your earlier assessment, and to inform your decision on the most appropriate gas management option for your site.

Introduction

Background

Monitoring is a routine element of managing any landfill, even during the prolonged aftercare period. It is often used in a variety of different ways throughout the lifecycle of a landfill, including for regulatory purposes. The monitoring techniques outlined in the following section are suggestions of how innovative monitoring can help validate the results of landfill gas modelling (using the ACUMEN GET or other models), or provide other information which will aid the improvement of gas capture, and where possible, utilisation, during a landfill's aftercare period.

This section is not intended to be prescriptive, but rather to highlight the availability and usefulness of some relatively new monitoring techniques.

Standard monitoring techniques

A range of long established monitoring techniques (including spot monitoring, flux box testing etc.) exist for landfill gas monitoring. When appropriately deployed, these techniques can provide useful insights into gas behaviour and composition at closed landfills.

As the use of these techniques is well documented elsewhere, we haven't replicated this detail in this report. Instead, we've chosen to highlight a range of innovative techniques and combination of techniques which you can use to better understand various aspects of gas emissions from your closed landfill.

Monitoring matrix

The following matrix indicates a range of available monitoring techniques, and highlights where each technique can be useful.

Use / Technique	Lateral migration	Surface emissions	In-waste
Surface Emission Survey		X	
Quantified-Surface Emission Survey		X	
Purge & Recovery Test and Repeated Purge & Recovery Test	X		X
Continuous monitoring	X		X
Depth profiling	X		X
Spot monitoring	X	X	X
Flux box testing		X	

Surface emission survey (SES)

What is the technique?

The surface emission survey (SES) records measurements of methane concentrations (ppm) occurring at the landfill surface. The methane concentrations can then be mapped and presented as a contour plot on a Google Earth image or similar of the site.

How does it work?

Each SES is undertaken along predetermined transect lines, approximately spaced at 10 to 5 metres apart, retrieving an air sample of any localised emissions from the landfill surface using an instrument that can detect methane at parts per million (ppm). The collected data is then processed and plotted using 'kriging' methodology in a GIS software package. The accuracy and presentation of the surface emission survey is improved by increasing the spatial resolution of the walkover – optimum transect spacing would be 5 metres apart.

What can it tell you?

The primary function of the SES technique is to identify the location and concentration of methane emissions occurring across a relatively large area of landfill surface, thus enabling the landfill owner or operator to precisely locate any point source emissions, faults in their landfill's capping layer (such as cracks or settlement) or gas collection or containment infrastructure (such as damaged or poorly sealed well heads).

How can you use it?

The surface emission survey can be used to verify cap integrity, maximise gas collection efficiency or provide a 'line of evidence' of potential gas risk to nearby properties. It can also be used to inform the design of an intrusive gas migration investigation. The monitoring of landfill surface methane emissions is an integral part of demonstrating compliance with the landfill directive.

The collection of high spatial resolution data of methane concentrations occurring at the landfill surface will therefore provide valuable information on key aspects of landfill gas management. For example, SES can lead to the detection of capping faults or emissions from the gas management system that can then be subsequently remediated. If applicable, the landfill gas collection efficiency can then be improved upon.

What are the outputs?

The outputs from the SES technique are:

- A raw data file of methane concentrations occurring at the landfill surface (ppm) with GPS coordinates;
- A graphical representation of the measured surface methane concentrations across the whole landfill site or survey area.

ACUMEN example	ACUMEN employed a surface emission survey at four of the demonstration sites at the start of the project. This technique demonstrated that there were minimal and isolated surface emissions at ACUMEN's two permitted demonstration sites (Sugden End and Docking 2). By contrast, ACUMEN's two historic demonstration sites (Strumpshaw and Maesbury Road) revealed significant and widespread instances of surface methane emissions. During the project, we used this learning to help inform our choice of demonstration technology.

Example outputs

Example SES

An example of a surface emission survey being carried out, and the resulting data.

Quantified-Surface Emission Survey (Q-SES)

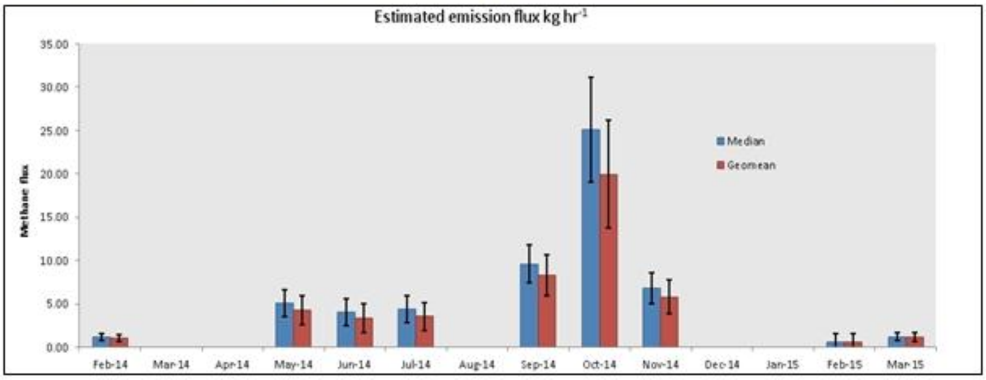
What is the technique?	The innovative Quantified-Surface Emission Survey (Q-SES) technique combines information on methane concentrations measured at the landfill surface and analysis of flux calculations from closed chamber flux tests to estimate methane emissions to atmosphere from closed or historic landfill sites.
How does it work?	Q-SES uses a high spatial resolution surface emission survey (SES) to gather detailed information on the presence of methane concentrations above background levels across a landfill's surface, or a portion of it. This information can then be combined with the results and analysis from a large library of traditional closed-chamber flux tests (flux boxes) to calculate a quantified surface methane emission flux. If required, the surface emission walkover can be repeated at different times throughout a calendar year to enable seasonal estimates of surface methane emissions to be estimated.
What can it tell you?	The primary function of the Q-SES technique is to identify the location and magnitude of methane emissions across a relatively large area of landfill surface. This use allows gas losses and greenhouse gas emissions to be quantified. In addition to its primary function, Q-SES can also allow landfill owners or operators to precisely locate any point source emisison, faults in their landfill's capping layer (such as cracks) or gas collection or containment infrastructure (such as damaged or poorly sealed well heads).
How can you use it?	The collection of high spatial resolution data of methane concentrations occuring at the landfill surface will therefore provide valuable information on key aspects of landfill gas management. For example, Q-SES can lead to the detection of capping faults or emissions from the gas management system that can then be subsequently remediated. The data from the same walkover survey can also be used to provide an estimated methane emssion flux from the whole site (if accessible for a walkover survey) or survey area. Reducing emissions from the landfill surface or gas management system can lead to improved gas collection efficiency and as a consequence, lessen the climate change impact.
What are the outputs?	The outputs from the Q-SES technique are: ▪ A raw data file of methane concentrations occurring at the landfill surface (ppm) with GPS coordinates; ▪ A graphical representation of the measured surface methane concentrations across the whole landfill site or survey area; ▪ A quantified flux estimate of methane emissions to atmosphere.
ACUMEN example	ACUMEN carried out significant development work on this technique, in particular, through repeated deployments at the Maesbury Road site. The repeated deployment of this technique has allowed the project to refine this technique significantly, and to better understand the seasonal nature of surface emissions at the site. The technique indicates that during 2014/15, the surveyed area of Maesbury Road emitted between 0.5 and 25.0 kg hr^{-1}.

Need more information?

For more detailed information about the technique, please refer to the ACUMEN technical report, which is due for publishing during Autumn 2015.

Example outputs

Example Q-SES



Some examples of a Q-SES survey and the resulting data.

Continuous ground-gas monitoring

What is the technique?

Innovative continuous ground-gas monitoring involves deploying an autonomous monitoring device into a borehole (either in a perimeter or in-waste monitoring well or potentially a gas collection well), and leaving it for a selected period of time.

The continuous monitoring device will measure several key variables at set intervals for the duration of the sampling period. Continuous ground-gas monitoring can provide a much more robust assessment of landfill gas composition, quality and behaviour.

How does it work?

When a sampling frequency is equal to, or is greater than, the frequency of a parameter change, the data collected can be termed 'continuous'. A continuous data set will therefore capture the full range of variation in the parameter being recorded allowing for a new approach in ground-gas monitoring methodologies and assessment.

The collection of time series data of permanent gases (methane, carbon dioxide, oxygen, hydrogen sulphide, carbon monoxide and total volatile organic compounds) and other environmental parameters, such as atmospheric pressure, borehole pressure, water level and temperature provides a wealth of information to identify the dominant processes of gas generation, gas behaviour and migration, thus leading to an improved understanding of the ground-gas regime and allowing for a more accurate and truly site specific assessment to be completed.

What can it tell you?

A continuous monitoring device, such as GasClam®, can give you detailed time series data on key aspects of landfill gas behaviour and the dominant processes driving change. For example, continuous monitoring can capture changes in atmospheric pressure, leachate or groundwater variability, gas collection efficiencies, differential pressures in the monitoring well, gas compositions or quantification and sub-lateral migration events.

How can you use it?

Continuous ground-gas monitoring aids the interpretation of lateral migration issues, gas quality and composition, borehole conditions, gas collection issues, gas behaviour and correlations with environmental change. The collection of time series data will therefore provide valuable information on several key aspects of landfill gas management.

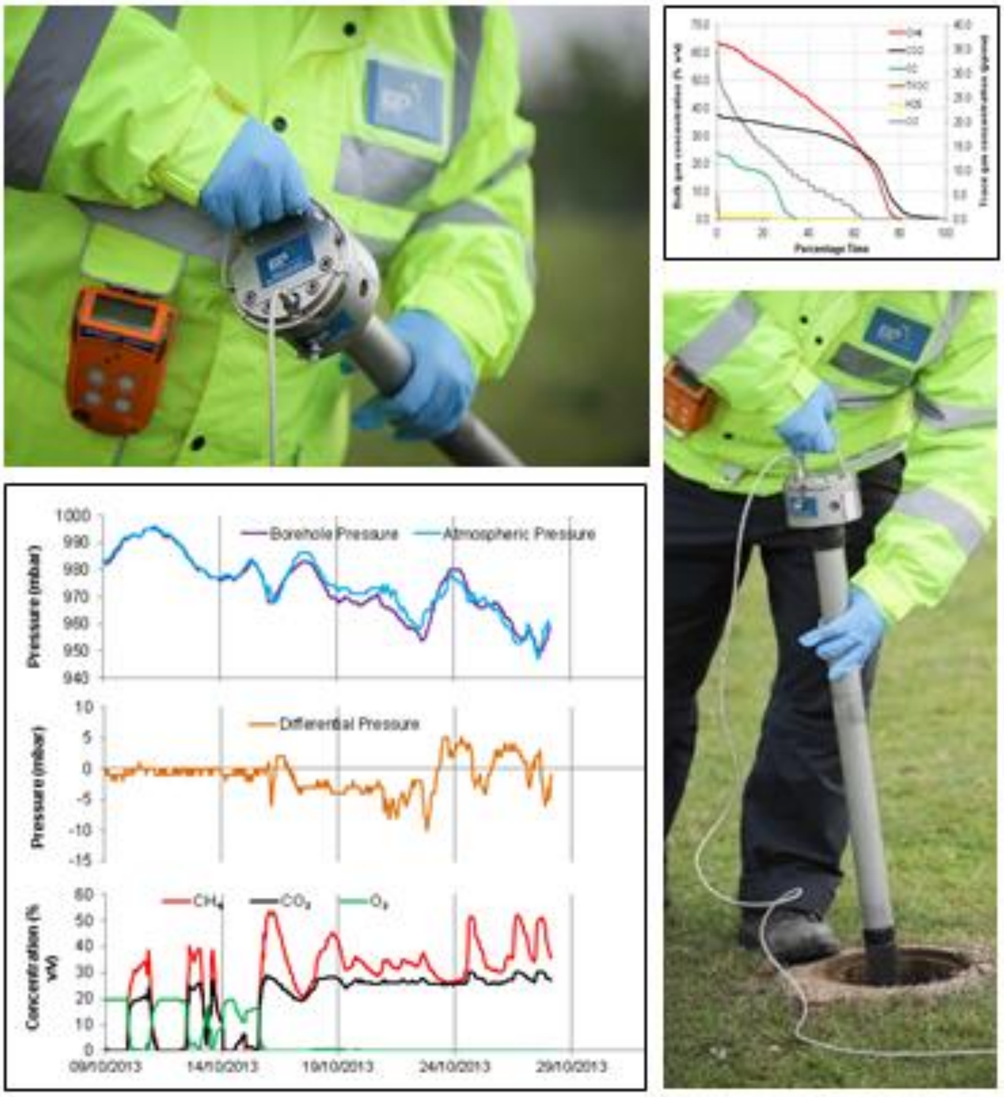
ACUMEN example

ACUMEN availed of significant amounts of continuous ground-gas monitoring throughout the project for a range of purposes. These included:

- Characterising ground gas composition at Maesbury Road;
- Monitoring biofilter performance at Strumpshaw;
- Investigating suspected condensate blockages at Sugden End;
- Characterising lateral migration frequency at Docking 2.

Example outputs

Example continuous monitoring



A GasClam® instrument being deployed and some examples of continuous data.

Purge & Recovery Testing (PRT)®

What is the technique?

The ground-gas purge and recovery test (PRT)®, developed by Ground Gas Solutions Ltd, is designed to measure the rate of ground-gas recovery into a monitoring well following the displacement of gases within the borehole with nitrogen gas. The ground-gas recovery rate can then be used, in conjunction with well volume, to calculate a ground-gas flux. A ground-gas flux can provide an indication of gas generation rates and can be used within detailed assessments and modelling.

How does it work?

In each test, boreholes are purged with nitrogen until oxygen, carbon dioxide and methane fall to negligible levels; a continuous monitoring device is then immediately installed, sealed with a rubber neck collar, and set to measure ground-gas recovery at three minute intervals. Continuous monitoring will record data at this frequency for up to an hour or until ground-gas concentrations have reached a plateau. It is possible to undertake purge and recovery tests on several monitoring wells in conjunction, should there be additional continuous monitoring devices available.

Alternatively, a portable gas analyser can be used with the readings recorded by a site engineer. This method does not record ground-gas recovery autonomously; therefore due to logistical constraints only one test can usually be carried out at any given time.

What can it tell you?

The PRT can give you a qualitative indication of gas generation rates through assessments of the calculated flux values and recovery profiles. Multiple repeated purge and recovery tests (rPRT) are an innovation that has also been trialled during the ACUMEN project to investigate if the test can provide a useful, and cost effective precursor to a pumping trial.

The test involves purging the borehole with nitrogen and recording the ground-gas recovery using a continuous monitoring device and then repeating, usually up to a maximum of six tests in one well. The rPRT should remove any local reservoir of gas within the monitoring well, and thereby observe the underlying rate of gas generation within the vicinity of the tested borehole.

The calculated ground-gas fluxes can then be compared within individual boreholes and across site, leading to detailed analysis and estimations of ground-gas generation rates.

How can you use it?

Through detailed assessments and modelling, the purge and recovery test, in conjunction with other monitoring techniques, could aid in both quantitative and qualitative estimates of landfill gas generation or identify stagnant gas – allowing for multiple wells to be compared and full site assessment to be completed. The effect of environmental variables can also be assessed when monitoring visits occur across a calander year – such as; effect of atmospheric pressure on landfill gas recovery or seasonal affects on landfill gas generation. Ultimately, the purge and recovery test can be used as a lower cost intermediate step between a desk study and pumping trial to provide qualitative estimates of landfill gas generation.

What are the outputs?

The PRT® and rPRT tests provide landfill gas recovery profiles and flux calculations from a number of wells across the whole site.

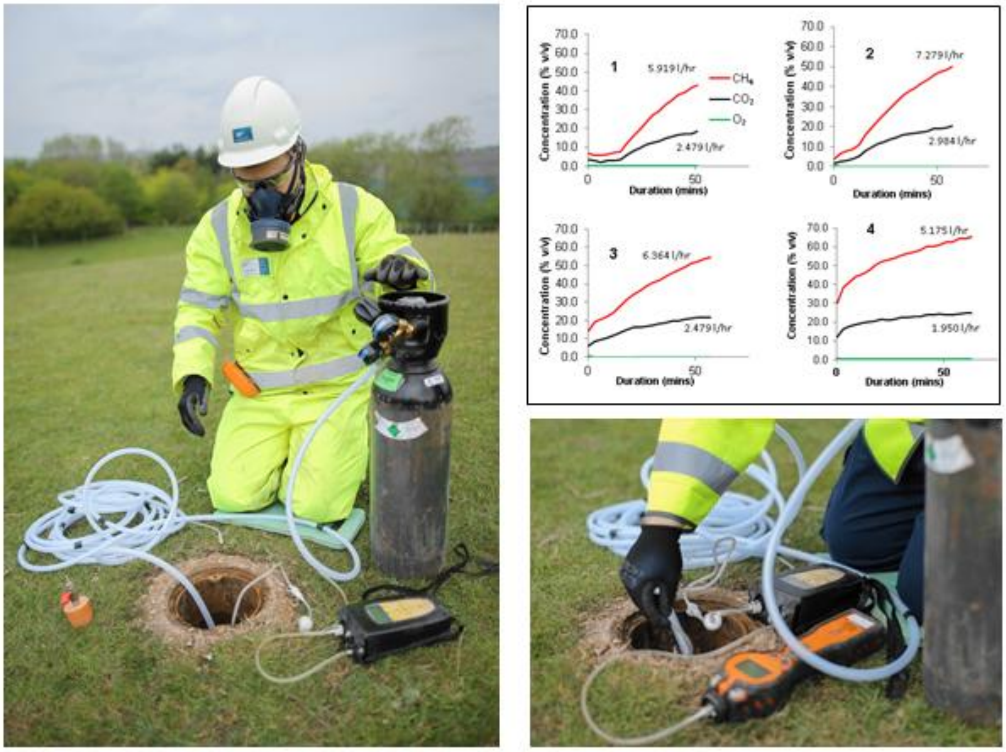
- Purge and recovery profiles from individual or multiple wells.
- Repeated purge and recovery profiles from individual or multiple wells.
- Flux calculations from individual or multiple wells.
- Detailed qualitative and quantitative assessments of landfill gas generation.

