Volume 4 Quantification and Assessment of Emission Reductions

Project Code: ORI001-001
Review of options for reducing GHG emissions from landfills in Scotland 2012
Zero Waste Scotland works with businesses, individuals, communities and local authorities to help them reduce waste, recycle more and use resources sustainably.

Find out more at www.zerowastescotland.org.uk

Written by: IKM Fehily Timoney

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<th>Rev. Nr.</th>
<th>Description of Changes</th>
<th>Prepared by</th>
<th>Checked by</th>
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Abstract: The purpose of this report (Volume 4) is to Quantify and assess the scale of emission reductions possible at landfills in Scotland, taking into account the findings of Volumes 1-3 of this study.

IKM TT Report Reference Number: UW1276901_Rpt0011-2
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1 Introduction

1.1 The Brief

IKM Fehily Timoney was appointed by Zero Waste Scotland (ZWS) under Contract GHG Emissions from Landfills in Scotland 2012 ORI001-001. The outputs of this work are contained in five volumes:

- Volume 1 - Collation of Key Information on Small, Closed and Operational Sites Across Scotland
- Volume 2 - An Examination and Review of UK and International Best Practice For Mitigation of GHG Emissions
- Volume 3 - Pilot Landfill Gas Trials at Auchinlea Landfill Site to Test Various Mitigation and Capture Measures
- Volume 4 - Quantification and Assessment of the Scale of Emission Reductions
- Volume 5 – Recommendations for Future Works

This report forms Volume 4 of this work.

1.2 Quantification and Assessment of the Scale of Emission Reductions

The purpose of this report is to:

- Quantify and assess the scale of GHG emissions from landfill sites included in this study
- Examine the potential GHG emissions reductions which may be achieved through the use of alternative technologies
- Assess the financial implications associated with implementation of alternative technologies

Volume 1 of this study collated key information and developed a landfill gas production prediction model for operational (active and recently closed) and historical landfill sites across Scotland.

Volumes 2 and 3 defined operational limits for traditional and alternative utilisation and high temperature flaring equipment.

This report combines these information streams to make an estimate of the potential scale of emission reductions that can be achieved if the best available technologies are applied to landfill sites in Scotland and reviews associated financial costs.
2 Methodology

2.1 Calculation of Fugitive Emissions

2.1.1 Remaining Landfill Gas Production

The LandGEM gas prediction model contained in Volume 1 examined a range of input parameters including methane generation rate \( k \text{ year}^{-1} \), methane generation potential \( L_0 \text{ m}^3/\text{mg} \) and size of the ‘unknown landfills’ (i.e. those landfills for which details of volume/waste input were not available). For reporting purposes, a set of ‘median’ input parameters was selected. The gas prediction model also examined the landfill gas production from historical sites (closed pre-2001), recently closed sites (closed 2001-2012) and active sites. The umbrella term ‘operational sites’ is used to refer to the last 2 categories of landfill.

The results of these models have been transposed to the calculation table included in Appendix 1 which presents data under the following headings:

- **Section 1: Total Remaining Emissions** - These emissions represent the cumulative methane emissions under a series of different headings/categories
- **Section 2: Conventional Technologies** - An estimate is made of the cumulative methane that may be oxidised using conventional utilisation and high temperature high calorific (HT HC) flares
- **Section 3: Alternative technologies** - An estimate is made of the cumulative methane that may be oxidised using best available alternative technologies i.e. micro-turbines for utilisation and high temperature low calorific (HT LC flares)

The landfill gas generation model in Volume 1 assumed a constant 50% methane content. The first order decomposition rate equation in LandGEM calculates the volume of methane generated in a given year, and adjusts it to account for the chosen methane percentage. In reality, the methane content of the landfill gas will change; however, the predicted amount of methane arising from the degradation of waste should be the same. In order to adjust for the assumed 50% methane content in LandGEM’s landfill gas volume predictions, Appendix 1 deals solely in methane emissions (i.e. 50% of the predicted LFG emissions).

