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An Ghníomhaireacht um Chaomhnú Comhshaoil

Climate Change Research Programme (CCRP) 2007-2013
Report Series No. 3

Estimates of Methane Recovery in Landfill Gas Flaring and Utilisation

SSTI

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Heritage and Local Government.

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- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

EPA Climate Research Programme 2007–2013

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CCRP Report

Prepared for the Environmental Protection Agency

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The EPA CCRP Programme addresses the need for research in Ireland to inform policy-makers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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1 Introduction

The Office of Climate Licensing and Resource Use (OCLR) of the Environmental Protection Agency (EPA) acts as the inventory agency in Ireland with responsibility for compiling, reporting and improving national greenhouse gas inventories. This project seeks to improve the methodology for the estimation of flaring and utilisation of landfill gas.

Landfill gas contains the greenhouse gases methane (CH_4) and carbon dioxide (CO_2). In order to offset the CH_4 content and combust other trace components, landfill gas is flared and utilised. Other components of landfill gas also have global warming potential but these are outside the scope of this study (details of trace components can be found in UK Environment Agency guidance [EA, 2004a]).

There is no formal mechanism in place for reporting flaring and utilisation of landfill gas in Ireland. According to the *National Climate Change Strategy 2007–2012* (Department of Environment, Heritage and Local Government, 2007), waste activities account for 2.5% of national greenhouse gas emissions.

This report has been prepared as per the structure of the 'Request for Tenders for the Environmental Protection Agency, Estimates of Methane Recovery on Landfill Gas Flaring and Utilisation' brief. This tender was prepared by the Climate Change Unit of the EPA.

2 Landfill Gas Flares

This section of the report addresses Task 1 of the Brief as outlined in the following requirements:

- Identify the landfills where flares are used or have been used;
- Determine the mode and periods of operation for flares and other technical information relevant to gas consumption;
- Quantify the CH_4 input to individual flares and compile the national total for all relevant years.

Historically, open flares were used on landfills, especially as temporary flares. It is now a condition of EPA waste licences that enclosed flares are employed for improved emissions control.

2.1 Flare Use

A survey of the major flare suppliers to the Irish market was carried out as part of this project. Table 2.1 shows the different types of flare that are reported to have been operational in Ireland in the period 1996–2008. It was found that:

- 86 flares were operational from 1996–2008;
- 53 flares were in use in 2008 (of which 5 are open flares).

Figure 2.1 shows the number of sites that were flaring CH_4 during the period 1996–2008.