ACUMEN example

ACUMEN carried out several deployments of the rPRT technique at the Maesbury Road site. The repeated deployment of this technique has allowed the project to explore this innovative technique, and to better understand the variable nature of in-waste gas behaviour at the site. The technique indicates that several of the boreholes were yielding between 4 – 7 litres per hour of methane even after repeated purging.

Example outputs

Example PRT



An example of an rPRT test being carried out, and the resulting data.

Ground-gas depth profiling

What is the technique?

Ground-gas depth profile monitoring involves taking measurements of bulk gas concentrations (methane, carbon dioxide and oxygen) down a borehole and monitoring their recovery after purging with inert gas displacement.

How does it work?

Depth profile monitoring can form part of an assessment to investigate gas quality, well integrity or lateral migration. This technique can identify if ground-gas concentrations are stratified, stagnant or elevated at particular depths within a monitoring well or gas collection well. In each case, the measurement of CH_4, CO_2 and O_2 concentrations are recorded at one metre intervals down borehole from ground level until the standing water level or borehole base is encountered. These measurements can also be used in conjunction with the borehole logs (if available) and conceptual site model to provide an improved understanding of a sites landfill gas characteristics and behaviour.

After a depth profile is completed, a depth purge and recovery test can be undertaken. Each borehole is purged with nitrogen until oxygen, carbon dioxide and methane fall to negligible levels or to as low as practically possible. The ground-gas recovery is then measured at different depths using separate gas analysers (preferably at three depths) and concentrations recorded at one minute intervals up to 30 minutes or until concentrations have reached a plateau. This test enables landfill gas recovery to be observed at different depths, thus providing a semi-qualitative assessment of landfill gas entering the borehole from the surrounding waste or strata.

What can it tell you?

The use of ground-gas depth profile monitoring can help identify or inform on stagnant gas, gas well integrity, laminated waste, gas generation or lateral migration. The data collected can therefore be used in detailed site assessments and several key aspects of landfill gas management. Along with other landfill monitoring techniques, depth profile monitoring can provide valuable data to feed into ground-gas risk assessments.

What are the outputs

The outputs from undertaking depth profile monitoring are:

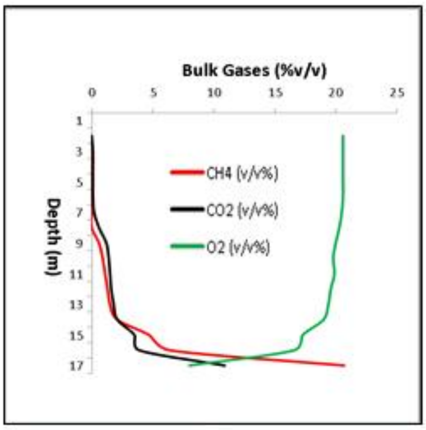
- Data of measured bulk gas concentrations measured down borehole and from the depth ground-gas recovery tests.
- Depth profile graphs of bulk gas concentrations in each borehole.
- Profile graphs of ground-gas recovery occuring at predetermined depths.

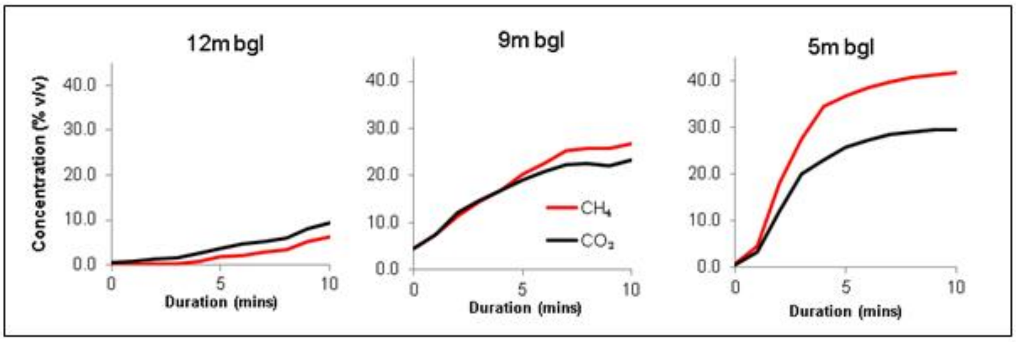
ACUMEN example

ACUMEN deployed this technique on an identified migration pathway at Docking 2. In combination with the secondary analysis of continuous monitoring data, this technique was used to better define the migration of landfill gas in space and time to inform a refined risk assessment of offsite gas migration.

Example outputs

Example ground-gas depth profile





Depth profiling being carried out on a landfill perimeter well, and some examples from different wells of the data this technique produces.

Conclusions - Monitoring

Conclusion

As described above, ACUMEN has made extensive use of both traditional and innovative monitoring techniques throughout the project to help characterise the gas regime at each of our demonstration sites.

These techniques, in particular continuous monitoring, offer real benefits in understanding gas generation, migration and emissions at closed and historic landfills.

A well designed and targeted monitoring regime can provide a highly cost-effective way to verify and validate gas behaviour on all aspects of your landfill gas management system.

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Chapter 4 - Residual LFG management – Available technologies

This chapter provides a brief overview of some of the options available for managing methane at closed sites. It is not intended to be an exhaustive list, but does provide some information on the options demonstrated during the ACUMEN project as well as some of the options the team discussed.

Introduction

Background

From a European perspective, the Landfill Directive (1999/31/EC) sets the context for our work on the ACUMEN project. Some of the most relevant parts of the Directive to ACUMEN are summarised in 'Landfill Gas Control - Guidance on the landfill gas control requirements of the Landfill Directive'.

LFG management technologies

This section aims to provide a brief overview of the technologies and techniques which we have demonstrated during the ACUMEN project. Additionally, it also highlights some potential options for managing landfill gas at closed sites not demonstrated during ACUMEN. This section of the report is not exhaustive - our intention is simply to provide some insight for closed landfill site owners into the options that may be relevant to them for managing their sites.

As with all aspects of managing landfill gas, it is important to have a good understanding of the gas being generated at your site to help you identify an appropriate technology from those discussed in this report.

Other resources

The subject of managing gas at landfills is not new and there are many reviews of available technologies already published. One particularly useful resource on this topic is the US EPA Landfill Methane Outreach Programme[4]. However, it is noted that this work has tended to focus on landfill sites producing significantly more methane than the ACUMEN demonstration sites.

Zero Waste Scotland have also produced a range of reports and resources which may prove useful when considering UK and European landfills.

Selecting a technology

The most appropriate option for your site depends on the methane generation characteristics, with large–scale electricity production requiring the highest gas volume and methane concentration within the gas. The passive management of LFG is only appropriate for the very lowest gas flows and methane concentrations when no other option is available. Where LFG is utilised, combined heat and power or tri-generation (electricity + heat + cold) should be considered since this can boost the efficiency of energy conversion from 30% to 80%. This is only feasible where there is a viable heat load requirement on or near the site. Programmes for incentivising the production of energy from LFG vary across Europe with new schemes being introduced as others are closed down. See chapter 5 for further details.

[4] http://www.epa.gov/lmop/

Options relevant to ACUMEN

Central to ACUMEN's purpose as a demonstration project is the need to demonstrate technologies which are not presently widely employed on closed and historic landfills. At such sites, LFG quantity and methane concentrations, generally, are both low in comparison to operational sites.

Looking ahead, it is foreseeable that many landfill sites will find themselves in the position whereby gas with low flow rates and lower methane concentrations will need to be managed. Therefore this section of our report focuses on small scale power generating engines, low calorific value gas flaring and bio-oxidation.

Methane utilisation technologies

Internal combustion engines

Small scale internal combustion (or spark ignition) engines suitable for operation with LFG are widely available, but our practical experience of their use in the UK has been relatively limited up until now as sites have either been flaring the gas or running larger engines.

Although the technology is well known and widely used, there are few operational examples of its application to low flow and low methane concentration LFG from older closed sites.

ACUMEN demonstration

ACUMEN has demonstrated the use of a small scale spark-ignition internal combustion engine at our Sugden End demonstration site which is producing approximately 100 m^3 hr^{-1} of landfill gas at 37% methane. Further details about this work are presented in chapter 7, Case study A. The ACUMEN team feel that this site is representative of 'typical' medium-sized municipal biodegradable landfills where the gas has dropped to a level that would not support a larger engine.

A small-scale spark ignition engine as installed at one of our ACUMEN demonstration sites in the UK.

Grid connection

One of the issues that had prevented the operation of an engine at this site to date was the fact that there was no electricity grid connection for exporting the power generated by the engine. The issues associated with installing an electricity grid connection are explored in chapter 6.

Suitability

Generally speaking, this type of engine:

- could be suitable for sites where the rate of gas production is greater than 50 m^3 hr^{-1} and less than 250 m^3 hr^{-1} and the methane concentration is greater than 30%.
- either needs to be connected to the electricity grid, or have a user nearby.
- could be an option for you if your site is currently flaring LFG at the levels mentioned above.
- could deliver increased efficiency - in terms of energy recovery from the LFG – if there were a facility nearby that is able to use the surplus heat.

External combustion engines

There are several types of external combustion engines advanced as suitable for burning LFG with heat or power production. Notable amongst these are Stirling Cycle engines and Organic Rankine Cycle (ORC) devices. The ACUMEN project included a demonstration of two Stirling engines at a closed landfill site in Norfolk and this was the first time Stirling engines had been deployed at a landfill site in the UK. Further details about this are presented in Chapter 7, Case Study B.

Stirling engines can operate at methane concentrations as low as 20% and gas flow rates as low as 10 m^3 hr^{-1} and:

- either needs to be connected to the electricity grid, or have an electricity user nearby.
- could be an option for you if your site is currently flaring LFG at the type of levels mentioned above.
- could deliver increased efficiency – in terms of energy recovery from the LFG – if there were a site nearby to use the heat.

ACUMEN demonstration

The units installed at our demonstration site had a combined electricity production capacity of 18kW – each unit being 9kW. It is noted that these units are modular in the sense that you can put on as many units as required to meet the volume of gas available. Generally speaking, this type of engine:

- is suitable for sites where the rate of gas production is greater than 20 m^3 hr^{-1} and the methane concentration is above 20%.
- either needs to be connected to the electricity grid, or have a user nearby who is able to accept the electricity.
- could be an option for you if your site is currently flaring LFG at the type of levels mentioned above.

From an ACUMEN project perspective, the limiting factor in terms of how many units we installed at our demonstration site was the budget available.

Two external combustion Stirling engines in use at one of our ACUMEN demonstration sites in the UK.

Heat utilisation

A by-product of running an external combustion Stirling engine is heat. Where possible, it is desirable to utilise this heat for a beneficial purpose. At our demonstration site we utilised the ‘surplus’ heat to dry woodchips for biomass boilers and this is addressed in more detail in chapter 7, Case Study B. Not only does utilising the surplus heat help to make maximum use of the methane as a resource, it can also help boost the cost-benefit case.

From a practical perspective:

- both internal and external combustion engines will generally be containerised and so there would be a requirement for a hard standing area on the site to locate the units. In both of the ACUMEN engine demonstrations, the containers used to house the engines were 20ft x 8ft (6.1m x 2.6m).
- both internal and external combustion engines may require some form of gas de-watering and cleaning. However, this is largely dependent upon the composition of the gas at each site.

To utilise the ‘surplus’ heat from the Stirling engines, we included a woodchip drying unit at our ACUMEN demonstration site.

Methane emission mitigation technologies

Low calorific flaring

Low-calorific value LFG flares are used to burn gas, which is not sufficiently rich or plentiful to sustain a utilisation technology, such as an engine, or combustion in a ‘standard’ LFG flare.

Flaring LFG, which is not suitable for viable economic exploitation is a well established technology and can ensure that a site complies with the relevant environmental regulations. From a UK perspective, the environmental and technical details relating to flaring LFG are set out in the document ‘Guidance on landfill gas flaring (Environment Agency; 2010)[5].

However, when the methane content of LFG falls below 20 %, standard gas flares can have difficulty in sustainable and safe combustion. Low calorific flaring involves the use of specially adapted flares which can burn gases effectively below this methane concentration[6].

5 https://www.gov.uk/government/publications/landfill-gas-flaring

6 Management of Low Levels of Landfill Gas Prepared by Golder Associates Ireland Limited on behalf of the Environmental Protection Agency (Office of Environmental Enforcement).

ACUMEN demonstration

Our work on the ACUMEN project involved the development and use of a prototype low calorific flare designed to operate over a wide range of gas flows from 40 - 300 $m^3 hr^{-1}$ and at methane concentrations of between 8 – 65% without support fuel.

Our experience during ACUMEN has been that flares at some closed sites are now too big for the current gas conditions at the site. Low calorific flaring could be an option to consider at a closed site if there is no opportunity for a utilisation technology, but there is still a need to manage the gas to comply with environmental regulations.

The prototype flare (on the left) at one of our UK demonstration sites.

Suitability

Generally speaking, low calorific flaring could be suitable for sites at which the rate of gas production is greater than $40m^3 hr^{-1}$ and the methane concentration is at or above 8%. Our work to develop a prototype low calorific flare is presented in more detail in chapter 7, Case Study C.

Active bio-oxidation

Bio-oxidation technologies concentrate, and exploit, the natural activity of methanotrophs (methane-consuming microbes) which oxidise methane, converting it to carbon dioxide and water. Biofilters achieve this methane conversion by artificially enhancing and optimising the conditions necessary for methanotrophs to metabolise methane.

Bio-oxidation can be used in various configurations to treat LFG. Two different approaches which have been trialled include an in-situ active biofilter and a containerised modular biofilter.

Our work during the ACUMEN project involved the construction of a biofilter at our Strumpshaw demonstration site (see chapter 7, Case Study D) as well as a modular biofilter unit at our Maesbury Road demonstration site (chapter 7, Case Study E)

The 'active' element of such a system consists of collecting the gas, through a network of standard wells, and pumping or blowing it to a central location where it passes through a biofilter of limited size. The obvious benefit of such a system is that a relatively small apparatus can be used to process the gas from an entire site, without having to physically cover it.

Conditions for optimum methane degradation can be achieved by controlling moisture, temperature and the physical environment of the methanotrophic bacteria which oxidise the methane. Actively extracting the gas provides greater control over the flow and volume of gas to be treated, often improving the breakdown of methane relative to passive management. This technology is not known to have been commercially applied widely as yet, but there are trials in progress that have proved successful so far[7].

The Environment Agency Active Bio-oxidation project looked at three different biofilters in different areas of England to establish their efficiency, and identify any changes in performance over different seasons[8]. The results indicated that biofilters can achieve methane destruction efficiency figures comparable with LFG flares (>95%), but that the biofilter infrastructure and oxidation media conditions need to be managed in order for this to be consistently achieved. A draft methane bio-oxidation monitoring protocol has also been developed following the reporting from the trials so that regulatory approaches to the use of biofilters can be developed and shared (developed as part of the Active Bio-oxidation Project, Environment Agency; 2015).

Suitability

Generally speaking, bio-oxidation:

- could be suitable for sites where the rate of gas production is >10 $m^3\ hr^{-1}$ and the methane concentration is <15%.
- involves relatively modest cost for the construction and operation of the biofilter.
- requires a power and water supply during normal operation.
- is somewhat susceptible to climatic conditions and may stop operating normally during cold weather, or if the bed becomes flooded or dried out.

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[7] Parker et al; 2013: Lessons learned from first full-size methane oxidation biofilter in the UK; Sardinia Symposium 2013.

[8] Environment Agency; 2015: In preparation – Action Bio-oxidation Project Report.

ACUMEN demonstration

The ACUMEN project included a demonstration of this technology at a landfill site in Norfolk.

Our experience during ACUMEN has been that careful design of the biofilter is essential to ensure optimum methane destruction performance.

In-situ biofilters could be an option to consider if the gas concentrations have fallen to levels that could make it difficult to run a flare and where you have a gas collection system already in place.

A containerised solution was also demonstrated under ACUMEN, at a site in Shropshire (Chapter 7, Case Study E). It was found that this could be a successful mitigation option at your closed landfill site, but you would need to arrange for a power and water supply for the unit.

Other technologies not demonstrated under ACUMEN

Introduction

This section highlights some alternative options for managing landfill gas at closed sites that members of the ACUMEN project team have experience of, but we have not demonstrated during ACUMEN. These are not considered in detail, but where possible we have provided links to other sources of information.