Figure 2.1 overleaf shows the predicted methane emissions based on the output from Volume 1. The volume of methane generated from historical landfills (i.e. closed pre 2001) is relatively minor in the overall picture, particularly from 2001/2002 on. For reference, collated yearly return data from the Scottish Pollution Release Inventory (SPRI) are included, as is the extrapolated overall production volume based on the SPRI returns. The accuracy and limitations of the SPRI database is discussed in Volume 1.

Appendix 1 shows the total remaining methane emissions from a given cut-off point (year) for both operational and historical landfill sites and also shows the annual emissions for each category. Emissions have been reduced by a factor of 29% (from 2013) to account for the effects of diversion of biodegradable municipal waste (BMW) from landfill. The impact of the diversion targets will be significant and modelling estimates (emissions and time related) in Figure 2.1 need to be treated with caution as input assumptions are very basic.
Figure 2.1: Methane Production Curves (median input values)
2.1.2 Methane Content

In order to estimate the methane content for each year examined, a number of assumptions were made. Figure 2.2 overleaf illustrates the eight phases of the evolution of landfill gas.

Whilst some of the newer landfills will lie within Phase IV & V and some of the older landfills will lie in Phase VII, an assumption has been made in this assessment that all the landfills lie within Phase VI Methane Oxidation.

Phase VI describes methane oxidation when the rate of methanogenesis has fallen to low levels and breakdown in surface waste is aerobic. The ratio of carbon dioxide to methane reflects the change from anaerobic to aerobic processes. The methane scale within this stage can range from 60% methane to approximately 7%.

The duration of the phases as shown on Figure 2.2 are not to scale. Typically, for a traditional municipal solid waste (MSW) landfill, Phase VI may last for between 1-20 years. For a landfill accepting post-MBT (mechanical biological treatment) waste or other residual waste, the duration of Phase VI will likely be reduced. For the purpose of this assessment, it has further been assumed that Phase VI will last for 20 years, as shown in Appendix 1.

Methane concentrations for each year have been estimated based on the idealised shape of the graph included as Figure 2.2. These assumed methane concentrations are shown in Section 1 of the table in Appendix 1, and are used solely in relation to the cut-off point for various technologies, as discussed in the following sections.
Figure 2.2: Evolution of Landfill Gas

Phases of Landfill Gas Development

- Phase I
- Phase II
- Phase III
- Phase IV
- Phase V
- Phase VI
- Phase VII
- Phase VIII

- Methane
- Oxygen
- Hydrogen
- Carbon Dioxide
- Nitrogen
- LFG Production (illus.)


Q:/2012/UW12/769/01/Reports/Ppt13-2.doc
2.1.3 Conventional Technologies

Appendix 1 examines ‘conventional’ and ‘alternative’ technologies (Sections 2 and 3 of the Appendix 1 table). In this case, the conventional technologies examined are those currently used at operational landfill sites in Scotland, i.e. reciprocating engines and enclosed high temperature high calorific (HT HC) flares.

Landfill gas with a methane content greater than 45% v/v is typically required to start an engine; once the engine is running methane content greater than 35% v/v can be used for utilisation. For the purpose of this assessment, we have assumed a cut-off point of 40% for engine use.

Currently, where landfill gas is present in sufficient quantities and of sufficient quality, sites in Scotland generally use HT HC flares which under compliant stack emissions typically oxidise methane between 30% v/v and 50% v/v. For the purposes of this assessment, we have assumed that the cut-off point for use of HT HC flares is 30% v/v methane content.

The Conventional Technologies assessment in Appendix 1 assumes that between 2013 and 2020, the majority (typically 75%) of methane collected at operational sites will be utilised in engines, with the remainder flared in HT HC flares. After 2020, the assumed methane content drops to below 40% so utilisation is no longer possible. Between 2021 and 2023, it is assumed that all collected methane (a collection efficiency of between 90-95% has been assumed in these calculations), is flared in HT HC flares. After 2023, the assumed methane content drops to below 30%, and treatment of methane in landfill gas using current conventional technologies is no longer possible.