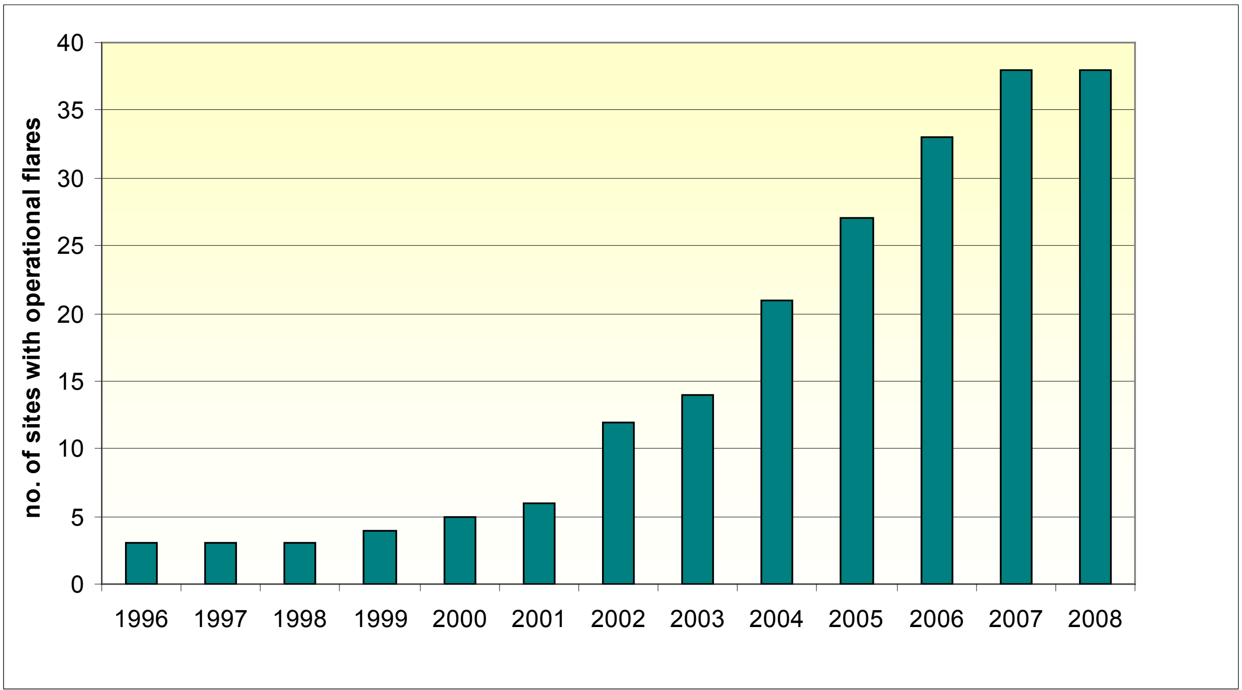

Figure 2.1. Number of sites with operational flares, 1996–2008.

Table 2.1. Landfill gas flares at Irish landfills, 1996–2008.

Model	Capacity (m^3/hr)	Type	No. flares reported as operational 1996–2008	No. flares reported as operational, 2008
(AFS) HT1000	1,000	enclosed	3	3
(AFS) HT1200	1,200	enclosed	2	2
(AFS) HT150	150	enclosed	1	1
(AFS) HT250	250	enclosed	3	3
(AFS) HT500	500	enclosed	11	10
(AFS) HT750	750	enclosed	6	5
AFS 500 (Open)	500	open	1	
Biogas BG2468	1,000	enclosed	1	1
Biogas Flare	1,250	open	1	1
Fans and Blowers 1500	1,500	open	1	
Flare Tech 500	500	open	2	1
Haase 1750	1,800	enclosed	1	1
Haase 2500 Haase HT 12.5	2,500	enclosed	7	7
Haase 500	500	enclosed	2	1
Haase 500	500	open	1	
Haase 600	600	enclosed	2	2
Haase HTN 2000	2,000	enclosed	2	2
Haase Technik Enclosed Fare	4,000	enclosed	1	1
Haase Technik Enclosed Flare	1,500	enclosed	5	3
Hofsetter	250	open	1	
Hofsetter EGH-01A	250	open	2	
Organics 750	750	open	1	
Organics 750	750	enclosed	1	1
Organics f300	300	enclosed	1	1
Organics Open Flare	4,000	open	1	1
Organics SC250	250	enclosed	1	1
Organics Type HTN	1,500	enclosed	2	1
Organics	1,500	open	2	
Small mobile diesel powered flare	unknown	enclosed	1	
Small mobile electrically powered flare	unknown	enclosed	1	
UFO-2500	2,500	open	2	1
UFO-500	500	enclosed	2	1
UFO-500	500	open	5	
Unknown	250	open	3	
Unknown	500	open	5	
Unknown	1,500	open	1	1
Unknown	1,500	enclosed	1	1
Total no. flares operational			86	53

Table 2.2. Number of sites surveyed.

Status of site	Surveyed	Survey returns	Non-returns	Response rate (%)
Open	27	25	2	93
Closed	37	33	4	88
Total licensed sites	64	58	6	91

There are 64 licensed landfill sites in Ireland. Some of these are ‘active’ and others are ‘closed’. An active site is defined as a landfill site that is currently accepting waste material for deposition. A closed site is defined as a landfill site that has ceased accepting waste material for deposition. The closed sites have subsequently been re-developed for other waste-management activities, the most common being waste-transfer stations. Landfills that fall into this category are now regulated under the waste licences for these new waste infrastructures. A survey was sent to each of the licensed landfills in Ireland – Table 2.2 summarises the number of sites surveyed and the response rate.