Microturbines

Microturbines can also be used for small scale LFG utilisation projects and are available from upwards of 30 kW units. These units typically require approximately 20 to 30 $m^3 hr^{-1}$ of LFG to operate.

The commercial application of microturbines is limited, with only a few examples of extended operation, and limited performance data, available from the UK. In general, microturbines have lower efficiencies than spark ignition engines. Evidence also suggests that microturbines may be more susceptible than spark ignition engines to damage from contaminants within the gas (such as siloxanes and halogenated hydrocarbons). Successful operation of these systems is likely to require gas pre-treatment prior to its delivery to the turbines. This could include the removal of moisture and gas impurities and add additional cost.

A project of particular relevance to people considering microturbines is 'MICROPHILOX - Energy recovery from landfill's biogas by the use of microturbines and biological removal of hydrogen sulphide and siloxanes'[9].

[9] http://www.microphilox.com/ - LIFE05 ENV/E/000319

Organic Rankine Cycle engines

Organic Rankine Cycle engines utilize the Organic Rankine Cycle (ORC) system to use surplus heat (for example, from a flare or LFG engine) to generate additional electricity. The key to this system is the use of an organic liquid medium with a lower boiling point than water, meaning that the liquid can 'work' at lower temperatures. The liquid medium (working fluid) is evaporated in a boiler, which causes sufficient pressure and expansion to drive a turbine or similar, before being pumped through a condenser heat exchanger where it is re-condensed for re-circulation and re-use. The application of ORC engines to LFG engines is currently being undertaken at various landfill sites around Europe, including the UK.

Relevant LIFE projects - A project of particular relevance to people considering Organic Rankine Cycle Engines is 'CLIM-WASTENER - Energy recovery system from landfill waste as a contribution to the fight against climate change'[10].

Air sparging/ soil vapour extraction systems

Air sparging involves injecting air under pressure into the landfill waste mass to dilute the generated gas, partially dissolve it from leachate and change the conditions in the landfill body from anaerobic to aerobic thus preventing methane generation. The extracted mixture of air and methane is then treated, for instance in a biofilter, low calorific value gas flare or oxidiser.

There are several potential risks which need to be managed when using this technique. Fire or explosions could occur; dissolved substances may be precipitated, thereby blocking injection points and gas migration pathways; the introduction of air into the subsurface may promote bacterial degradation in the sub-surface (fouling); gas volumes for treatment will increase; and other materials, such as hydrogen sulphide, may be mobilised and lead to an odour problem if the cap is inadequate. Furthermore, rapid degradation of the waste, following the introduction of oxygen, can lead to differential settlement of the landfill surface which, in some cases, can cause 'dishing'.

Passive bio-oxidation

Spreading a layer of compost (biocover) over a methane-emitting landfill can be a useful means of reducing emissions. Aerobic micro-organisms convert methane to water, carbon dioxide and microbial biomass and under optimum conditions emissions can be cut by up to two-thirds. Key factors for effective microbial oxidation in soil include moisture content, temperature, soil characteristics and composition, pH, nutrients and oxygen concentrations.

Compost is a more effective cover material than soil since the oxidation rate generally increases with increasing organic matter content, however mature composts can limit microbial respiration and reduce efficiency, so ensuring the correct compost/inert cover mix is vital for successful results in these cases. Placing a compost and sand layer within, and (in some cases), instead of an existing cover appears to reduce the methane flux[11]. In all cases, a thorough baseline study of emissions is required before installing a biocover.

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[10] http://www.clim-wastener.eu/index.php

[11] Cabral et al; 2010; Biocover performance of landfill methane oxidation – Journal of Environmental Engineering.

Chapter 5 – Assessing the costs and benefits

This chapter is intended to highlight some of the issues that need to be considered when developing an economic case for changing the way that gas is being managed at a closed landfill. This chapter is therefore aimed at site owners wishing to start thinking about developing an outline business case for changing a gas management regime.

Introduction

Background

This chapter does not provide a detailed methodology for carrying out a cost benefit analysis. The reason for this is that it became clear over the course of the ACUMEN project that businesses that focus on supplying gas management equipment already have their own detailed economic models. Additionally, local authorities, councils and municipalities will all have their own rules to comply with when presenting a case for financial investment.

Chapter overview

This chapter starts with the presumption that you are currently reviewing the way that you are managing the gas at your closed landfill and may want to consider making a change. This change may involve developing an economic case for changing to a different gas management approach. For example, you may be in a situation whereby your existing gas management plant is too big for the flow/quality of gas now being generated. At a closed landfill, this would almost certainly involve moving down the landfill gas hierarchy and considering some of the technologies presented in chapter 4.

The chapter concludes with focus placed on the current UK programme for generating electricity via the Renewable Obligations Order (ROO) and Renewable Obligation Certificates (ROCs) that are issued as part of it. This is because, from our ACUMEN experience, this is the most appropriate financial incentive scheme for generating electricity from landfill gas in the UK, and that it has a significant impact on whether a landfill gas energy-generating scheme is economically viable or not.

Management options

Options

Broadly speaking, the options when considering a change in the gas management regime at a closed site could be categorised as the three listed below. In practice the best approach for your site may well involve a hybrid of these simplified options. It is noted that these options are primarily aimed at sites that have the potential to generate income from power sales (i.e. methane utilisation) – There would be a different set of options for sites considering alternative gas management such as flaring or bio-oxidation (i.e. methane emissions mitigation).

Direct investment

This could involve buying or leasing new gas management equipment and installing, operating and maintaining it yourself or through an O&M contract. From a public sector viewpoint, this would involve you having to develop a business case for capital investment in new equipment.

Gas field balancing and monitoring would remain with the operator of the landfill, as would the financial risk of the project. All income derived from the sale of the electricity and heat, whether used on site or exported to the national grid would be retained by the operator. Expertise to operate the gas field and the gas management system would need to be contracted in or retained within the organisation.

An operation and maintenance contract could stipulate a minimum annual running time with commensurate compensation should this target not be met.

This option would bring the greatest income, but also the greatest risk.

Joint venture

This option would involve entering into a partnership with a supplier who would provide the engine(s) at the site. This could involve developing some form of contractual agreement to share the income gained from the sale of electricity generated from the landfill gas.

A joint venture is still likely to require some capital investment, but the investment risk would be shared with the supplier/contractor. The contractor would also be incentivised to achieve a high level of efficiency and run time.

This option is a balance between risk and income/costs avoided.

Contract out

This option could involve letting a contract to a supplier who would then bring in plant to manage the gas at your site and take all the income generated from power sales. This option may involve the site owner agreeing to sign over the gas rights for a period of time as part of the contractual arrangements. From a site owner's point of view, this could be a particularly attractive option in the sense that it could significantly reduce the need to secure capital for investment in new plant and reduce ongoing operation and maintenance costs.

This option may allow for costs avoided, but with little income and risk.

Advantages and disadvantages

The advantages and disadvantages of each option are briefly set out in the table below.

Option	Advantage	Disadvantage
Direct investment	Highest potential income from energy sales. Owner maintains full control over the site.	Highest risk to the site owner. Ongoing annual operation and maintenance costs for the site owner. Owner is responsible for negotiating deals with energy supplier and obtaining best incentive rates etc.
Joint venture	Site owner will still get some income from the site.	The site owner may still incur costs associated with the operation and maintenance of the site. The site owner may also retain risks (e.g. gas or plant failure, incentives not obtained etc.)
Contract out	Reduced operation and maintenance costs for the site owner. Potential reduction in risk for the site owner (the contractor carries more of the risk with this option). Incentive for contractor to maximise utilisation and efficiency as it would be linked to income.	May involve the site owners receiving no income from power sales.

An important point that would need to be considered when assessing any option is *Who owns the gas rights at the site*? This is particularly important when considering the joint venture option.

Costs

Overview

Some of the items that would need to be considered when assessing potential costs for any gas management option are outlined below. Where possible we have also tried to give an indication of the scale of possible costs associated with each item[12] However, it is noted that each site is different and so the potential costs for a specific site should obviously be considered in more detail when preparing an outline cost benefit analysis for the site.

Through ACUMEN we have developed a specialist CBA tool to assist decision making in this area. The CBA tool is briefly outlined later in this chapter.

Gas field infrastructure improvements

Updating the plant and pipework needed to ensure consistent and best quality gas is provided to your LFG engine or flare. This could include new plant, from the installation of a new extractor (also known as a blower) to a new set of gas extraction wells.

ACUMEN suggestion

Our experience in ACUMEN suggests that this can cost several thousand pounds. For example, the installation of new gas extraction wells can cost around £1-2,000 each. Wellhead replacement costs in the region of £100 per well.

Systems renewal

An ongoing cost where plant and infrastructure would require replacement and updating due to wear and tear, and as new and more efficient methods and technologies come on line in what is a very fast moving area of the industry.

ACUMEN suggestion

Our experience in ACUMEN suggests that an estimate of around £5-10,000 every five years would be reasonable, based on UK experience for a medium sized landfill site.

Personnel costs

All of the technologies demonstrated in the UK under ACUMEN require some sort of operational (people) input in order to run effectively and the performance monitored. This could be provided by a specialist contractor or using the site owners own resource.

ACUMEN suggestion

Our ACUMEN experience suggest that a sensible estimate, for a medium-sized landfill site with micro/ small-scale generation, could be in the region of £5,000 to £10,000 per year.

[12] These are our best estimates at the time of writing (Summer 2015)

Utilities (electricity and water)	All generation units require electricity to power the gas extraction and start up, with much of this requirement provided by the LFG engine as a 'parasitic load'. **ACUMEN suggestion** Our ACUMEN experience suggests that electricity costs can go down in situations where an engine is replacing a flare as the engine can produce power for use on site. For bio-oxidation schemes, there is also a need to provide a water supply as well as electricity with estimates ranging from £1,000-2,500 per year.
Emissions monitoring	Emissions monitoring requirements may vary depending on the environmental permit conditions. It is noted that these could be closely related to the Personnel costs discussed above (i.e. the person visiting the site for equipment management and/or maintenance duties would carry out the monitoring). **ACUMEN suggestion** Emissions monitoring may be a regulatory requirement, but the data can also be useful to ensure that management systems are running effectively and efficiently.
Site security and access	Basic maintenance, including site security and ensuring access, would need to be considered, particularly where new equipment is installed. This could involve additional cost, and although it is often provided as 'baseline costs' for local authorities, it may need to be reviewed following the installation of new plant and infrastructure. **ACUMEN suggestion** This is a consideration for the site operator and technology supplier to address at the project design stage to minimise longer term input and costs.
Leachate management	Changing the gas regime may affect leachate management and vice versa, so this would need careful consideration ahead of any changes to avoid any potential pollution and/or mobilisation of any contaminants resulting from the installation of a new technology or management technique. **ACUMEN suggestion** It is noted that leachate management was not considered as part of our ACUMEN demonstration site work and that none of the demonstration sites reported any impacts on the landfill sites leachate as a result of the technologies installed. However, it is recognised that changes to gas fields should be looked at in terms of the whole environmental setting of the landfill, and these changes carefully considered in the design phase. This is because changes to the gas field can impact gas readings in, for example, migration monitoring wells. It is considered unlikely that you would require separate leachate treatment costs, for example, outside of those already identified for the operation and maintenance of new gas management systems.

Liabilities

What is retained and what is passed on under each option would need careful consideration – for example, where the energy generation is contracted out, does this mean that the liabilities are transferred also?

ACUMEN suggestion

Ultimate liability will remain with the permit holder on a permitted site, or with the operator on a non-permitted site.

Costs avoided

Generally speaking, owners of closed landfills are incurring some ongoing costs associated with managing their portfolios of closed landfills. This could include, managing the site to ensure compliance with an environmental permit and/or to minimise the risk to public health and safety from the site.

Our experience through the ACUMEN project suggests that these costs can be in the region of £7-40,000 per annum. Bearing in mind that landfills can, dependent upon the waste deposited, require management for many decades – public bodies may find it attractive to look into the potential costs avoided by signing over gas rights (and income generated from the gas) to a site in exchange for a contractor taking on responsibility for operation and maintenance of the site. That is, is it possible to avoid the ongoing cost that you are incurring for running a closed landfill site? If so, this *cost avoided* would need to be built into the economic analysis of options for future management of the site.

Generating an income

Opportunity?

Generating an income is important to closed site owners as it can help to offset the costs associated with managing a site over its lifetime. Dependent upon the material deposited at the site when it was operational, closed landfills can continue to produce methane at slowly decreasing rates for many decades. This methane could, potentially, offer an opportunity to generate a modest income and so help offset the cost of managing the site.

Environmental benefits

It is of course noted that options such as flaring and bio-oxidation do not offer the opportunity to generate direct income. However, these options can offer significant environmental benefits in terms of reducing greenhouse gas emissions. This aspect of the economic consideration is explored in more detail in the cost benefit analysis (CBA) tool that we have developed during the ACUMEN project. The CBA tool is briefly outlined later in this chapter.

Estimating gas generation

The amount of gas available from your site will depend upon how far along the gas generation curve your site is. One way to get an idea of this is to run the ACUMEN Gas Estimation Tool (GET) described in chapter 2. The amount of gas available will impact on the potential income that you could hope to generate from electricity sales. Just to give a feel for the figures involved, we have presented an example from one of the ACUMEN project partner's experience of using the direct investment approach of managing a site that accepted biodegradable waste and closed in 1997.

Example – Small scale generation

This example highlights some of the potential costs, additional to business as usual, and income associated with installing and running a small scale electricity generation scheme at a closed landfill. The assumptions made when building up the cost and income estimates are based on figures applicable in Summer 2015. The figures below assume that you already have a good understanding of the gas generation potential of the landfill and so do not include investigative or gas monitoring costs.

Costs

- The capital expenditure needed to procure and commission a new 50kW landfill gas engine could be in the range of £60,000 to £100,000.
- Infrastructure improvements – These are clearly dependent on the specific conditions at the site. However, if it is assumed that there is already a landfill gas flare operating at the site, it could be reasonable to budget for infrastructure improvement capital costs (possibly involving additional gas wells, upgrading and improving the existing gas collection system, site compound security) in the region of £5,000 - £10,000.
- Operation, maintenance and servicing – Again, this cost will be dependent upon site conditions. However, for budgeting purposes it could be reasonable to assume an annual cost for operation, maintenance and servicing of the engine and the gas field of approximately £15,000 per year.

Taking the midpoint of the cost estimates above suggests that this scheme would require a capital budget of £87,500 and an annual operational cost of £15,000 per year.

Income

- The landfill gas engine installed is capable of producing 50kW of electricity for export.
- There is around 45 $m^3\ hr^{-1}$ going to the engine @ 40% methane
- The scheme is eligible for support under the UK Renewable Obligations Order at a level of 1.9 ROCs.

- The company buying the electricity pays 4.5p per kWh of power
- The company buying the electricity also pays other benefits which vary from area to area, but could be a further 1 to 2p per kWh
- Under ROCs, the site owner (or the site owner's contractor) can claim a further 8.4p per kWh of power.
- The engine runs for 85% of the time (i.e. 85% availability)
- This would result in an income from electricity produced and sold of approximately £54,000 per year. One operator reports availability of 96% or higher, giving a potential revenue of around £60,000 using these indicative rates

Financial incentives applicable to landfill gas schemes

UK incentives

From a UK specific perspective, the sale of electricity produced from landfill gas engines is eligible for financial support under the Renewable Obligations Order through issue of Renewable Obligation Certificates (ROCs). This can have a significant impact on the economic case for any future investment and the process of applying for ROCs is outlined at the end of this chapter.

ROC bandings

Different bands of support are available within the ROCs scheme depending on the technology used in generating the electricity and these are presented in the guidance available from DECC[13]. There is a specific band for *closed landfill sites* which was introduced in April 2013. From an ACUMEN project perspective, the ROCs bands of greatest relevance to our demonstration sites are:

Landfill gas – closed sites

This level of ROCs support would be available to a closed landfill site generating power at a level greater than 50 kW. For example, our demonstration site at Sugden End (see chapter 7, Case Study A) which generated 140 kW of electricity would have been eligible for this band.

Micro-generation

This level of ROCs support is available to electricity generated from a closed landfill site at a level below 50 kW. For example, our demonstration site at Docking 2 (see chapter 7, Case Study B) which generated 18 kW of electricity would have been eligible for this band.

As of Summer 2015, the ROCs bandings available are:

Band	13/14 support (ROC/MWh)	14/15 support (ROC/MWh)	15/16 support (ROC/MWh)	16/17 support (ROC/MWh)
Landfill gas – closed sites	0.2	0.2	0.2	0.2
Microgeneration	2.0	2.0	1.9	1.8

[13] https://www.gov.uk/calculating-renewable-obligation-certificates-rocs - accessed July 2015

UK Renewable Obligation Order

Financial incentive schemes and programmes vary across European Union countries depending on targets, resources and finance available. This section outlines the current situation in the UK, with information provided by our Polish ACUMEN partners relating to the equivalent Polish incentive programme, included later in this chapter.

The Renewable Obligation Order (ROO) is designed to incentivise electricity generation from renewable sources in the UK. Administered by Ofgem, the scheme ensures that licensed electricity suppliers source an increasing amount of their electricity from renewable sources. The Renewable Obligation Certificates (ROCs) scheme uses a system of issued certificates that are traded, usually with electricity suppliers. Ofgem makes a payment to the producer of the electricity (the generator).

To give an indication of the steps involved in making a ROCs application, an overview of the process is presented in the table below.