Figure 2.3 illustrates the assumed phasing of various technologies considered in this assessment.

2.1.4 Alternative Technologies Modelled

The pilot trials element of this study is documented in Volume 3. These trials examined inter alia the use of high temperature, low calorific (HT LC) flares. This assessment will also include the use of micro-turbines (discussed in Volume 2).

Findings from the pilot trials indicate that “The HT LC was able to ignite its burners with CH₄ concentrations as low as 13.2 % v/v CH₄ and was able to maintain sustained operations thereafter with CH₄ as low as 8.8 % v/v CH₄.” For the purpose of this assessment, an assumed cut-off point of 10% methane content for the use of HT LC flares has been selected.

Volume 2 discusses micro-turbines and notes that it has been “shown in recent trials that when one of their micro turbines is coupled with a thermal oxidizer it is possible to generate power from CH₄ (methane) concentrations as low as 12 % v/v”. For the purpose of this assessment this report uses the findings of trials at Fort Benning, in the USA, which show sustained operation over extended periods with landfill gas containing 16% methane concentration and this has been used as the cut-off point for use of micro-turbines.

The Alternative Technologies assessment in Appendix 1 assumes that between 2013 and 2020 the majority of methane is utilised in engines, with the remainder flared in HT HC flares (as per the Conventional Technologies assessment). From 2020 on, the assumed methane content drops to below 40% and conventional engines are no longer suitable. At this point, it is assumed that utilisation in micro-turbines commences, with the majority (typically 85%) of methane produced at operational landfill sites utilised in micro-turbines between 2021 and 2027. After 2027, the assumed methane content drops to below 16%, and utilisation in micro-turbines is no longer possible.

HT HC flares are included in the Alternative technologies assessment between the years 2013 and 2023. From 2024 on, it is assumed that HT LC flares will be used as backup to the micro-turbines. The assumed methane content drops to below 10% in 2031 and oxidation in HT LC flares is deemed no longer possible.

After 2031, the assumed methane content drops to below 10% and treatment of methane in landfill gas using the alternative technologies selected is no longer possible.
Figure 2.4 illustrates the assumed phasing of various technologies considered in this assessment.

Figures 2.5 and 2.6 show the phasing of technologies for the Conventional and Alternative scenarios from 2019 to 2032, to illustrate more clearly the effect of the implementation of the Alternative technologies model. The resulting reduction in fugitive emissions is discussed in Section 2.2.

2.1.5 Biological Filters

In the absence of full scale trials of biological methane oxidation filters as part of this study, this technology has not been included in the assessment in Appendix 1. However, it is likely that biological filters may be suitable for oxidation of methane at low levels (i.e. below the 10% cut-off point for HT LC flares above). If included as part of a proprietary capping design at operational landfills, it may be possible that all remaining fugitive emissions could be oxidised in biological filter systems.

2.1.6 Comment on Assessments

It is to be noted that the assessments presented in Section 2.1.3 and 2.1.4 give a general overview of future landfill gas treatment options. They are not to be read as a definitive timeline for changes in methane content, landfill gas volume or suitable technologies, but as an overall picture of the potential issues in relation to landfill gas treatment technologies. Inherent in the assessment are a number of critical assumptions including:

- Methane concentration decline over time
- Methane concentration cut-off point for utilisation of various technologies

Nonetheless, the assessments above do indicate that conventional technologies and practices may be problematic in the coming years, as methane contents drop below the respective cut-off points for HT HC flares and engines. This suggests that investment in new, alternative technologies and infrastructure should be investigated now.
Figure 2.3: Methane Production and Oxidation Regime - Conventional Technologies Model