2.2 Technical Data

All of the major flare and utilisation engine suppliers in Ireland were contacted at project commencement. Manufacturers of both flares and engines were reluctant to provide support information in relation to the criteria governing the ability and efficacy of units to recover CH_4.

The UK Environment Agency has published guidance documents for monitoring flares and engines. These documents provide generic information in relation to the design and performance of both flares and engines.

An extract from the Environment Agency document (EA, 2004b) states that:

> Flares use landfill gas as the fuel and air is used as the oxidant (containing approximately 21 per cent oxygen). The stoichiometric ratio of air to CH_4 for idealised combustion is 9.52:1, with the basic combustion reaction given by CH_4+2O_2+7.52N_2+CO_2+2$H_2$0+7.52N_2+heat+light This stoichiometric mixture represents the precise amount of air needed to completely burn one molecule of CH_4. If more air is supplied than required for stoichiometric combustion, the mixture is termed lean and oxidising. If, however, too little air is supplied, the mixture becomes too rich and reducing, and carbon monoxide and saturated/unsaturated hydrocarbons (non-CH_4 volatile organic compounds – NMVOCs) form during the combustion process. Excess air is added to provide a lean mixture to aid complete combustion within the flare. The emissions from combustion systems can contain compounds that are:
>
> - Derived from an unburnt fraction of the gas;
> - Products of complete combustion;
> - Products of incomplete combustion;
> - Contaminants present in the air used in combustion.

Operating criteria for flares and engines are designed to optimise combustion at defined temperatures and gas concentrations. However, landfill gas generation is not uniform in relation to gas composition or production rates.

Current licence conditions are designed to control emissions when CH_4 is available in sufficient quantities to facilitate combustion under controlled conditions.

In modern landfills, the decaying waste uses up the oxygen entrained within the waste and creates anaerobic conditions (i.e. an absence of oxygen). Under these oxygen-free conditions, specific anaerobic bacteria (methanogens) flourish and continue to degrade the waste, producing landfill gas.

Christiansen and Kjedsen (1989) identify eight distinct phases in the evolution of landfill gas (Figure 2.2).