Application process - UK

The following table outlines the process for making a ROCs application in the UK.

Stage	Description
1 Introduction	A generator, once accredited (by registering with Ofgem) is issued with ROCs according to the net electricity generated each month from their installation. The generator can then sell the ROCs on to electricity suppliers or agents for further selling-on. The suppliers can then count these certificates towards their ‘renewable obligation’ that is, the legal requirement for them to produce a given proportion of renewable electricity in their output
2 Calculation	A record of the electricity generated (and used), via accurate metered records, is very important. The generator must provide output and input information on a monthly basis. Approved meters must be used in order for calculations to be considered eligible.
3 Direct uses	ROCs may also be issued for electricity use on the site of generation and can also be passed directly to a third party without going to an electricity supplier. They are not issued for electricity used in running the generation plant.
4 Accreditation	Preliminary accreditation and final accreditation applications can be made via the Ofgem Renewable and CHP site: https://www.renewablesandchp.ofgem.gov.uk/. Preliminary accreditation is advisable in order to assist with planning, and to gain more certainty in final accreditation. Certain permissions, in particular planning permission, must be in place before a preliminary accreditation can be approved
5 Accreditation number	Getting accreditation, either full or preliminary, will result in being allocated a unique accreditation number, including the code for the type of technology used in electricity generation. There are certain circumstances where accreditation may be refused or delayed and there is an appeals and representation process available. Audits are undertaken from time to time by Ofgem as are investigations and enquiries into levels of electricity generated. Ofgem expects generators to cooperate in these cases.
6 ROCs issue	Once approved, ROCs are issued on the basis of reported electricity generated which can be either monthly or annually. Electricity suppliers, or a third party, can then purchase the ROCs from the generator. Approval for ROCs lasts for 20 years, with an annual review of the generating circumstances to demonstrate continued eligibility.

Financial incentives – Around the EU

Our findings in researching comparable incentive schemes across the EU indicated that there are country-specific programmes, aimed at different generating sectors with different procedures for applicants, dependent on the objectives and resources available for each country.

ACUMEN's Polish partners were able to provide an overview of the financial support for energy generated from landfill gas in Poland which is included below.

Polish incentives

Since joining the EU in 2004, Poland has looked closely at increasing its renewable energy generation to comply with climate change directives and provide alternatives to 'traditional' energy generation e.g. from coal. This has culminated in the drafting of the Act on Renewable Energy Sources, passed in March 2015. Under this Act, energy generated from gas from landfill (biogas), is considered 'renewable' and with generators eligible to receive incentives from the new support system.

Current position

'Certificates of origin', which are traded, in a manner similar to ROCs, via the Polish Power Exchange, will continue to be used until December 31 2015. From January 2016, a new system of 'auctions' will be introduced and energy generators will need to voluntarily move from the support system provided by the certificates, to the new auction system.

Auction system

This will be obligatory for new renewable energy installations from January 2016, and is a system based on auctions organized by the energy regulation office.

These will be held once a year and will be separated into generation of up to 1MW and beyond 1MW. It is expected that at least 25% of the amount of electricity covered by the auctions will comprise of smaller (that is, <1MW) installations.

How it works

It works through an internet based system, the system is very simple with the 'lowest price' offered being the winner, with the auction criterion being the price of 1MWh of electricity for 15 years. The settlement around the amount of electricity produced will be every three years, and there will be cash penalties for non-compliance. Although linked to inflation rises, there is a maximum or 'reference' price set – and no minimum price – ensuring that the electricity generated in this way, is relatively affordable for the suppliers.

Future situation

It is anticipated that the new system will enable full competitiveness and stimulate the economy of the emerging renewable energy market. Furthermore, micro-generation (<10Kw – including generation from landfill gas) benefits from a fixed price.

However, it is not without risk, given the stipulations around the technologies to be supported, and the lack of a guaranteed amount of energy to be included in the auction. For more information please see PNP Update on Polish Act on Renewable Energy Sources [14].

[14] Update on Polish Act on Renewable Energy Sources, March 2015, PNP Law

The ACUMEN Cost Benefit Analysis (CBA) tool

Introduction

A spreadsheet-based CBA tool has been developed as part of the ACUMEN project. This has been designed to help estimate the financial and social costs and benefits of applying the different gas management technologies demonstrated under the project.

The CBA tool has been built to be compliant with UK government Treasury guidance and could be a useful way to assess the relative merits of different gas management options. However, the ACUMEN Project Team recognise that many site owners/ operators will already have detailed modelling tools and cost benefit methodologies that they are using. We have developed and shared the CBA tool, but recognise that it may possibly be more detailed than some owners require.

People interested in this aspect of the work are encouraged to explore the CBA tool to get a better understanding of the analysis undertaken.

How does the tool work?

From details about the closed landfill site, the CBA tool estimates the costs and benefits associated with different gas management options, based on projected scenarios from the base year (i.e. the year that the analysis is being undertaken) over a set period of time.

A ‘Business As Usual’ (BAU) condition is applied as a default option on the assumption that sites will need to be managed somehow in any case whichever option is selected (e.g. operating a standard flare, as was the case at several of the ACUMEN demonstration sites). *i.e. the potential new management option can be analysed against the current ‘business as usual’ gas management option*. The tool also allows you to apply multiple gas management interventions to reflect realistic landfill gas management scenarios (e.g. running a flare concurrently with a small landfill gas engine).

The CBA tool outputs a summary table which presents estimated cost and benefit figures based on the actual inputted data for the demonstration period. The financial sections are in essence a measure of the costs and income produced by installing a particular technology.

The ‘social’ section of the summary table includes the benefits to the environment due to the methane emissions reduction resulting from the particular gas management option, or options, being analysed.

Conclusions – Assessing the costs and benefits

Conclusion

Consideration of landfill gas utilisation *management options,* where issues such as contractor responsibilities, gas ownership and utilisation technology management are agreed, is needed as a first step in generating energy from landfill gas.

There are also potential cost increases such as additional extraction well installation and these – as well as any cost savings – need to be carefully considered when assessing the economic impact of changing the way that gas is managed at a closed landfill site. Our aim in this chapter has been to share what we have learnt to help people get a sense of the potential costs and benefits associated with changing the gas management option.

The ACUMEN Cost Benefit Analysis tool is available to help inform the development of an economic case for changing the way gas is managed – This tool additionally helps to quantify the environmental benefit that could be obtained from a different approach to managing the gas at a closed landfill site. *We recognise that the CBA tool is something that would benefit from further trialing and refinement, but this has not been possible within the time available for the ACUMEN project.*

Financial incentives are often available with different schemes and programmes evident across the EU, and in our experience, these can be a key factor in deciding whether a utilisation scheme is economically viable or not.

Finally, it is recognised that assessing the costs and benefits of different management options is complex and many organisations will already have detailed models/methodologies for carrying out this analysis.

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Chapter 6 - Regulation and grid connection

This chapter is intended to provide an overview of the environmental and planning regulations that need to be considered if you are thinking about changing the way that you manage gas at your closed landfill site.

Additionally, this chapter goes into detail about the experience gained by the project team on making an application for a grid connection at two of our demonstration sites.

Introduction

Background

Regulation of energy production from landfill gas falls into three general areas: energy licences, planning permission and environmental permitting. Different regulatory authorities will normally be responsible for the different areas, however this may not be the case in all EU countries. In the UK, for example, there are clear institutional responsibilities for each area.

The context of the information provided below is an application for generation made in the UK, specifically England where the key regulatory body is the Environment Agency. Each EU country will have different regulatory authorities involved in the process, however, broadly speaking, the authorisations and environmental considerations will be similar.

Changing the way landfill gas is managed in order to generate energy (and electricity in particular) often means that the infrastructure around electricity provision and export – the grid connection, needs changing. The experience gained from demonstrating energy generation through ACUMEN indicates that this is a time and resource consuming exercise, so this chapter includes a detailed step-wise description of the process applicable in the UK. It is recognised that different EU countries will have different approaches to this process, but as with planning and environmental permitting, common themes remain.

Getting planning permission

Planning permission

Before landfill gas utilisation and emissions mitigation plant can be constructed, (spatial) planning permission, from the relevant regulatory authority is normally required. This could be even if the installation is relatively small in size or is located on or in a facility that already has permission in place (e.g. in the UK). In the UK planning permission is also required for any transmission links to the electricity grid.

This type of permission is also known as spatial planning or development control. Depending on which member state a site is in, the relevant authority may be at national, regional, local or commune level, with diffrent countries having different authorisations and processes for this.

UK process

In the UK, the operator must submit a planning application to the relevant planning authority. For example, at one of the ACUMEN demonstration projects we had to apply for planning permission to the local planning authority in order to install a small-scale landfill gas engine whereas for the biofilter which was constructed in-situ and used the existing active extraction system at another demonstration site, no separate planning permission was required. For an overview and introduction to planning regulation in the UK (England and Wales) please see the following:

https://www.gov.uk/planning-permission-england-wales

Before starting any preparatory works for the installation of landfill gas utilisation or mitigation plant, the operator should consult the (local) planning authority about the proposals. In addition, before an application for incentives to generate electricity can be made (see below), planning permission for the generator must be secured. For more information on this, applicable to the UK, please see the following:

https://www.ofgem.gov.uk/electricity/distribution-networks/connections-and-competition/distributed-generation

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Other EU countries

There are different planning authorisation approaches found across the different EU states, with the level of notification and approval ranging from local (i.e. village, commune or town) level, through to municipal (i.e. local authority, county, departmental) up to regional or state level depending on the complexity and impact of the proposed installation.

In all cases, it is recommended that planning authorisation is considered early in the process, given that it can take many months for permissions to be granted.

Getting environmental permission

Environmental regulation

The Landfill Directive (1999/31/EC) guides regulation relating to activities involving the disposal of waste at landfill across the EU. Landfill gas is generally considered a hazardous waste, so utilisation or mitigation activities will normally need an environmental permit or equivalent (e.g. an exemption or Low Risk Position Statement), issued. In the UK this is the responsibility of the appropriate Environment Agency, for example in England it is issued by the Environment Agency under the Environmental Permitting Regulations (England and Wales) 2010 (EPR). This will include conditions which limit point source emissions to air.

Different types of permits apply to different activities. Accordingly, the type of application, the application fee and the permit conditions vary, depending on which type of permit is required. Different interpretations of the Landfill Directive and other applicable European Directives will be provided by the specific country's interpretation of the Directive requirements.

UK process

For a new bespoke permit application, or a substantial variation to an existing permit, the Environment Agency may consult formally on the application.

Smaller landfill gas engines, such as those at closed or historic landfill sites, generally present different, mostly lower-impact and frequency risks than the 'standard' engines usually found at larger, operational, landfill sites where gas generation is more significant. Consequently, in England, the Environment Agency has published a Low Risk Position Statement which covers the burning of landfill gas in engines with a net thermal input of less than 0.4MW or where all engines on the same site do not exceed 0.4MW. To comply with this position the operator must collect the gas in accordance with best practice, currently defined in 'Landfill Gas Industry Code of Practice – Management of Landfill Gas, March 2012'.

http://www.esauk.org/reports_press_releases/esa_reports/

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296861/geho0409bput-e-e.pdf

Other EU countries

Interpretation of the Landfill Directive varies from country to country, but the premise of appropriate permitting and risk management is the same. Consistency in the regulation of landfill gas-related activities across the EU means that broadly speaking, most countries will adopt a similar approach to permitting small landfill gas engines such as those demonstrated under ACUMEN, as the UK.

Setting up an electrical grid connection

Introduction

In addition to the permitting and licences required for the physical installation of any landfill gas utilisation and/or mitigation technology, there are other procedures that are set out around its operation.

This is particularly the case where energy generation and export is planned, where some governments have introduced schemes to assist and incentivise energy generation from landfill gas, for example, the Polish Act on Renewable Energy Sources (2015).

As ACUMEN only completed this process in the UK, no detail is provided on the processes in other member states. However, the general steps of the process of establishing a grid connection for power export are likely to be similar.

UK process overview

The table below outlines the key stages involved in installing or upgrading a grid connection at your site.

Stage	Description
1	Making an application
2	Approval by the Distribution Network Operator
3	Applying for incentives or subsidies
4	Establishing a supply agreement
5	Commisioning and connecting your generation equipment
6	Selling your generated power

Background

Whether you plan to use a new or existing grid connection, your first point of contact is likely to be your local distribution network operator (DNO). There are several geographically-defined areas in the UK, which are each operated by one of six DNOs. The DNO owns and operates the distribution network or towers and cables that carry electricity from the transmission grid to homes and businesses.

Each DNO's website offers a range of information and guidance on grid connections, including an indication of the network's available capacity in your specific area.

There are also a number of smaller, independent connection providers (ICPs) who are also able to carry out design and installation works on the distribution network.

By generating electricity while connected to the national grid, your activity will be classed as distributed generation. You will require prior consent from your DNO before you connect any generator in parallel with the DNO's distribution system.

Available options

There are four broad ways to use any power your generate at your site. These are:

1. Use on site

ACUMEN's experience suggests that using your generated electricity on site is one of the most efficient and beneficial outcomes of installing energy generation driven by landfill gas. The main benefit of this approach is that it offsets the cost of the electricity you would otherwise have to purchase from your provider. However, landfills are often capable of generating more electricity than can be used on site, meaning the surplus must be exported (see option 4 below).

Available options

continued

2. Local export

In some cases, where there is a 'closed' market for electricity (such as at a hospital complex, new housing estate or standalone industrial units), it may be possible to export your power locally using a 'privately owned network' or 'licence exempt distribution system'. This means that a DNO is not involved, and you sell your power directly to the end user. In such cases, you would need to liaise directly with the energy user to ensure all applicable licences and regulations are adhered to.

3. Grid export

This is the most common option for electricity generated at landfill sites. Any electricity you generate is effectively sold to the local DNO at an agreed rate. Often such schemes can attract government-backed incentives (such as ROCs in the UK) as landfill gas-derived electricity offsets more carbon-intensive forms of generation elsewhere. These incentives can generate enough income to cover both the capital and operational costs of the generating unit over a reasonable period.

4. 'Hybrid' options

This is another very common option for electricity generation from landfill gas, given there are often power requirements on the site itself (such as gas extraction, lighting etc.). However much electricity the site requires is used directly, with the (often significant) surplus being fed into the national grid for use elsewhere. Similar to option 3, the site owner or generator operator will receive a payment for the exported power. An example of this type of scheme is ACUMEN's Docking 2 demonstration where some of the generated power was used to supply the gas extraction system, with the remainder exported to grid.

Stage 1 Making an application

Regardless of how much power you plan to generate, or which option you choose, you will need to complete and submit an application form to your DNO (or private network operator). The application requires details such as the capacity and specifications of the intended generation and your proposed location. You will also need to include a map of your site showing its location and the layout of any onsite services (utilities – water, power, gas etc.).

You can find more details at: http://www.energynetworks.org.

Generally speaking, the larger your planned electricity output is, the more detail will be required for your application. For example:

- Low voltage schems and those less than 16A per phase will need to comply with the small-scale embedded generation definition (G83/1-1)
- Higher voltage, or low voltage greater than 16A per phase will need to comply with the G59/2 connection process

For micro-generation plants (G83/1-1), and when little or no infrastructural work or adaptation is required, it may be that no additional works, either new or reinforcement, are required, in which case, there are no additional costs to pay.

Stage 2 Approval by the DNO

Your local DNO will decide where your proposed generation 'fits' in terms of the available connection processes (G83, simplified G59 or full G59). They will also determine what level of information they will require from you, and what (if any) works to the site's electrical infrastructure will be required. Your DNO will also have details on the existing connection at your site, if it has one. Generally speaking, the larger your proposed level of generation, the more information they are likely to require. This is because larger schemes may require a diversion of, or reinforcement of the existing grid connection at your site.

Connection costs

In addition to the potential electrical works, your site may also require some civil engineering (i.e. building) works to accommodate your generator and grid connection. Your DNO can provide these services, or alternatively, you can appoint a nationally accredited company such as an ICP to carry out these so-called 'contestable works'.

Every DNO publishes a so-called 'heat map' on their website. These maps show areas where the distribution grid has the capacity to accept more generation, and where it is already saturated. Grid connection costs are likely to be higher in areas where the grid is already at, or approaching, capacity.

Factors which can affect the cost of your connection include:

- the distance from your generator to the point of connection;
- whether reinforcement of the upstream network is required;
- whether legal permissions (such as wayleaves) are required for the connections;
- the suitability of the connection route between the existing network and your generator;
- whether the local network uses single phase overhead lines;
- whether a transformer and/or substation is required between your generator and the network;
- any existing technical limitations of the network.

Stage 3 Applying for incentives or subsidies

The electricity you generate may attract incentives via government-backed schemes set up to support low-carbon electricity generation. At present, the scheme in the UK most likely to support power generation from landfill gas is the Renewable Obligations Certificates (ROCs) scheme (see chapter 5).

The ROCs scheme works by incentivising the large power generation companies to source a proportion of the power they sell from low carbon sources. In practice, the power companies pay a premium for low-carbon electricity (including landfill power generation) to help them meet their 'renewable obligation'. This means that you, as the landfill owner or power generator get paid a premium rate by the power company to supply your low-carbon electricity to them.