Extrapolated SPRI data for 2010 assuming 85% capture efficiency estimates a 2010 total production volume of 578,804,752 m³ methane.
Figure 2.4: Methane Production and Oxidation Regime - Alternative Technologies Model

Extrapolated SPRI data for 2010 assuming 85% capture efficiency estimates a 2010 total production volume of 578,804,752 m³ methane.
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2.2 Fugitive Emissions

2.2.1 Fugitive Emissions

Both the Conventional and Alternative Technologies assessments include an estimate of fugitive emissions (i.e. all methane not utilised/flared). While active treatment of landfill gas is ongoing (i.e. to 2023 in the case of the Conventional Technologies assessment and to 2031 in the case of the Alternative Technologies), this fugitive emissions element is that fraction of methane which is not collected, and typically ranges between 5-10% of total landfill gas produced at operational sites in line with industry norms. This is added to the methane produced at historical sites, to give an estimate of total fugitive emissions for all sites examined.

Once active treatment of methane in landfill gas ceases, the fugitive emissions element from operational sites becomes 100% of all methane produced at these sites. Again, this is added to the methane produced at historical sites, to give an estimate of total fugitive emissions for all sites examined.

Figure 2.7 illustrates the fugitive emissions arising from both the conventional and alternative assessments. Table 2.1 tabulates the results in relation to fugitive emissions. The predicted total fugitive emissions from the Conventional Technologies assessment between 2013 and 2032 is calculated as $206 \times 10^6$ m$^3$ of methane ($4.12 \text{ MtCO}_2\text{e}$), and from the Alternative Technologies assessment the predicted total fugitive emissions is calculated as $115 \times 10^6$ m$^3$ of methane ($2.30 \text{ MtCO}_2\text{e}$). These figures do not take into account the emission of post-combustion landfill gas, which will contain carbon dioxide and other greenhouse gases.

It should be noted that post-2032 additional emissions are predicted in the order of $3.7 \times 10^6$ m$^3$ of methane for both scenarios. Based on the assumptions in this assessment, this will be very low calorific gas (methane content <7% v/v) and will not be treatable using current technologies. This figure is added to those presented above to give the total remaining fugitive emissions for all sites as $210 \times 10^6$ m$^3$ of landfill gas for the Conventional Technologies, and $119 \times 10^6$ m$^3$ of methane for Alternative Technologies (4.19 and 2.38 MtCO$_2$e respectively).

The figures above suggest that a reduction of $91 \times 10^6$ m$^3$ of landfill gas emissions ($1.81 \text{ MtCO}_2\text{e}$) could be achieved through the use of alternative technologies on site.

Figures 2.5 and 2.6 above show the impact on fugitive emissions of the introduction of alternative technologies from 2019 to 2032.

2.2.1 Relative Impact of Historical Landfills

It is worth noting that even though the emissions from historical landfills are significant the relative impact of historical landfills to the overall volume of fugitive emissions remains low, even when utilisation is taken into account, as shown in Appendix 1.

In the Conventional Technologies assessment, 1.16% of total fugitive emissions in 2013 come from historical landfills. This reduces to 0% of total fugitive emissions by 2025.

In the Alternative Technologies assessment, 1.16% of total fugitive emissions in 2013 come from historical landfills. This reduces to 0% of total fugitive emissions by 2032.
Figure 2.7: Fugitive Emissions

Predicted Fugitive Emissions (All Sites)

- Fugitive Emission (Conventional Technologies)
- Fugitive Emissions (Alternative Technologies)
- Methane Concentration (assumed)

Cumulative Methane (m³)

Year

Utilisation in Engines no longer possible beyond this point

Flaring in HT HC flare no longer possible beyond this point

Utilisation in Microturbine no longer possible beyond this point

Flaring in HT LC flare no longer possible beyond this point

91 x 10⁶ m³ in methane emissions reduction
**Table 2.1: Predicted Fugitive Emissions**