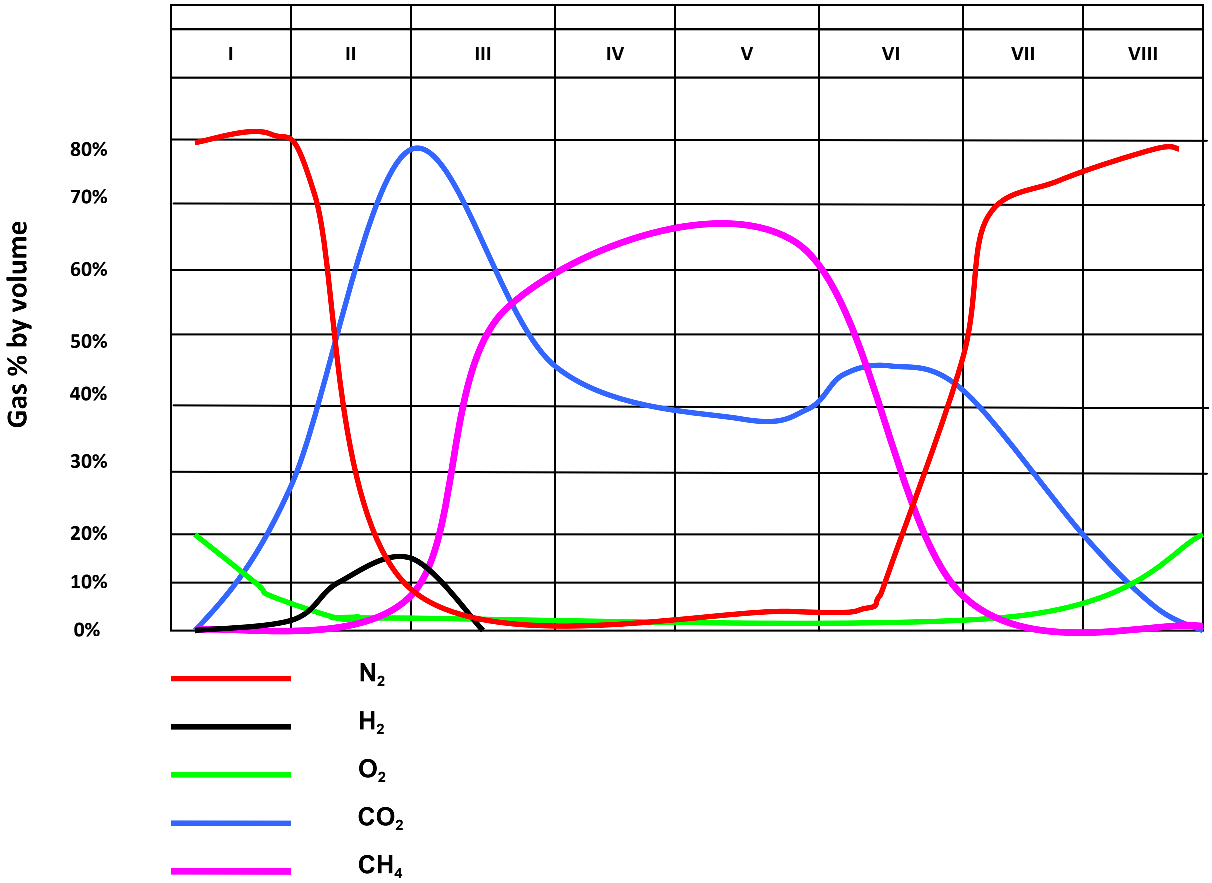

Figure 2.2. Eight phases of landfill gas development (Source: Christiansen and Kjedsen (1989)).

The eight phases are described as:

Phase I: *Aerobic* – follows waste deposition in which the residual oxygen is used up. This phase typically lasts for a few days to a number of months, depending on local factors such as temperature and moisture availability.

Phase II: *Acid* – populations of facultative and fermentative anaerobic bacteria develop, producing volatile (aliphatic) acids, CO_2 and H_2, displacing the remaining N_2 entrained with the waste. This phase may last from weeks to years, depending on conditions.

Phase III: *Initial methanogenic* – microbial respiration reduces oxygen concentrations to extremely low values, allowing populations of methanogenic bacteria to develop, producing CH_4. Concentrations of H_2 and CO_2 start to fall.

Phase IV: *Stable methanogenic* – the remaining H_2 is used in the reduction of CO_2 to CH_4 and H_2O. Phase IV may begin within months to years after waste deposition and last for decades. Typical landfill gas collected in this phase consists of 40–65% by volume of CH_4 with most of the balance made up by CO_2.

Phase V: *Air intrusion* – the rate of methanogenic activity begins to fall as substrate is used up, resulting in air beginning to enter the waste. Lower rates of gas formation lead to relatively faster washout of CO_2, so that its concentration falls relative to that of CH_4.

Phase VI: *CH_4 oxidation* – rates of methanogenesis have now fallen to low levels, allowing the rate of air ingress to increase, so that surface layers of waste and the capping material now become aerobic (oxygen rich). Methane concentration in landfill gas decreases while that of CO_2 increases steadily.

Phase VII: *CO_2* – return of aerobic conditions. At this stage, the rate of landfill gas formation has almost ceased because of substrate limitation; anaerobic decomposition becomes inhibited by the ingress of O_2 in the air. This allows the aerobic decomposition of solid organic matter resistant to anaerobic decomposition.

Phase VIII: *Soil air* – the final phase occurs when degradable organic matter has been oxidised and the landfill gas resembles that of typical soil air.

The duration of each of these phases is highly variable. Apart from the initial aerobic decomposition, which may be complete in days to months, the remaining phases have durations measured in years, decades or even centuries for the final phases. The concentrations at which landfill gas cannot be managed using traditional treatment methods are shown in Figure 5.1 in Section 5 below.

In Phases I, II, VI, VII and VIII, CH_4 availability may be insufficient to facilitate combustion under controlled conditions. The use of traditional large-scale engines in these zones is unlikely to be economic, and the operation of enclosed flares may also be difficult. While the operation of open flares may be possible, typical licence conditions prevent such an activity.