The details of how to apply for ROCs accreditation are detailed in chapter 5. If you're successful in gaining ROCs accreditation, you will receive an accreditation number. You will need to use this number in your correspondence with the electricity supplier who will receive the power you generate. You will also need to enter into a 'provision of electricity contract' with your electricity supplier (see below).

Note: There is no obligation for you to seek ROCs accreditation. If you choose to, you can sell your generated power for a standard rate, or indeed for free.

Stage 4
Establishing a supply agreement

Once you've received approval from your DNO, you will need to contact your electricity supplier regarding the export and purchase of your generated electricity, and the activation of your connection. You can access a list of electricity suppliers from Ofgem or the Electricity Supply Trade Association websites.

Your chosen electricity supplier will need your ROCs accreditation number if you plan to avail of ROCs support. Every metered connection to a licensed distributor's system requires a meter point administration number (known as an MPAN) to measure consumption (that is, electricity import) and supply (that is, electricity export) from your site.

In order to supply your electricity to your supplier, you will need to submit an application to them, and provide them with your MPAN.

Stage 5
Commissioning and connecting your generation equipment

Your DNO may charge you a one-off connection fee to cover the costs of connecting your generator. The fee they charge will depend on the extent of works required to modify your existing connection, or provide a new one where none exists.

If no additional works are required, or the planned output is relatively low, there is often no fee payable to the DNO.

The DNO may levy other charges, including 'continuing charges' which cover the use of their systems, and 'top-up' and 'standby' charges for periods where you use more power than your generator produces (that is, power is imported into your site).

Once all the necessary permissions are in place, the installation and connection of your generator can take place. You must use an approved installer, and all wiring must comply with current IEEE specifications. You will need to notify both the electricity supplier and the DNO before you can commence generating. They often require on-site witnessing or testing as a precondition for starting to generate.

Stage 6
Selling your generated power

You receive revenue from your electricity supplier by selling the electricity you generate, or by being issued with ROCs certificates which you can trade (often with your electricity supplier) in return for payment.

You will need to provide meter readings to Ofgem on either a monthly or annual basis (depending on your output) in order to receive ROCs or payment.

Conclusion

Before any energy generation from landfill gas is proposed, the necessary planning and environmental permissions must be obtained. The institutions and levels of authorisation involved for both planning and environmental permissions vary across the EU states, but in general, different levels of government contact will be needed. This means that adequate resource and time needs to be set aside for these processes ahead of any generation installations.

Our experience during ACUMEN suggests that closed landfill site owners thinking about changing to a power generation scheme at their site will find the advice on the process and steps needed for upgrading an electricity grid connection helpful.

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Key findings from our ACUMEN project work

Introduction

The sections below present some of the key findings from the work at our ACUMEN demonstration sites.

Producing electricity from closed landfills

We demonstrated two different types of landfill gas engine, a 150kW small-scale spark ignition engine and a pair of micro-scale 9kW external combustion engines. These were installed to take gas that was previously being flared and the engines operated very successfully and generated electricity for export to the power grid.

Installing smaller scale engines could be a good way for owners to generate income, possibly to help offset aftercare costs, from their sites for longer as the landfill gas from the sites diminishes over time.

Our experience suggests that:

- a 150 kW engine running on landfill gas at a methane content of 42% at a flow rate of 86 $m^3 hr^{-1}$ could have the potential to generate an income of approximately £4,000 per month from power sales, based on 0.2 ROCs.
- a pair of 9kW engines (total of 18kW) running on landfill gas at a methane content of 32% at a flow rate of 25 $m^3 hr^{-1}$ could have the potential to generate an income of approximately £750 per month from power sales based on 2 ROCs.

At full capacity and availability, these demonstration technologies could power approximately 100 typical homes at any one time from landfill gas that would otherwise have been flared.

Grid connection

Our experience was that it is possible to export power back to the national grid using the existing electricity connection (i.e. the connection that brings in power to run the gas extraction system) for an export of less than 50kW. If you want to export more than 50kW of electricity you would probably need to install a new grid connection or upgrade an existing connection.

This process takes time and is not straightforward. It would be essential to investigate the potential issues relating to exporting electricity from your closed landfill site early on in the development of a power generation scheme.

We hope that the lessons from the project will give people increased confidence in the options that we have demonstrated for managing landfill gas at both permitted and non-permitted closed landfill sites.

Low calorific flaring

We installed a low calorific flare at a site where the existing flare was now too big for the amount of gas being produced. We trialled the flare over a range of different scenarios and found that it has operated successfully down to flows of 40 $m^3 hr^{-1}$ and down to 8% methane without support fuel.

A benefit of running this flare at the lower flows was that it significantly reduced the electricity needed at the site as the gas extraction system could also be downsized. Our experience was that this could result in a saving of approximately £9000 per year in electricity costs.

Using a biofilter for managing gas at low flow rates

Our in-situ biofilter was developed based on the lessons learnt from other biofilters in the UK. We used an innovative flux sheet to monitor the performance of the biofilter. The results suggest that the biofilter we constructed could demonstrate methane removal at the surface of up to 90% at landfill gas concentrations of 5 - 10% methane and at flow rates of 45 m^3 hr^{-1}.

Monitoring

ACUMEN's experience of using innovative monitoring techniques, in particular continuous monitoring, has demonstrated the improved understanding and potential cost savings these techniques can yield.

Our experience suggests that using such high resolution techniques can enable genuine understanding of the drivers and effects of changing gas behaviour, which simply isn't possible with traditional monthly or quarterly spot monitoring.

Additionally, further innovation in this area is likely to lead to further improvements in the benefits of landfill gas monitoring, and the possible cost savings it can yield to those operating landfills through their aftercare phase.

Estimating gas generation

The ACUMEN Gas Estimation Tool has been developed to allow people to quickly and easily assess the volume of gas that you could expect to get from your closed landfill site without the need to gather significant amounts of data about the site.

Our experience of using the tool at our demonstration sites suggests that it could be a simple and cost effective way to get an initial feel for which methane utilisation or mitigation technology might be right for the site.

Assessing costs and benefits of gas management

The ACUMEN CBA tool has been developed to allow people to assess the financial and social costs and benefits of applying the different gas management technologies that ACUMEN has demonstrated.

To fully utilise the tool you would need to have information about the current costs associated with managing your closed landfill site(s).

Conclusion

In conclusion, we hope that the work presented in this project report and the tools that we have developed will allow people to assess whether similar approaches might be applicable to managing gas at their own closed landfill sites.

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Chapter 7 - ACUMEN demonstration case studies

This chapter provides more technical detail about the work that we undertook at five demonstration sites in the UK. We selected these sites as being broadly representative of closed landfills within the UK.

Our intention in this chapter is to share what we learned from the work at each site and this is presented as five standalone case studies. We hope that site owners will find them useful and help them decide whether similar approaches might be appropriate for their sites.

Introduction

Background

This chapter provides an overview of each of the demonstration sites that ACUMEN has worked on.

The aim of this chapter is to allow you to identify which of the ACUMEN demonstration(s) most closely match your site, and therefore which gas management option might be well suited to your site.

The ACUMEN demonstration sites cover the following ranges:

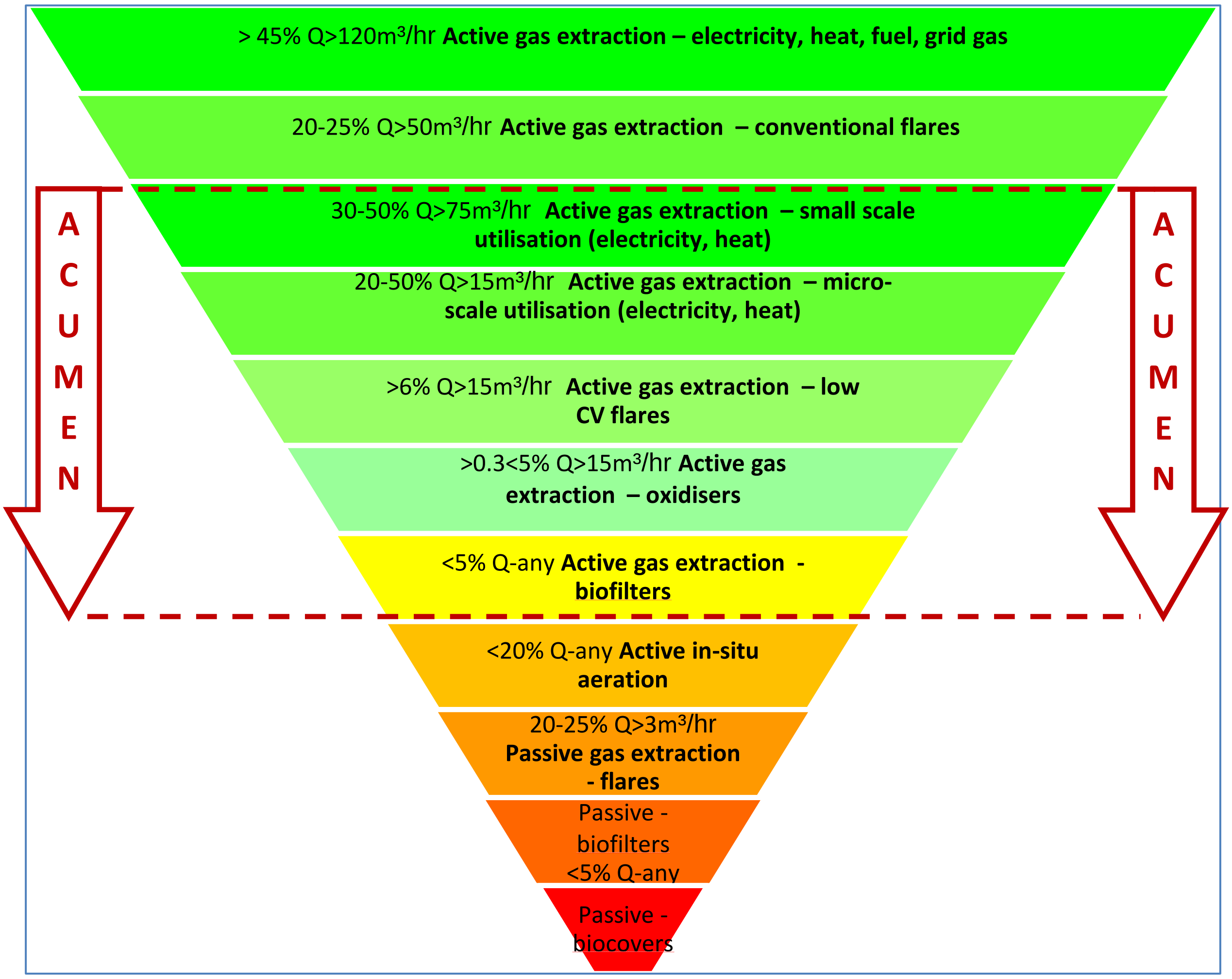
- Landfill size: 5 – 45 hectares
- Landfill age (since closure): 15 – 33 years
- Landfill regulation: Both permitted and unpermitted closed sites
- Landfill gas flow: 20 – 200 $m^3 hr^{-1}$ @ between 7% - 50% CH_4.

LFG treatment hierarchy

All permitted landfills in the EU are governed by the Landfill Directive (1999/31/EC). In the UK where ACUMEN was based, the requirements of the directive were incorporated into the Landfill Regulations 2002 (and subsequent legislation). In summary, the Landfill Regulations require that landfill gas must be 'collected, treated, and where possible, used'. The regulations further state that any landfill gas which cannot be used to produce energy must be flared. This position is likely to be common across all EU member states.

These requirements have given rise to a framework of management options for landfill gas at various quantities and qualities. In the UK, this framework is referred to as the landfill gas treatment hierarchy. The different levels within the hierarchy are represented below.

Highest methane concentration & flow



Lowest methane concentration & flow

Note: In the UK, and possibly in other member states, there are former landfills (that is, landfills without a current licence or permit) which are no longer governed by landfill regulation, but which may still be generating significant quantities of landfill gas. These landfills are typically referred to as 'historic' or 'unpermitted'. Such landfills are home to three of ACUMEN's five demonstration technologies.

ACUMEN's demonstrations

The five ACUMEN demonstrations span several layers of the LFG treatment hierarchy, and are further detailed throughout this chapter. The chapter is arranged in the same order as the hierarchy, that is, with those options with the highest amounts and percentage of methane presented first.

A summary of the demonstration findings for each site is presented in case study format below, with more detail available on request from the demonstration site contractors' reports. These are available by request from acumen@environment-agency.gov.uk

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Case study A – Small scale power generation

Sugden End closed landfill

Site location

Sugden End closed landfill site

Keighley

West Yorkshire

England

Owner: City of Bradford Metropolitan District Council

Size: 17 hectares

Temporarily covered portion of Sugden End landfill

Sugden End site location

Sugden End aerial view

Permitting status

Sugden End is a closed, permitted landfill (under the Environmental Permitting Regulations). This means that the site is legally required to manage its landfill gas, and prevent fugitive emissions from the site.

Site history

The site accepted waste between the late 1960s and its closure in 1998. Throughout its life, the site accepted a range of wastes including household, commercial and industrial wastes. In total, the site accepted approximately one million tonnes of waste during its operational period.

Site engineering

The site is a so-called 'dilute and disperse' site, located within a dry valley feature. As such, it has no basal liner. The site is partially restored with around 40% capped with an engineered clay liner, and the remaining area currently awaiting permanent capping.

Environmental setting

The site is located in a generally rural area, with few nearby receptors. However, the site is situated above a Secondary A sandstone aquifer so careful control of gaseous and liquid emissions is required and maintained.

Current gas management

Prior to ACUMEN's involvement, Sugden End collected its landfill gas through a network of 48 vertical gas collection wells. These wells feed into four collection manifolds which in turn feed the gas to an existing gas management compound via a trunk gas main which runs almost the full length of the site.

Current gas collection at the site averages approximately 140 m^3 h^{r-1} at up to 40% methane. This gas is flared using a standard landfill gas flare which was approaching the end of its useful life. The flare was replaced with a more appropriately-sized model at the start of the demonstration period in January 2015.

The site had an existing electrical grid connection, but this was not of adequate capacity to handle the projected power generation at the site.

Demonstration case study

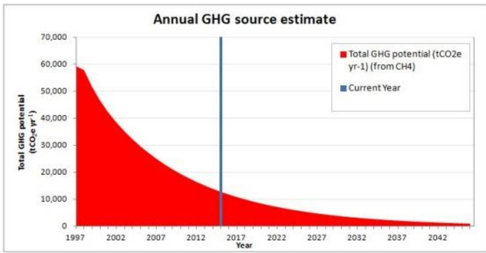
Summary

Demonstration summary	
General details	
Landfill type	Permitted closed non-hazardous landfill
Opening year	Early 1960s
Closure year	1998
Total waste deposited	1,343,500 tonnes
Site area	17 Hectares
Demonstration details	
Demonstration type	Small scale electricity generation
Average gas flow	140 m^3 hr^{-1} at 40% CH_4
Indicative costs	£130,000 (Engine & grid connection)
Electricity income generated	c. £45,000 per year
Operator cost savings	C. £2,000 per year

GET indication

The ACUMEN Gas Estimation Tool indicated a value of 164 m^3hr^{-1}, assuming 50% methane concentration, based on the site's operational period and total waste deposited. This equates to a potential emission of 12,839 tCO_2e this year.

The operational LFG graph for Sugden End from the ACUMEN GET tool.



The Annual GHG graph for Sugden End from the ACUMEN GET tool.

Demonstration technology

Following an assessment of the site, its infrastructure and the current gas regime, ACUMEN concluded that the site was likely to be able to support a small-scale power generation technology.

Small scale SI engine

Following a competitive tendering exercise, the winning option was for the installation of a small-scale spark ignition engine, with a projected output of 148 kWe.

The winning bid proposed the installation of a Scania SGI-12STM, six cylinder SI engine. This engine is rated for 400 kWe when used on traditional fuel. This engine is a standard and commonly available model. As well as being technically appropriate, this choice has the added benefit of enjoying readily available spare parts and servicing expertise.

This unit is similar to, but smaller than, the types of engines that are commonly used on operational and recently closed landfills. Due to its small size, the engine is easy to transport and quick to install. The main installation, connection and testing works were completed within three days of arriving at the site. To further improve the speed and safety of the installation, many of the associated works availed of pre-fabricated and modular construction to allow a speedy installation without the need for any significant onsite civil engineering or 'hot works'.

Grid connection upgrade

Although the site had a pre-existing connection to the national grid to power onsite services, this connection wasn't adequate to handle the projected output of the planned power generation scheme.

In association with the site owner, ACUMEN worked with the local distribution network operator (DNO) to investigate, design and carry out the necessary upgrades to the local electricity infrastructure.

In the case of Sugden End, this process took several months, and cost in the region of £70,000 (2014 prices). Although site specific factors may change the exact time and costs involved, the general point to allow time and budget for this are likely to be relevant to many similar sites.

Some key learning points from this process, include the need to involve all parties early on, and to ensure 'critical path' items are clearly identified and understood by all involved. Issues such as agreeing third party land access and arranging meter installation and connection safety testing can cause delays if not planned early and closely monitored throughout the development process.

Subsidies and incentives

As power generation from landfill gas has the potential to offset carbon intensive electricity generation elsewhere, it may be eligible to receive subsidy payments over and above the basic revenue generated by selling the resulting power. In the UK, such power generation is currently supported by the scheme under the Renewable Obligations Order (see chapter 5 for more details). Different levels of subsidy apply to different scales of power generation, but these subsidies can be essential in improving the economic viability of any scheme proposing to use landfill gas to generate power.