<table>
<thead>
<tr>
<th>Year</th>
<th>Conventional Technologies</th>
<th>Alternative Technologies</th>
</tr>
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<tr>
<td></td>
<td>Annual Fugitive Methane Emissions (all sites)</td>
<td>Cumulative Fugitive Methane Emissions (all sites)</td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>m³</td>
</tr>
<tr>
<td>2013</td>
<td>21,855,953</td>
<td>21,855,953</td>
</tr>
<tr>
<td>2014</td>
<td>18,872,319</td>
<td>40,728,272</td>
</tr>
<tr>
<td>2015</td>
<td>13,188,952</td>
<td>53,917,224</td>
</tr>
<tr>
<td>2016</td>
<td>9,741,816</td>
<td>63,659,040</td>
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<td>2017</td>
<td>7,651,022</td>
<td>71,310,062</td>
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<td>2018</td>
<td>6,382,892</td>
<td>77,692,953</td>
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<td>2019</td>
<td>11,214,817</td>
<td>88,907,770</td>
</tr>
<tr>
<td>2020</td>
<td>7,245,779</td>
<td>96,153,549</td>
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<tr>
<td>2021</td>
<td>4,838,435</td>
<td>100,991,984</td>
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<tr>
<td>2022</td>
<td>3,378,308</td>
<td>104,370,292</td>
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<td>2023</td>
<td>2,492,696</td>
<td>106,862,988</td>
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<tr>
<td>2024</td>
<td>19,540,104</td>
<td>126,409,092</td>
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<td>2025</td>
<td>16,291,795</td>
<td>142,700,887</td>
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<td>2026</td>
<td>14,317,957</td>
<td>157,018,844</td>
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<tr>
<td>2027</td>
<td>13,120,763</td>
<td>170,139,607</td>
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<tr>
<td>2028</td>
<td>12,394,628</td>
<td>182,534,236</td>
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<tr>
<td>2029</td>
<td>10,821,390</td>
<td>193,355,625</td>
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<tr>
<td>2030</td>
<td>6,563,504</td>
<td>199,919,130</td>
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<td>2031</td>
<td>3,980,967</td>
<td>203,900,097</td>
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<tr>
<td>2032</td>
<td>2,414,579</td>
<td>206,314,675</td>
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2.3 Financial Analysis

The implementation of new, alternative technologies will have an obvious financial implication for landfill operators. The following section presents the findings of an initial financial assessment. This assessment is not a definitive financial model, but rather it illustrates the relative costs/incomes associated with various scenarios, and indicates the relative merits of the alternative technologies.

2.3.1 Inputs

Table 2.2 below shows the input parameters used in the financial assessment.

**Table 2.2: Indicative Costs**

<table>
<thead>
<tr>
<th>Input Variables</th>
<th>Rating/Unit size</th>
<th>Unit Cost</th>
<th>Gas flow to energy</th>
<th>Electricity Revenue</th>
<th>Maintenance as % of Capital Expenditure</th>
<th>Run time</th>
<th>Flare (HT HC)</th>
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</thead>
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<td>Engines</td>
<td>1 MW</td>
<td>£800,000</td>
<td>375 m³ CH₄/hr/MW</td>
<td>£0.09 £/kWh (estimate)</td>
<td>15%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>Flares (HT HC)</td>
<td>500 m³/hr methane @50% v/v</td>
<td>£180,000 £/flare (assuming a 1,000 m³/hr flare unit)</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro-turbines</td>
<td>1 MW</td>
<td>£2,352,000 £/MW</td>
<td>375 m³ CH₄/hr/MW</td>
<td>£0.09 £/kWh (estimate)</td>
<td>15%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>Flares (HT LC)</td>
<td>500 m³/hr methane @50% v/v</td>
<td>£200,000 £/flare (assuming a 1,000 m³/hr flare unit)</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid</td>
<td></td>
<td>£100,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Credits (CRC)</td>
<td></td>
<td>£12.00 £/tCO₂ emitted 2011-2014</td>
<td>£16.00 £/tCO₂ emitted 2014-2015</td>
<td>75% % offset claimed via CRC scheme</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail Price Index</td>
<td></td>
<td>2.59% % increase per annum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discount Rate</td>
<td></td>
<td>5.00%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capping and Gas Extraction Costs</td>
<td></td>
<td>£0.02 £/m³/hr landfill gas (estimated)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The figures above are guidelines figures only and should not be used for detailed financial planning. No cost estimates are included above for methane oxidation through biological filters.
Detailed financial assessments should be carried out on a site-specific basis when planning the installation of new infrastructure. This assessment should include site-specific landfill gas data and costs.