In relation to CH_4 recovery, there is a requirement to determine how best to deal with these fugitive emissions that cannot be oxidised using enclosed flares or engines. In addition to scoping alternative technologies to deal with this problem, it should be asked whether it is less damaging environmentally to allow oxidation of CH_4 in open flares than to allow CH_4 to vent to the atmosphere.

2.3 Volume of Methane Flared, 1996–2007

The following information on flare operation was collated from each site:

- Number of flares on site;
- Operational performance of each flare;
- Flare maintenance;
- Recording methods;
- Recorded parameters:
  - function of flare on site;
  - average flow rate (m^3/hr);
  - average pressure at inlet (mbg);
  - average gas quality % v/v (CH_4, CO_2 and O_2);
  - average runtime (hrs/day).

The volume of CH_4 flared was calculated from the recorded parameters.

In general, the quality of data recorded was better for newer enclosed flares than for older open flares.

Table 2.3 shows that CH_4 volumes flared in Ireland between 1996 and 2007. The table was generated from records of 64 sites that responded to the questionnaire.

Estimates of the volume of CH_4 flared were made in the cases where partial information had been recorded in the survey by the licensee. Typically, this related to the operation of open flares. In other cases, the licensee was missing records either of gas quality or of flow rate. Where partial information was supplied in the survey, estimates for Table 2.3 were made. Figure 2.3 gives a comparison of measured volumes and estimated volumes, demonstrating that the bulk of the data collected was measured rather than estimated. Typical examples of the approaches used are presented below:

- If, for example, the flare was operational for 5 years and there was a full set of data for the last 3 years, it was assumed that the flare operated to the same parameters for the first 2 years;
- If no flow records were available for the flare but the rated flow capacity was defined, a subjective assessment was made, assuming that the flare operated at 50% of the defined rated flow capacity and at 20% v/v CH_4 for an open flare and at 25% v/v CH_4 for an enclosed flare;
- If no data was available, it was defined in the database behind Table 2.3 as not recorded using the abbreviation 'nr'. For example, there were two instances where the operator knew that two temporary flares had been in operation on site but there was no data available about the operational period, capacity, flare model, gas quality or throughput. A subjective assessment was not possible in these instances.

Table 2.3. National total volume of CH_4 flared, 1996–2007.

Year	CH_4 flared (measured) (m³/yr)	CH_4 flared (estimated) (m³/yr)	Sum measured and estimated (m³/yr)	Sum measured and estimated (t/yr)**
1996	10,238,250	2,847,000	13,085,250	9,382
1997	10,238,250	2,847,000	13,085,250	9,382
1998	10,457,250	3,066,000	13,523,250	9,696
1999	10,457,250	3,066,000	13,523,250	9,696
2000	14,735,050	3,230,250	17,965,300	12,881
2001	15,862,900	3,372,600	19,235,500	13,792
2002	26,245,690	9,121,350	35,367,040	25,358
2003	34,937,800	6,241,500	41,179,300	29,526
2004	58,461,386	6,749,098	65,210,484	46,756
2005	62,813,427	1,628,477	64,441,903	46,205
2006	69,014,361	1,249,213	70,263,573	50,379
2007	86,794,263	602,250	87,396,513	62,663
2008*	87,488,323	625,063	88,113,385	63,177

*Preliminary results for the volume of CH_4 flared in 2008 (estimated based on data to October/November).

** A density of 0.716 kg/m³ was assumed.

Figure 2.3 gives a comparison of the volume of estimated CH_4 flared to measured CH_4 flared. The proportion of estimated CH_4 diminished with time, so that in 2007 less than 1% of CH_4 flared was estimated from incomplete data in survey returns.

The density of CH_4 at standard temperature and pressure (STP) was used to calculate the mass of CH_4 recovered. STP assumes a temperature of 0 °C and an atmospheric pressure of 1 atmosphere (atm).