In the case of Sugden End, generation of 148 kWe would have attracted support at 0.2 ROCs per MWh exported for 2016/17.

Due to the comparatively short duration (approximately 12 months) of ACUMEN's demonstration period at this site, we did not claim ROCs for the work. However, any power generation project at a closed landfill to permanently utilise landfill gas in this way is likely to require ROCs support to be viable.

Note: Operators should be aware that at present, the ROCs scheme is proposed to close to new entrants in April 2017.

Obstacles

As with any project of this nature, issues can be encountered which risk delaying or preventing a successful landfill gas utilisation scheme. Three particular issues which ACUMEN encountered are as follows.

LFG control system interfaces

ACUMEN observed that where a landfill gas flare and a newly installed engine require integrating into a single, linked gas control system, unforeseen issues and complexities can arise in prioritising the delivery of a stable gas stream to the generator due to mechanical, electrical and software interfaces not behaving as expected. ACUMEN learnt that all prospective landfill gas utilisation schemes should be designed in conjunction with, or with consideration of, the existing landfill gas control and collection equipment.

Metering uncertainties and gas field issues

During the development of the Sugden End demonstration, ACUMEN observed some difficulties in respect of achieving the expected yield of gas (quantity and quality) being delivered from the landfill to the gas control compound. Metering inaccuracies and leachate/condensate conditions in the gas field can cause different gas conditions to be realised when switching from a flaring-only gas control system to a system which includes a generator set. Operators should make best efforts to ensure flow meters are appropriately place and correctly fitted to ensure accurate flow readings. Additionally, maintenance of the infrastructure (wells, pipework, knock-out pots) in the gas field itself is critical in ensuring the delivery of the maximum gas (and therefore revenue) to the installed generator set.

Performance

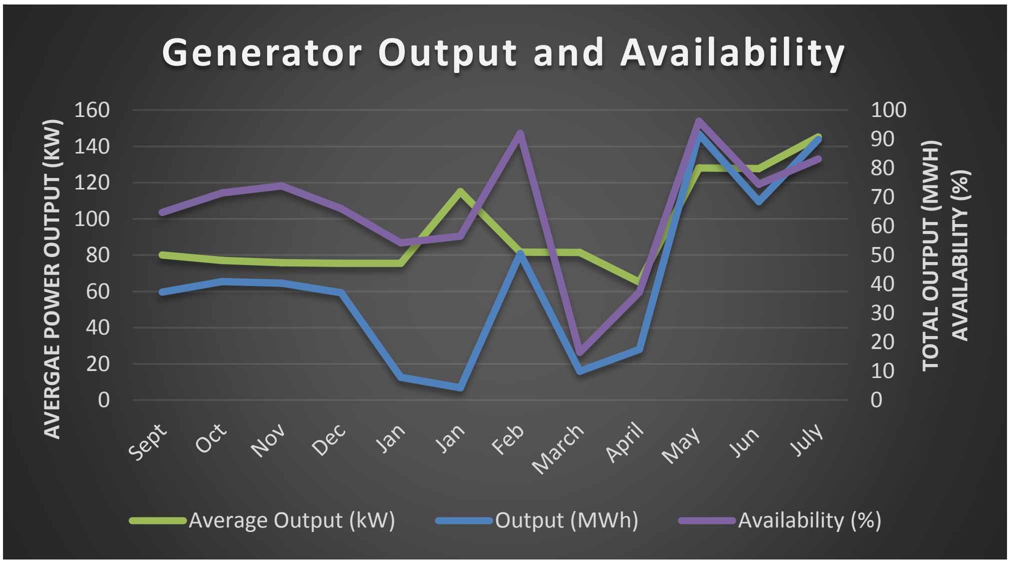
Due to some delays in the upgrading of the grid connection at Sugden End, ACUMEN decided to operate the selected engine temporarily at an alternative site for a short period before its installation at Sugden End. This allowed the project to demonstrate the use of this technology under two distinct sets of gas conditions.

Temporary site

Gas conditions at the temporary site involved 100 m^3hr^{-1} of landfill gas with average methane concentrations of 35%. During 20 weeks of the generator running at this site, an average power output of 80-115kWe was generated. In total during this period, 163,434 kWh of power was generated by combusting 200,000 m^3hr^{-1} of landfill gas.

Sugden End site

Gas conditions at Sugden End averaged 140 m^3hr^{-1} of landfill gas with average methane concentrations of 40% during the demonstration period. During 25 weeks (6 months) of the generator running at this site, an average power output of 65-130 kWe was generated. In total during this period, 257,776 kWh of power was generated by combusting 328,127 m^3 hr^{-1} of landfill gas.



This graph shows overall performance (output in terms of kW and MWh and engine availability), of the engine across both demonstration sites (Note: the two January points correspond to the temporary site, and Sugden End). The output in MWh is the total amount of electricity produced in the period. The average output is calculated by dividing the actual output (MWh) divided by the actual operating hours to give a kW rate. Availability is calculated by the number of hours the generator ran in the month, divided by the total hours in the month. The two 'low points' on the Output (MWh) plot relate to the engine being moved between sites (Jan) and gas system control issues at Sugden End (March).

Stress testing

During April 2015, when the engine was at Sugden End, variable gas flow and low methane concentration (75 m^3hr^{-1} and 25% methane approximately) enabled the operators to assess the engine performance under different landfill gas conditions.

Exhaust emissions

During the demonstration period at the two sites, several rounds of investigative emissions monitoring were carried out. This work was completed to inform future regulatory approaches to the wider use of such technologies for the utilisation of landfill gas at closed and historic sites.

The applicable compliance limits for traditional landfill gas engines in the UK are as follows. The reference exhaust gas conditions typically used for such emissions monitoring are temperature - 0°C (273°K), pressure – 101.3 kPa and oxygen – 5% (Dry gas).

Parameter	Compliance limit	Units
Oxides of nitrogen (NO_x)	500	mg Nm^{-3}
Carbon monoxide (CO)	1400	mg Nm^{-3}
Volatile organic compounds (VOCs)	1000	mg Nm^{-3}

A total of four rounds of monitoring were carried out on the engine used at Sugden End. A summary of the results achieved is contained in the following table.

Parameter	Test 1	Test 2	Test 3	Test 4	Units
NO_x	655 ± 18	394 ± 39	721 ± 22	582 ± 16	mg Nm^{-3}
CO	724 ± 27	697 ± 28	806 ± 29	905 ± 29	mg Nm^{-3}
VOCs	401 ± 17	664 ± 25	506 ± 24	382 ± 17.97	mg Nm^{-3}

Based on ACUMEN's experience and the current emissions standards for landfill gas engines, managing the combustion process to minimise emissions of oxides of nitrogen is likely to be the key challenge for smaller engines of this kind.

Costs and revenues

The total capital cost of establishing a successfully operating LFG gas utilisation scheme at Sugden End for the ACUMEN project were of the order of £150,000 (2014 prices) for installation hire, operation and removal of the engine for a 12 month period. The ongoing revenue costs of maintaining such a scheme in future years is approximately £15,000 [Note: these costs are for the engine maintenance and operation only and are mainly personnel, systems renewal and infrastructure improvement and servicing costs].

The expected revenue from the sale of the generated power is approximately £45,000 per annum (assuming ROCs support at 0.2 ROCs per MWh). As gas generation degrades at the site, the resulting revenue will decrease year on year also. This regression must be factored into any assessment of the costs and benefits of landfill gas utilisation at other sites.

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Case study B – Micro-scale power & heat generation

Docking 2 closed landfill

Site location

Docking 2 closed landfill site

Docking, near King's Lynn

Norfolk

England

Owner: Norfolk County Council

Size: 7 hectares

Surface showing gas and leachate wells

Docking 2 site location

Docking 2 aerial view

Permitting status

Docking 2 is a closed, permitted landfill (under the Environmental Permitting Regulations). This means that the site is legally required to manage its landfill gas, and prevent fugitive emissions from the site.

Site history

The site accepted waste between 1988 and its closure in 2000. Throughout its life, the site accepted a range of wastes including household, commercial and industrial wastes. In total, the site accepted approximately 400,000 tonnes of waste during its operational period.

Site engineering

The site is also a 'dilute and disperse' site, located in a former sand and gravel pit. As such, the site has no basal liner, but is fully capped and restored with a combination of geosynthetic clay and plastic sheet cap.

Environmental setting

Docking 2 sits within sand and gravel deposits, situated directly above a principal chalk aquifer and surrounded by agricultural land. The site has few nearby receptors, with the nearest dwelling being almost 600m away.

Current gas management

Due to historic migration issues, Docking 2 has extensive gas collection in place, and has historically used a standard landfill gas flare to control emissions. A network of 83 gas collection wells extract gas from the site's centre and perimeter. The gas is then delivered by way of two collection lines to a single gas management compound which houses a traditional landfill gas flare. The current gas yield from the site is approximately 130 $m^3 hr^{-1}$ at 30% CH_4.

Demonstration case study

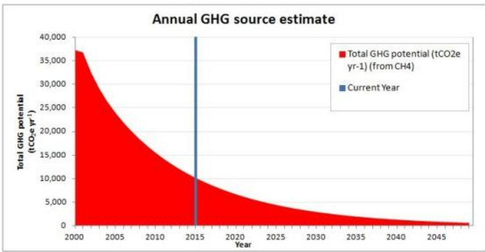
Summary

Demonstration summary	
General details	
Landfill type	Permitted closed non-hazardous landfill
Opening year	1988
Closure year	2000
Total waste deposited	400,000 tonnes
Site area	7 Hectares
Demonstration details	
Demonstration type	Micro-scale electricity generation & Direct heat utilisation
Average gas flow	25 $m^3 hr^{-1}$ at 32% CH_4
Indicative costs	£120,000 (Two engines)
Income generated	c. £7,000 per annum
Operator cost savings	c. £2,000 per annum

GET indication

The ACUMEN Gas Estimation Tool indicated a value of 130 m^3hr^{-1}, assuming 50% methane concentration, based on the site's operational period and total waste deposited. This equates to a potential emission of 10,169 tCO_2e this year.

The operational LFG graph for Docking 2 from the ACUMEN GET tool.



The Annual GHG graph for Docking 2 from the ACUMEN GET tool.

Demonstration technology

Following an assessment of the site, its infrastructure and the current gas regime, ACUMEN concluded that the site was likely to be able to support a micro-scale power generation technology. Subsequently, ACUMEN further developed a direct heat utilisation scheme using the exhaust heat from the power generation scheme.

Note: The amount of gas available at the Docking 2 site was greater than that required to fully power the selected ACUMEN technology. The choice to employ a 'smaller than possible' scheme was to allow demonstration of a wider range of options across the five demonstration sites.

Micro-scale Stirling engines

Following a competitive tendering exercise, the winning option was for the installation of two micro-scale 'Stirling' external combustion engines, with a maximum projected output of approximately 18 kWe. In addition to their electrical engine, these engines produce approximately 40 kW of heat as a by-product of their operation.

The winning bid proposed the installation of two Cleanergy C9G micro-CHP engines.

As Stirling engines are external combustion engines, they are less vulnerable to trace contaminants in landfill gas than spark ignition engines or gas turbines. Our work at Docking 2 is the first time that Stirling engines have been demonstrated on a landfill site in the UK. This site was deemed most suitable for the technology given the gas yield and, significantly, the characterisation and available control of the gas regime.

The very modest fuel requirements of these micro-CHP means that power generation off very low flows of landfill gas are potentially possible at a huge number of closed landfills around Europe.

Direct heat utilisation

In addition to the installation of the two Stirling engines, ACUMEN installed a simple system to harness the waste heat from the two engines. During the demonstration the heat production remained relatively stable with an average ratio of 1:2.35 electrcity:heat The waste heat is converted to hot water by way of a heat exchanger, then transported a short distance (<50m) by way of highly insulated piping. The hot water is then reconverted to hot air by way of a second heat exchanger. This hot air is then blown into a specially modified biomass-drying unit.

The biomass drying unit is being used to speed up the drying process for wet woodchip, which is destined to be used as fuel in biomass boilers in the local area.

Some of the facts and figures from the heat utilisation work at Docking 2 are presented below:

- More than 230 000 kWh of heat energy in a usable form was generated by the Stirling system.
- The usable heat energy was supplied as warm water with output temperatures generally ranging between approx. 25-35 °C.
- With both Stirling engines on full load, the heat output from the air dryer was approximately 40kW.
- Running on a 24 hour basis the air dryer system dried 11 tonnes of saturated woodchip to approximately 25-30% moisture content in 3 - 4 days. The finished weight was approximately 8 tonnes.

Heat transfer unit at Docking 2 with hot air piping attached.

Grid connection

Like many sites, Docking 2 had a pre-existing connection to the national grid to power onsite services. As the electrical output of the chosen demonstration is so low, the existing connection was found to be adequate without the need for upgrading. An important learning point for ACUMEN has been understanding the possibility of using existing grid connections at site for power export when the planned output is low (<50 kWe). In effect, such sites can quite straightforwardly become net exporters of power, rather than net importers.

In the case of Docking 2, approximately 4 kW of the power generated is used to power on-site services, with the remainder being exported to the national grid.

An additional learning point has been that such electrical export is unlikely to be affected by local saturation of grid capacity that can exist in some areas. Because the power output of such schemes is so modest, they potentially have the ability to be located across a wide area, rather than being restricted to areas with surplus grid capacity.

A small amount of electrical connection and safety testing work was however required to connect the power generation scheme to the national grid. This work cost ACUMEN approximately £1,000 to complete.

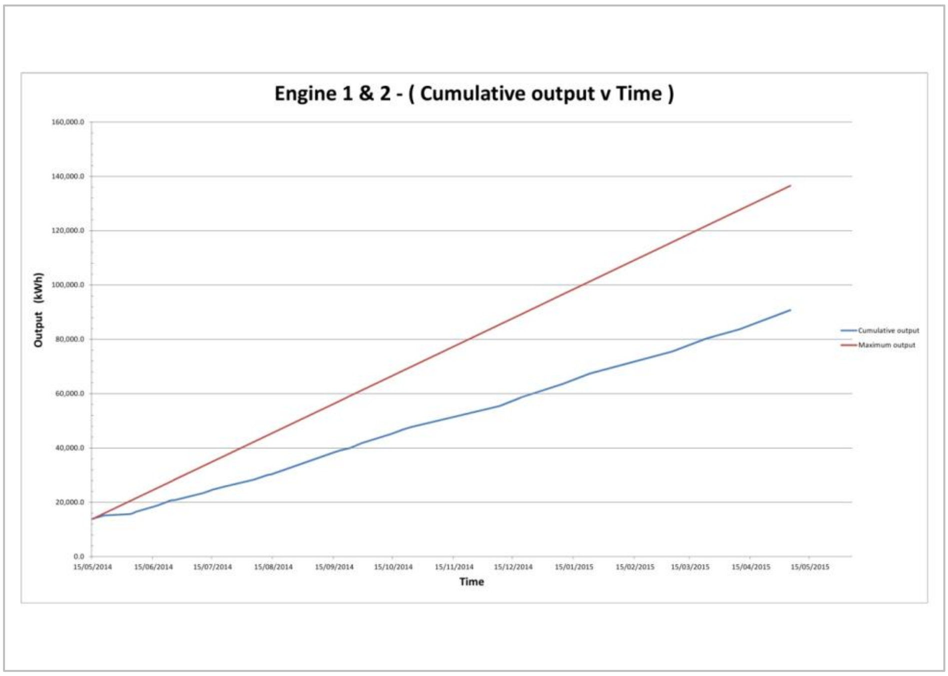
Subsidies and incentives	In the UK, a dedicated banding exists in the ROCs scheme for 'micro-generation' (<50kWe). At present, such micro-generation schemes attract 2.0 ROCs per MWh exported. Due to the comparatively short duration (approximately 18 months) of ACUMEN's demonstration period, the project chose not avail of ROCs support. However, any project to permanently utilise landfill gas in this way is likely to require ROCs support to be viable. **Note**: Operators should be aware that at present, the ROCs scheme is proposed to close to new entrants in April 2017.
Obstacles	No significant obstacles were encountered, however consideration should be given to: ▪ Location - the shipping container housing the Stirling engines required careful emplacement given the limited space available in the existing gas compound. [Note: the heat utilisation plant was not a significant addition to the infrastructure given that the storage and drying bins were located outside of the gas compound.] ▪ Grid connection – although the Docking 2 connection was sufficient, other projects may require upgrading or amendment; ▪ Gas supply – a consistent quantity and quality of landfill gas is needed for best results.

Performance

Both of the engines performed very well over the 18 month period they were operated. During this period, the two engines generated over 100,000 kWh and achieved an engine availability of 80%. The typical unit output of each of the two engines was 6-7 kWh over the eighteen months under normal operating conditions.

During the demonstration period, the engines combusted over 140,000 m^3 of LFG with an average methane concentration of 32 %. This equates to 32 tonnes of methane used productively for energy generation rather than simply being combusted in the site flare. The two engines typically used 20 -25 m^3 hr^{-1} of the available gas, with an average methane concentration of 32%.

The heat utilisation demonstration at Docking commenced in February 2014. During the demonstration, the engines generated approximately 230,000 kWh of heat which was used to dry 11 tonne loads of wet biomass, on average increasing the fuel's calorific value by 30 %.