Appendix 2 contains a preliminary financial model of the capital costs and potential revenue achievable from utilisation and income derived from carbon reduction credits. The assessment in Appendix 2 is broken into three distinct stages as follows:

- **Stage 1, 2013-2020**: Conventional Technologies. This stage includes the utilisation of landfill gas/methane in conventional engines and additional oxidation in HT HC flares. Revenue in this stage is from electricity generation and carbon credits, while expenditure comprises capital costs, grid connection costs, and maintenance.
- **Stage 2, 2021-2027**: Alternative Technologies. This stage includes utilisation in micro-turbines and flaring in HT HC flares initially, with flaring in HT LC flares from 2024-2027. Revenue in this stage is from electricity generation and carbon credits, while expenditure comprises capital costs, grid connection costs, and maintenance.
- **Stage 3, 2027-2030**: Alternative Technologies. This stage includes flaring in HT LC flares. There is no revenue in the phase, while expenditure comprises maintenance only.

### 2.3.2 Carbon Reduction Credits

The Carbon Reduction Credit (CRC) is a UK-wide emission trading scheme designed to incentivise the take-up of cost-effective energy efficiency opportunities. Organisations that meet the qualification criteria are required to take part. Participants are typically large public and private sector organisations. Government Departments must participate, regardless of whether they meet the qualification criteria or not. As part of this study, a report on the potential to use methane emission reductions from landfill in Scotland for reduction of Local Authority CRC obligations has been prepared. This report is included as Appendix 2 of Volume 2. The discussion below is based on the content of this report.

The CRC scheme is split into phases. Each phase is a specified time period within which a qualifying organisation must participate.

- Phase 1 started on 1 April 2010 and runs until 31 March 2014.
- Phase 2 is from 1 April 2014 to 31 March 2019.

Thereafter there will be four further phases, each of five years, and a final phase of four years commencing in April 2039.

In each year of a phase, CRC participants are required to monitor and report their energy usage. The scheme uses this information to calculate the participant’s emissions of carbon dioxide. To offset these emissions, each participant must purchase and surrender carbon allowances. One allowance must be surrendered for each tonne of CO2 emitted.

The allowance price of £12, which was introduced in 2011-12, remains unchanged through to 2013-14. It will rise to £16 in 2014-15, and from 2015-16 onwards will increase in line with the retail price index. If a local authority or large organisation meets the CRC qualification criteria, they will need to register for Phase 2 by 31 January 2014. The registration window will open when the new CRC Order 2013 comes into effect on 1 June 2013. After that, local authorities may need to apply under new rules and guidance that has yet to be published. The UK Government is due to lay an Order before the Scottish Parliament, with the Order intended to come into force on 1 June 2013, it is important to note that this may make changes from the current rules of the Scheme.

Currently for each compliance year from 2011/12 onwards, participants must order, pay for and surrender allowances to cover their annual CRC emissions. These are reported in each participating body’s Annual Report for that year. Many Scottish Councils are already committed to the CRC Scheme and as such are exposed to its requirements.
2.3.3 Application of CRC Credits to Landfills

Landfill gas has only been included in the CRC as a renewable fuel with reference to combined heat recovery plants (CHP); however with the proposed simplification of the scheme, renewable fuels will now be excluded from the scheme in the 2012-13 reporting year. From this perspective, if a CRC participant were to invest in a landfill CHP unit, this would reduce the amount of energy they would need to report in the CRC. Likewise if the landfill operator generated electricity or heat via landfill gas utilisation technology, and it consumed the energy on its own site, it would reduce the amount of metered energy it consumes from the national electricity or gas networks.

2.4 Financial Results

Figure 2.8 overleaf and Table 2.3 below illustrates the cash flow over the three stages considered. It can be seen that both Stages 1 and 2 (i.e. the utilisation phases) generate revenue, while Stage 3 (which is flaring only) does not.

Table 2.3 also clearly illustrates that use of micro-turbines as a utilisation technology on existing landfills has the potential to attract positive internal rates of return (IRR). However income from carbon credit offsets may be a critical factor for investors as shown by the IRR for Stage 2 excluding CRC offsets which shows an IRR of zero.

Table 2.3: Financial Results

<table>
<thead>
<tr>
<th>Stage</th>
<th>Assessment incl. carbon credits</th>
<th>Assessment excl. carbon credits</th>
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<tbody>
<tr>
<td>Stage 1</td>
<td>Net Present Value</td>
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<td>Internal Rate of Return</td>
<td>72%</td>
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<td>Payback Period</td>
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<td>Stage 2</td>
<td>Net Present Value</td>
<td>£33,464,567.96</td>
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<tr>
<td></td>
<td>Internal Rate of Return</td>
<td>75%</td>
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<tr>
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<td>Payback Period</td>
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<tr>
<td>Stage 3*</td>
<td>Present Value</td>
<td>-£1,461,181.30</td>
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<tr>
<td></td>
<td>Internal Rate of Return</td>
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<tr>
<td></td>
<td>Payback Period</td>
<td>Not Economic</td>
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</table>

*Carbon credits are not included in the Stage 3 assessment.

The net present value of the Stage 1 regime, i.e. Conventional Technologies, is calculated as £237 million; while the additional net present value of the Stage 2 regime, i.e. additional utilisation using micro-turbines, is calculated as £33 million. Stage 3 does not yield an economic return, but nonetheless contributes to the reduction of greenhouse gas emissions.

It should be noted that the financial assessment is very sensitive to inputs. For example, changing the Stage 1 input cost for an engine from £800,000 to £900,000 (a 12.5% increase), results in a reduction of the:

- NPV from £237 million to £222 million including carbon credits (i.e. a 6% reduction in NPV)
- NPV from £39 million to £24 million excluding carbon credits (i.e. 38% decrease in NPV).
Figure 2.8: Predicted Cash Flow from LFG Utilisation
3 Summary

3.1 Limitations & Assumptions

A number of key assumptions have been made in this assessment, as highlighted throughout this report. The key assumptions include:

- Utilisation of the median value estimates from Volume 1 of this study
- Assumption that all the landfills lie within Phase VI Methane oxidation
- Assumption that Phase VI will last for 20 years
- Estimation of methane concentrations for each year have been estimated based on the idealised shape
- Capture efficiency has been assumed at between 90-95% throughout

In addition, the uncertainties inherent in the landfill gas prediction models included in Volume 1 are carried through to this report.

3.2 Conclusions

3.2.1 Overview

The findings of this assessment suggest that operational landfills post 2013 will be responsible for the majority of GHG emissions.

Landfill gas emissions from historical landfill sites (closed pre 2001) represent less than 1% of the total remaining emissions from all sites, even when utilisation and flaring are taken into account. Figure 2.1 (and the detailed numerical analysis in Appendix 1) illustrates the relative emissions from historical landfills (closed pre 2001) and operational landfills.

It is worth noting that the operational sites in this assessment also include ‘recently closed’ sites, (post 2001). ‘Recently closed’ sites may require intervention and improvements (subject to site specific assessments).