Graph showing the cumulative power output of the Stirling engines at Docking 2.

Stress testing

During the demonstration period, ACUMEN decided to 'stress' the engines for one day during May 2015. This involved blending the two streams of gas onsite to produce a gas with lower methane concentrations. At the limits of the project's tests, the two Stirling engines continued generating electricity burning gas with methane concentrations of just 18%. During this period, the engines experienced a reduction in their power output, but they continued to generate at least 4 kW hr^{-1} on this very lean landfill gas.

On a separate occasion, ACUMEN demonstrated that it is possible to continue generating power from as little as 7 m^3 hr^{-1} of landfill gas. This was achieved while one of the engines was offline for scheduled maintenance.

Exhaust emissions

During the demonstration period, several rounds of investigative emissions monitoring were carried out. This work was completed to inform future regulatory approaches to the wider use of such technologies for the utilisation of landfill gas at closed and historic sites.

The applicable compliance limits for traditional landfill gas engines in the UK are as follows. The reference exhaust gas conditions typically used for such emissions monitoring are temperature - 0°C (273°K), pressure – 101.3 kPa and oxygen – 5% (Dry gas).

Parameter	Compliance limit	Units
Oxides of nitrogen (NO_x)	500	mg Nm^{-3}
Carbon monoxide (CO)	1400	mg Nm^{-3}
Volatile organic compounds (VOCs)	1000	mg Nm^{-3}

A total of four rounds of monitoring were carried out on one of the engines used at Docking 2. A summary of the results achieved is contained in the following table.

Parameter	Test 1	Test 2	Test 3	Test 4	Units
NO_x	46 ± 11	63 ± 9.2	54 ± 9.0	127 ± 12	mg Nm^{-3}
CO	75 ± 13	277 ± 23	197 ± 4.9	206 ± 15	mg Nm^{-3}
VOCs	545 ± 29	194 ± 15	241 ± 16	53 ± 13	mg Nm^{-3}

Based on the results above, the ACUMEN results suggest this type of landfill gas utilisation technology can be successfully used to utilise gas while attaining the same exhaust emissions as more established technologies.

Costs and revenues

The total contract cost of establishing a successfully operating LFG gas utilisation scheme at Docking 2 were of the order of £214,000 (2014 prices) for installation hire and operation of the engines for an initial 12 month period. We estimate the ongoing revenue costs of maintaining such a scheme in future years is approximately £15,000 per annum. The expected revenue from the sale of the generated power is approximately £18,000 per annum (assuming ROCs support at 2.0 per MWh).

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Case study C – Low-calorific landfill gas flaring

Otterspool former landfill complex

Site location

Otterspool former landfill complex

Liverpool

England

Owner: City of Liverpool Council

Size: 45 hectares

The gas management compound at Otterspool

Otterspool site location

Otterspool aerial view

Permitting status

Otterspool is a large complex of unpermitted, historic landfills. The site is managed to control landfill gas emissions, but is no longer subject to modern landfill regulation. Some areas of the site operated entirely before the advent of modern waste regulation, while some areas were operated under waste resolutions in line with the UK's Control of Pollution Act 1974.

Site history

The landfill is sited on reclaimed land formed by the construction of the Otterspool promenade during the 1930s – 1950s. The site accepted a wide range of wastes between the 1950s and its closure in 1981. The site accepted several million tonnes of waste during its operational period. The site was redeveloped as a public exhibition space following its closure, and has been derelict since the early 1980s.

Site engineering

The site is another dilute and disperse site, located in the void space created behind the construction of the Otterspool promenade. The site has no basal liner, but is fully restored with an engineered clay cap.

Environmental setting

Otterspool is situated above a principal sandstone aquifer, and located adjacent to the River Mersey. The site's northern edge is surrounded by a large number of residential properties, which were constructed after the site was filled.

Current gas management

Prior to ACUMEN's involvement, Otterspool collected its landfill gas through an extensive network of gas collection wells. These wells feed into a central collection line and a perimeter migration control line, which in turn feed the gas to an existing gas management compound.

Current gas collection at the site averages approximately 100 $m^3 hr^{-1}$ at approximately 20% methane. This gas is flared using a large, standard landfill gas flare which was approaching the end of its useful life. The site had previously housed a 3MW gas utilisation scheme, which was decommissioned in the early 1990s due to falling gas yields.

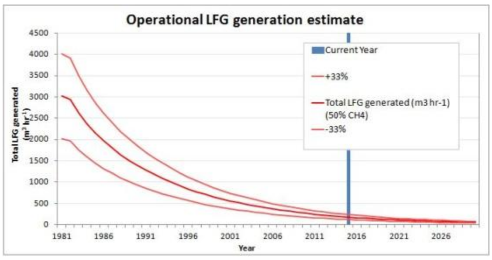
Demonstration case study

Summary

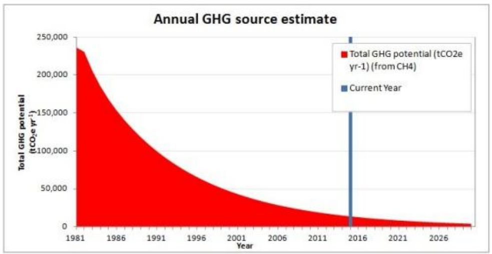
Demonstration summary	
General details	
Landfill type	Unpermitted closed non-hazardous landfill
Opening year	1950s
Closure year	1981
Total waste deposited	4,500,000 tonnes
Site area	45 hectares
Demonstration details	
Demonstration type	Low calorific landfill gas flaring
Average gas flow	100 $m^3 hr^{-1}$ at 20% CH_4
Indicative costs	c. £50,000 (Production version)
Income generated	Not applicable
Operator cost savings	c. £9,000 per annum

GET indication

The ACUMEN Gas Estimation Tool indicated a value of 180 m^3hr^{-1}, assuming 50% methane concentration, based on the site's operational period and total waste deposited. This equates to a potential emission of 14,077 tCO_2e this year.



The operational LFG graph for Otterspool from the ACUMEN GET tool.



The Annual GHG graph for Otterspool from the ACUMEN GET tool.

Demonstration technology

Working in conjunction with the long term operator of the site, ACUMEN decided to use the Otterspool site as a test location for a prototype low calorific flare.

ACUMEN installed a new type of landfill gas flare which is capable of operating over a wider range of gas qualities and quantities than traditional low calorific flares, including combusting landfill gas with methane concentrations as low as 8% without carbon intensive support fuels (such as propane or butane).

Note: The amount of gas available at the Otterspool site is sufficient to support a power generation scheme (similar to Sugden End). The choice to use Otterspool to demonstrate a flaring technology was to allow demonstration of a wider range of options across the five demonstration sites.

Prototype low-calorific value flare

Biogas Technology Ltd, an ACUMEN partner, developed and installed a new type of low calorific flare which uses a new type of burner technology to achieve stable combustion on very lean landfill gas flows.

The installed flare is configured for landfill gas flows of up to 300 m^3 hr^{-1}, and can achieve turn-down ratios of up to 10:1. The flare can also be configured for larger or smaller gas flows using different stack heights and diameters, and different burner head configurations.

In normal operation at Otterspool, the flare successfully combusts approximately 100 m^3 hr^{-1} at methane concentrations of 18%. During testing, the flare has successfully combusted landfill gas flows of between 40 m^3 hr^{-1} at methane concentrations of24% and 250 m^3 hr^{-1} at methane concentrations of 8%.

Obstacles

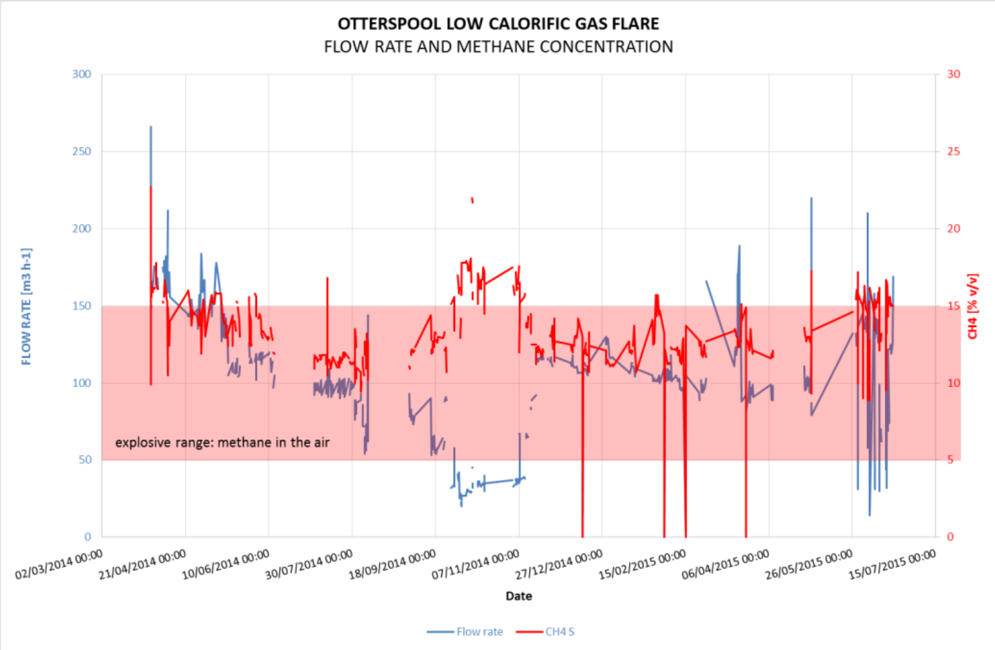
No significant obstacles were encountered, however consideration should be given to:

- Wind-induced turbulence – When flaring low volumes of low calorific landfill gas, turbulence within the flare stack can cause unplanned outages. Wind shielding on the top of the flare stack can mitigate this issue.
- Flame detection – Due to the very low calorific nature of some of the landfill gas combusted, the resulting flame can be very small. Flare control systems need to be carefully designed to account for this to prevent unintended shut downs.
- Combustion temperatures – Very low calorific landfill gases can cause flares to burn at lower temperatures than standard flares. Careful consideration of the gas stream and flare siting is required to mitigate against the risk of dioxin creation in the exhaust gas stream.

Performance

At the time of writing, the gas yield at the site is 100 m^3hr^{-1} at approximately 18% methane. The lowest methane concentration combusted was 8 % and the lowest flow rate achieved was 40 m^3 h^{-1}.

Given the stable performance of this flare at very low flows and low methane concentration, this technology opens the prospect of active thermal oxidation of methane at managed landfills for a much greater proportion of a landfill's total lifecycle. It would be important on sites requiring active gas management, for example, to control underground gas migration.



Exhaust emissions

During the demonstration period, several rounds of investigative emissions monitoring were carried out. This work was completed to inform future regulatory approaches to the wider use of such technologies for the mitigation of landfill gas at closed and historic sites.

The applicable compliance limits for traditional landfill gas flares in the UK are as follows. The reference exhaust gas conditions typically used for such emissions monitoring are temperature - 0°C (273°K), pressure – 101.3 kPa and oxygen – 3% (Dry gas).

Parameter	Compliance limit	Units
Temperature	1000	° C
Oxides of nitrogen (NO_x)	150	mg Nm^{-3}
Carbon monoxide (CO)	50	mg Nm^{-3}
Volatile organic compounds (VOCs)	10	mg Nm^{-3}

A total of six rounds of monitoring were carried out on one of the engines used at Otterspool. A summary of the results achieved is contained in the following table.

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Units
Temperature	922	975	504	894	884	752	° C
NO_x	33.6	49.4	66.7	12.3	32.4	16.4	mg Nm^{-3}
CO	75.6	20.5	49.8	21.0	21.0	20.3	mg Nm^{-3}
VOCs	2.1	0.2	4.9	0	1.8	1.3	mg Nm^{-3}
LFG flow	240	240	40	252	164	50	m^3 hr^{-1}
Methane	24.6	24.6	22.0	8.0	14	11	%

Although the combustion temperatures indicated above are below the 1000 ° C, this is allowable within the current UK compliance scheme provided all other emission limits are achieved.

Based on the results above, the ACUMEN results suggest this type of landfill gas mitigation technology can be successfully used to combust gas while attaining the same exhaust emissions as more established technologies.

Costs and savings

The flare at Otterspool was built as a prototype and so the costs associated with this demonstration site are not directly applicable to other similar sites.

The ongoing revenue costs of maintaining such a scheme in future years is approximately £10,000 per annum.

The replacement of the pre-existing gas extraction equipment with more modern, and variable-control blower and motors has significantly reduced the electricity required to extract the landfill's gas. In this example, this change has reduced the site's power consumption to approximately one-tenth of its former usage, saving the site operator £9,000 per annum, and avoiding carbon emissions elsewhere in the energy supply chain.

In this case, and based on the information available to the ACUMEN project, it would seem reasonable to predict significant benefits from both a financial and environmental perspective, as a result of installing a low-calorific flare at this site.

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Case study D – In-situ active bio-oxidation

Strumpshaw closed landfill

Site location

Strumpshaw Closed Landfill Site

Near Norwich

Norfolk

England

Owner: Norfolk County Council

Size: 12 hectares

Strumpshaw landfill during surface emissions monitoring

Strumpshaw site location

Strumpshaw aerial view

Permitting status

Strumpshaw is a closed, unpermitted landfill. The site is managed to control landfill gas emissions, but is no longer subject to modern landfill regulation. The site was previously operated under a waste resolution in line with the Control of Pollution Act 1974.

Site history

The site accepted waste between the 1972 and its closure in 1988. Throughout its life, the site accepted a range of wastes including household, commercial and industrial wastes. In total, the site accepted approximately one million tonnes of waste during its operational period.

Site engineering

Strumpshaw is also a dilute and disperse site, located within a former sand and gravel pit. As such, it has no basal liner. The full site is restored with a thin layer of sandy soil mixed with pulverised waste.

Environmental setting

The site is situated above a principal chalk aquifer, and located in close proximity to a designated SSSI site. Additionally, the site has residential dwellings within close proximity to its boundary. The site has a history of landfill gas migration affecting nearby dwellings.

Current gas management

The site has comprehensive gas collection in place, and has historically used a standard landfill gas flare on a part time basis to control emissions, particularly lateral migration. The current gas yield from the site is approximately 100 m^3 hr^{-1} at up 25% methane for 10-12 hours per day. Migration control extraction takes place 24 hours per day at very low flows, typically 10-20 m^3 hr^{-1} at 15% methane.

The current landfill gas flare is now oversized for the remaining gas generation at the site.

Demonstration case study

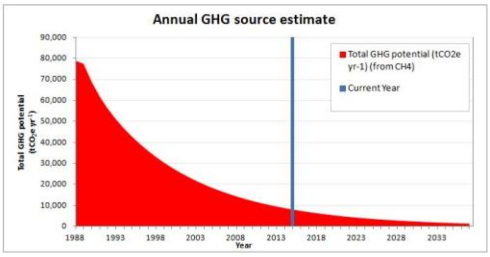
Summary

Demonstration summary	
General details	
Landfill type	Historic closed non-hazardous landfill
Opening year	1972
Closure year	1988
Total waste deposited	1,000,000 tonnes
Site area	12 Hectares
Demonstration details	
Demonstration type	In-situ active bio-oxidation
Average gas flow	75 m^3 hr^{-1} at 11% CH_4 (Diluted gas stream)
Indicative costs	c.£25,000
Revenue cost	No additional cost beyond business as usual

GET indication

The ACUMEN Gas Estimation Tool indicated a value of 103 m^3hr^{-1}, assuming 50% methane concentration, based on the site's operational period and total waste deposited. This equates to a potential emission of 8,110 tCO_2e this year.

The operational LFG graph for Strumpshaw from the ACUMEN GET tool.



The Annual GHG graph for Strumpshaw from the ACUMEN GET tool.

Demonstration technology

Working in conjunction with the site owner, ACUMEN decided that Strumpshaw was a promising candidate for an active bio-oxidation based gas treatment demonstration. Given the absence of an engineered capping layer, the project elected to construct the proposed bio-filter into the surface cover layer of the landfill.

The technique works by creating optimal conditions for naturally occurring methanotrophic (methane-consuming) bacteria to thrive, using the landfill gas to create a self-sustaining biological community.

Active in-situ bio-oxidation

Building on the experience of biofilters at other UK landfills, (Environment Agency, Active Bio-oxidation Project Report – in preparation 2015) ACUMEN designed an in-situ biofilter specifically to manage the perimeter/migration gas at Strumpshaw.

The chosen design is sized to provide ample capacity for the projected gas stream, based on academic literature[15]. The biofilter 'matrix' is a well mixed combination of expanded clay, coir, well-matured compost and oversized wood fibres (>40mm). These four matrix elements are required to prevent settlement and give the biofilter a porous structure, good moisture retention, and organic matter to 'seed' the bio-oxidation process.

In addition to the improved matrix relative to earlier biofilters, the Strumpshaw biofilter also features several other improvements including a gas distribution layer, sloped sides, slender monitoring probes and the provision of a final 'scrubbing' layer of chipped wood bark.

Gas supply

The Strumpshaw biofilter is primarily supplied by the site's perimeter migration control line. This line supplies 10 -20 m^3 hr^{-1} of landfill gas with methane concentrations of approximately 10%. During the initial operation of the biofilter, the operator made conscious efforts to supply a gas mixture below methane's lower explosive limit in air (5% v/v). The dilution was achieved by operation of a second blower which drew air into the biofilter feed line. Although bio-oxidation was successfully observed during this early period, the level of effectiveness was not as high as expected.