It may also be appropriate to carry out site specific risk assessments for individual historical sites to determine if emissions from the larger more recently closed sites require intervention.

From Figure 2.1 it is clear that the window of opportunity for utilisation, and more importantly for the reduction of greenhouse gas emissions, from historical landfill sites has been missed. This highlights the need for continued intervention on operational sites (and recently closed) in the aftercare phase to ensure that the emissions reduction from these sites continues once conventional practices associated with utilisation and HTHC flaring are no longer sustainable.

The key objective for the future, with immediate effect, should be the capture of landfill gas as it is produced on site. This will require a greater emphasis on capture efficiencies at individual landfill sites, and thereafter on the oxidation of all gas emissions.

Current technologies are limited by methane content and the analysis in this report shows that oxidation of methane in new, alternative, emerging technologies, such as micro-turbines and high temperature, low calorific flares, can have a significant impact on the scale of greenhouse gas emissions from landfills in Scotland. In addition, beyond the methane content cut-off point for oxidation in engines, micro-turbines or flares, the potential remains for oxidation of low methane content landfill gas in biological oxidation filters.

The financial analysis suggests that the capital costs associated with the implementation of alternative technologies has potential to generate an attractive return on investment, and that a revenue stream could be created through the sale of electricity and through carbon credit offsets.
3.2.2 Potential Reduction in Emissions

The analysis in this report suggests that fugitive (i.e. untreated) landfill gas emissions using current conventional technologies will be in the order of $4.19 \times 10^6$ m$^3$ of landfill gas ($4.19$ MtCO$_2$e). If alternative technologies, such as micro-turbines or high temperature low calorific flares are installed at operational sites, this figure can be reduced to $2.38 \times 10^6$ m$^3$ of landfill gas ($2.38$ MtCO$_2$e). This means that a reduction of $1.81 \times 10^6$ m$^3$ of landfill gas emissions ($1.81$ MtCO$_2$e) could be achieved through the use of alternative technologies on site.

3.2.3 Financial Implications

The net present value of the Stage 1 regime, i.e. Conventional Technologies, is calculated as £237 million; while the additional net present value of the Stage 2 regime, i.e. additional utilisation using micro-turbines, is calculated as £33 million. Stage 3 does not yield an economic return but nonetheless contributes to the reduction of greenhouse gas emissions. Income from carbon credit offsets may be a critical factor for Stage 2 investments.
### Appendix 1

#### Assumed Duration of Phase VI

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### Detailed Calculations for Utilisation

#### Total Remaining LFG Production & sites, median inputs

Appendix 3: Calculations for Utilisation of LFG site 1-100% Utilisation

### Section 2: Flaring & Utilisation

#### Total volume methane assumed utilised/flared (operational sites) m³

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APPENDIX 2

FINANCIAL ASSESSMENT
## Appendix 2

### Stage 1 (2013 - 2020)

**Input Variables**

<table>
<thead>
<tr>
<th>Year</th>
<th>Methane Flows Oxidised</th>
<th>Gas flow to energy (£/kWh)</th>
<th>Engines</th>
<th>Hourly flows</th>
<th>Run time</th>
<th>Unit Cost</th>
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<tbody>
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<td>2013</td>
<td>280,773,972</td>
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<td>15%</td>
<td>22,424,415</td>
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<td>2014</td>
<td>95,430,630</td>
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**Expenditure**

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<th>2013</th>
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<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
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<td>750,000.00</td>
<td>150,000.00</td>
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<td>Capital Expenditure</td>
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<td>750,000.00</td>
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<tr>
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<td>1,522,000.00</td>
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### Stage 2 (2021 - 2027)

**Input Variables**

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<th>Year</th>
<th>Methane Flows Oxidised</th>
<th>Gas flow to energy (£/kWh)</th>
<th>Engines</th>
<th>Hourly flows</th>
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**Expenditure**

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<td>1,084,842.40</td>
<td>486,555.30</td>
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