Following additional risk assessment, and the installation of a new flame arrester into the biofilter feed line, it was decided the operational conditions were sufficiently robust to alter the inlet gas mixture, including using methane concentrations within the explosive range. This was in part made possible by avoiding the inclusion of any ignition sources, and by availing of subterranean delivery pipework. The new, slightly richer gas mixture caused a noticeable improvement in the observed level of methane removal. The optimum gas mixture was found to be a 2:1 oxygen methane mixture. Typically this was achieved by balancing the inlet of the biofilter to achieve a gas mixture of 16% oxygen and 8% methane.

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[15] Streese, J., and Stegmann, R. Proceedings Sardinia 2005, Tenth international waste management and landfill symposium S. Margherita di pula, Cagliari, Italy; 3 - 7 October 2005

Operation and monitoring

As part of the routine management of the site, Norfolk County Council visit the site on a weekly basis. During this visit, the inlet to the biofilter is rebalanced to achieve the optimum gas mixture, the leachate drain is checked for any liquid build-up and each of the in-situ monitoring probes is sampled to record current performance. The monitoring probes within the biofilter are arranged in four clusters throughout the biofilter. Each monitoring cluster includes four different sampling ports which are located at different depths within the biofilter. The resulting sixteen monitoring ports allow detailed understanding of the gas mixture throughout the full area and depth of the biofilter.

One of the key operational challenges for the biofilter has been maintaining the optimum inlet gas mixture. Throughout the biofilter's operation, a tendency has been observed for the methane and oxygen concentrations of the inlet gas to converge, typically around 10- 12% each. This tendency alters the gas mixture within the biofilter, and has been observed to somewhat reduce the methane removal efficiency of the unit.

Verification

In line with the Environment Agency's draft monitoring protocol for biofilters, Norfolk County Council in conjunction with Ground Gas Solutions have undertaken additional monitoring efforts to verify that the biofilter is successfully abating the methane fraction of the landfill gas. This work has included periodic flux box surveys of the biofilter, detailed walkover surveys (at 1m transects) and a custom-designed 'flux sheet' which can be deployed over the full surface area of the biofilter to directly measure the 'exhaust' gas mixture that is emitted from the biofilter surface.

This work has concluded that preferential gas pathways can and do develop within the biofilter, but also that they amount to very small methane emissions overall. Additionally, ACUMEN has observed that the methane hotspots have the tendency to 'self heal' with methane hot spots apparently migrating around the full area of the biofilter during normal operation.

Obstacles

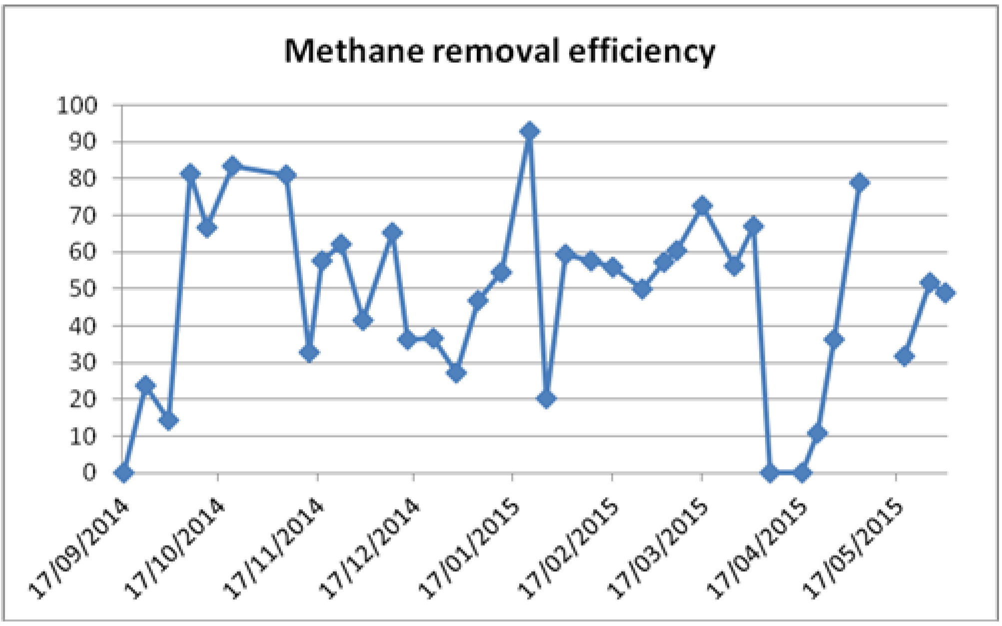
No major obstacles were encountered during the demonstration period at this site. However, the following issues are worthy of consideration:

- Available space on site – Although relatively modest in size, in-situ biofilters do require there to be sufficient available space relatively close to the existing gas control compound. In the case of Strumpshaw, the 75 m^3 biofilter required a compound approximately 25m x 5m in size.
- Gas control and balancing – The nature of older closed landfills, particularly 'dilute and disperse' sites, means the inlet gas stream can vary quite markedly in line with broader atmospheric conditions. The ability to remotely or automatically adjust the inlet gas stream to maintain the optimal inlet mix would represent a distinct advantage over the Strumpshaw biofiter.

Performance

ACUMEN has assessed the effectiveness of the Strumpshaw biofilter by assessing the weekly gas concentration data which is gathered from different locations and different depths within the unit. Generally speaking, this approach has demonstrated reducing methane concentrations and increasing carbon dioxide concentrations between the base and the surface of the biofilter.

The uppermost data point is taken from 20cm into the biofilter, at which point methane concentration reductions of 50 -60% are typical. As with other biofilters, ACUMEN has observed that a significant amount of methane is further oxidised in the top-most layer of the unit. The weekly average methane removal efficiency (as measured at 20cm depth) throughout the demonstration period is shown on the graph below. Further methane removal is believed to take place in the uppermost 20cm of the biofilter.



Methane removal efficiency, as measured at 20cm depth, at the Strumpshaw biofilter

In addition to monitoring the gas concentrations within the biofilter, ACUMEN has also carried out several independent measurements of methane flux from the biofilter surface. These have included DIAL lidar survey, high resolution surface walkover, flux box survey and deployment of the prototype flux sheet. These methods have largely indicated low levels of methane flux. As can be seen below, there is also a high degree of agreement between the different monitoring techniques.

Technique	Methane flux kg hr^{-1}	Uncertainty ±kg hr^{-1}
DIAL	2.9	0.4
Flux box survey	0.71 – 2.71	0.31 –0.67
Flux sheet	0.70 – 2.54	-
Q-SES	0.629	0.124

Surface methane flux at the Strumpshaw biofilter, as measured by various techniques.

Emissions

Bio-oxidation based landfill gas treatment techniques are suitable only where landfill gas flow and methane concentrations are low (i.e. the last phases of a landfill's life). In England, we found that many of the sites at this stage are historic landfills and as such are not subject to modern landfill regulation, so formal emissions standards do not apply. That said, effective bio-oxidation should ensure that, generally, emissions resulting from these techniques are minimal.

Demonstrating continued effectiveness throughout a biofilter's operational life is likely to prove essential to the wider take up of these techniques at UK landfills.

Costs and revenues

This section offers a very brief and indicative summary of the costs and savings involved in a gas mitigation scheme of this nature.

The total capital cost of establishing (e.g. constructing) a successfully operating LFG biofilter at Strumpshaw were of the order of £25,000 (2014 prices). The ongoing revenue costs of maintaining such a scheme in future years is approximately £10,000 per annum. This mainly comprised staff costs arising from regular visits to rebalance the inlet gas conditions. There were no significant costs relating to the ongoing operation of the biofilter itself. In many cases, these costs would be included in the 'business as usual' maintenance of a closed landfill.

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Case study E – Modular active bio-oxidation

Maesbury Road closed landfill

Site location

Maesbury Road Closed Landfill Site

Oswestry

Shropshire

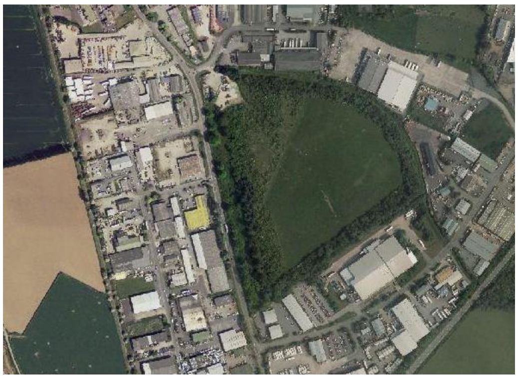
England

Owner: Shropshire County Council

Size: 12 hectares

Landfill surface showing passive vent pipes

Maesbury Road site location



Maesbury Road aerial view

Permitting status

Maesbury Road is a closed, unpermitted landfill. The site is routinely monitored to assess landfill gas emissions, but is no longer subject to modern landfill regulation. The site was previously operated under a waste resolution in line with the Control of Pollution Act 1974.

Site history

The site accepted waste between the 1972 and its closure in 1991. Throughout its life, the site accepted a range of wastes including household, commercial and industrial wastes. In total, the site accepted approximately one million tonnes of waste during its operational period.

Site engineering

The site is a dilute and disperse landfill developed as a domed land raise above the surrounding area. The site has no basal liner, but does have an engineered clay cap which was installed in the early 1990s to contemporary standards.

Environmental setting

Maesbury Road is situated above a principal sandstone aquifer. The site is surrounded by commercial premises, but given the above ground nature of the landfill, the risk of gas migration affecting neighbouring properties is quite low.

Current gas management

There is no active gas management present, gas control is maintained by passive venting using a network of 40 open venting pipes. Active gas collection and treatment has never taken place during the history of the site.

Demonstration case study

Summary

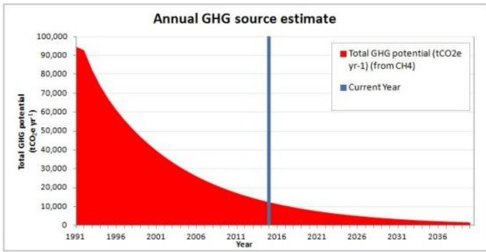
Demonstration summary	
General details	
Landfill type	Historic closed non-hazardous landfill
Opening year	1972
Closure year	1991
Total waste deposited	1,200,000 tonnes
Site area	12 hectares
Demonstration details	
Demonstration type	Modular active bio-oxidation
Average gas flow	75 $m^3 hr^{-1}$ at 20% CH_4
Indicative costs	£60,000
Operator cost savings	Not applicable

GET indication

The ACUMEN Gas Estimation Tool indicated a value of 158 m^3hr^{-1}, assuming 50% methane concentration, based on the site's operational period and total waste deposited. This equates to a potential emission of 12,417 tCO_2e this year.

Note: The significantly elevated leachate levels at Maesbury Road are thought to be the cause of the discrepancy between the GET estimate and the observed yield.

The operational LFG graph for Maesbury Road from the ACUMEN GET tool.



The Annual GHG graph for Maesbury Road from the ACUMEN GET tool.

Characterising the gas regime

Unlike the other four ACUMEN demonstration sites, Maesbury Road has no history of active gas collection. As a result, there was great uncertainty over the level of gas that might be expected from the site. To remove some of this uncertainty, ACUMEN carried out a landfill gas pumping trial during the spring of 2014. This trial extracted gas from approximately 40% of the area of the site, from waste of moderate age (that is, neither the oldest nor youngest wastes in the site).

The results of the pumping trial suggested a total gas yield of 75 $m^3\ hr^{-1}$ of landfill gas with methane concentrations of 50% likely.

Note: It is conventional to report pumping trials and landfill gas models with results normalised to 50% methane. In practice, a much leaner landfill gas (perhaps 20-25% methane) would be expected.

Demonstration technology

Working in conjunction with the site owner, ACUMEN decided that the predicted gas yields at Maesbury Road were too low to support an active combustion-based demonstration. As a result, the project explored what bio-oxidation techniques might be well suited to the site. Unlike the Strumpshaw demonstration site, Maesbury Road features a competent engineered clay cap, making an in-situ biofilter unsuitable. Following an extensive search of the market, only one methane-specific modular biofilter was identified. ACUMEN installed a single 'GeCO_2' unit produced by Entsorga SpA of Italy. The unit was installed in February 2015 and operated until the end of July 2015.

Like the in-situ biofilter at Strumpshaw, the GeCO_2 unit works by creating optimal conditions for methanotrophic bacteria to oxidise the methane in landfill gas into carbon dioxide and water.

Modular active bio-oxidation

The Entsorga GeCO_2 unit works by passing a stream of low-quality landfill gas (<20% methane) through a proprietary odour-scrubbing membrane, followed by a two-layer organic filter media. The unit is specifically designed for the lower flows of landfill gas (<150 $m^3\ hr^{-1}$) typically found at older closed landfills. In pre-ACUMEN deployments, the units have been observed to reduce methane concentrations by between 50 -67%, with lower gas flow rate being observed to offer the greatest methane destruction efficiency.

The landfill gas is extracted by a variable speed blower to offer increased flexibility and reduced fuel costs. At Maesbury Road, the power required to operate the gas extraction system was provided by a diesel generator.

In addition to a power supply, the GeCO2 also requires a continuous water supply to maintain the optimal moisture levels within the biofilter.

Due to there being no history of active gas management at the site, ACUMEN required planning permission for the demonstration at Maesbury Road.

Obstacles

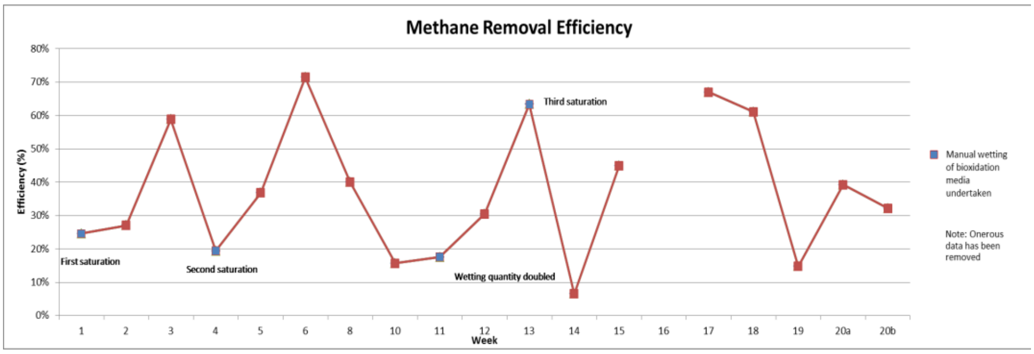
ACUMEN encountered several obstacles during the demonstration period at Maesbury Road. Several of these have the potential to recur at other sites, and so should be borne in mind. The key obstacles were as follows:

- Lack of infrastructure and utilities – As the site has never had any active gas management, significant effort was required to establish utilities connections (water and power) on the site.
- Planning permission – As there was no history of active gas treatment, the ACUMEN demonstration required full planning permission. This may be an issue at many similar sites, it is important to investigate this issue early and allow sufficient time for permission to be granted.
- Access and ground conditions – A particularly wet Spring in 2014 made accessing the site for drilling and monitoring works challenging. Adverse weather conditions can cause additional costs and delays, and may further increase leachate levels within a site and surface water run-off which needs to be managed.

Performance

From the graph below it is clear that during the period of operation there were times when methane removal efficiency exceeded 60%. This suggests a potentially effective method of oxidising methane from landfill gas comparable to the published manufacturer's figures (50-67%). The comparison of methane to carbon dioxide ratio tends to reinforce this level of methane removal efficiency at times during the period of operation. However, mean removal efficiency has been calculated at a much lower figure – around 35%. The project team considers that there are certain factors that could influence the performance of the unit, and have come up with some key learning points to this end:

- Existing LFG extraction infrastructure at the site, including three-phase electricity supply (or equivalent) and pressurised water supply would reduce time, resource and cost commitments at the outset;
- Weather conditions should be favourable to the establishment of the process (in particular the methanotrophic bacteria) – warmer temperature conditions would suit better than colder dryer conditions;
- Careful monitoring and control of the gas input and routine operation of the water supply resulted in better performance, but required a relatively higher time commitment than anticipated.



Methane removal efficiency, as measured at the outlet of the $GeCO_2$ unit.

Emissions

Bio-oxidation based landfill gas treatment techniques are suitable only where landfill gas flow and methane concentrations are low (i.e. the last phases of a landfill's life). In England, we found that many of the sites at this stage are historic landfills and as such are not subject to modern landfill regulation, so formal emissions standards do not apply. That said, effective bio-oxidation should ensure that, generally, emissions resulting from these techniques are minimal.

Demonstrating continued effectiveness throughout a biofilter's operational life is likely to prove essential to the wider take up of these techniques at UK landfills.

Costs and revenues

The total contract cost of establishing a successfully operating LFG gas mitigation scheme at Maesbury Road were of the order of £130,000 (2014 prices)) for installation hire, operation and removal of the engine for an 8 month period.. The ongoing revenue costs of maintaining such a scheme in future years is approximately £10,000 per annum, mainly comprised of staff costs involved in monitoring the biofilter unit and the utilities required for operation. No significant outlay is required for maintaining the unit, however the biofilter media is likely to require replacement approximately every five years.

[i] http://ec.europa.eu/environment/waste/pdf/guidance%20on%20landfill%20gas.pdf

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