In relation to CH_4 recovery it will be necessary to adjust data from future audits to reflect the impact of prevailing atmospheric and temperature conditions on STP or similar. Accordingly, for standardised estimates of CH_4 recovery, future surveys will need to record temperature

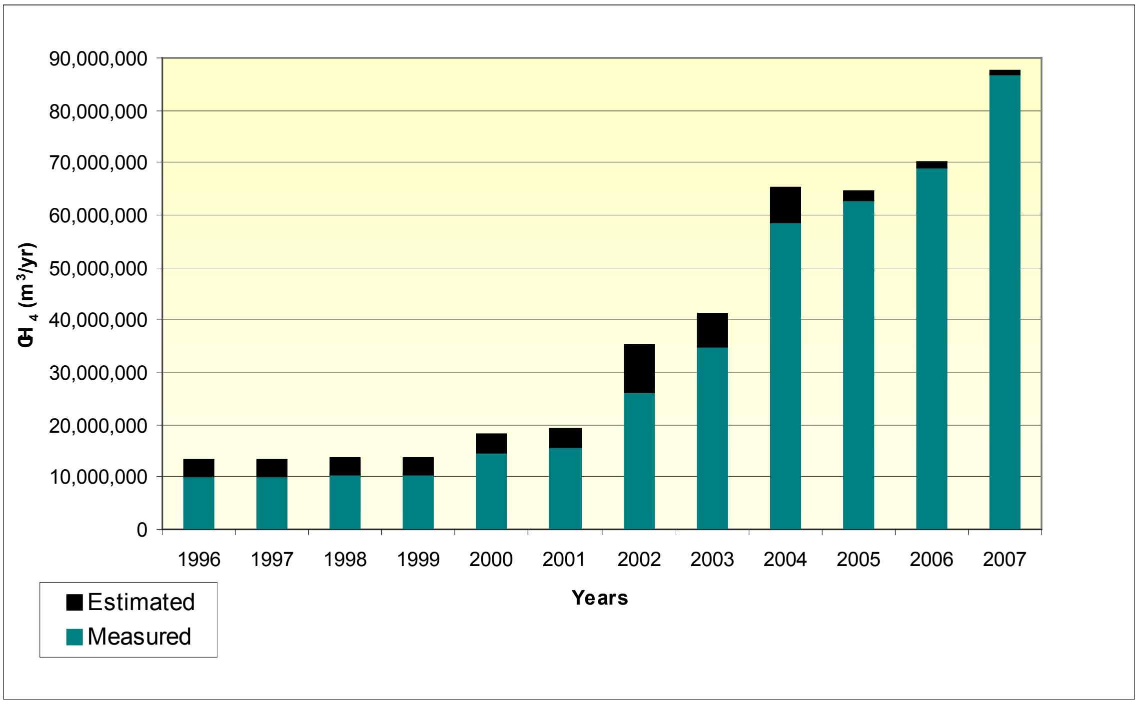

Figure 2.3. Comparison of measured and estimated flared CH_4.

and atmospheric pressure of landfill gas as it enters the flare or engine.

Sensitivity analysis carried out (not presented in this report) as part of this study emphasised the need for flow, gas quality, temperature and pressure records in order to estimate future CH_4 recovery accurately. Once this data is available in the future it may be possible to calibrate old models and retrospectively adjust historical estimates if required. It is believed that publishing sensitivity estimates of input variables (e.g. impact of alternate flare-rated capacities) in relation to the current study and other variables to evaluate previous EPA estimates is inappropriate and may be misleading.

Table 2.4 presents density changes with temperature.

In general terms, a change of plus or minus 10 ^{o}C is likely to impact volumes of CH_4 approximately equal to plus or minus 3.5%.

Table 2.4. Impact of temperature change on CH_4 density.

Temperature ^{o}C	Density (kg/m^3)
0	0.716
15	0.678
20	0.667
25	0.665

3 Landfill Gas Utilisation Plants

This section of the report addresses Task 3 of the Brief to:

- Obtain technical information on the plants utilising landfill gas for electricity generation and on their landfill gas inputs in order to estimate the precise energy content and CH_4 consumption;
- Validate the available estimates of energy input from landfill gas to such plants for the years 1996–2006 as contained in the Sustainable Energy Ireland (SEI) energy balances.

There are 6 operational landfill gas-utilisation plants in Ireland with a combined total of 24 engines. (Plants range in size from 1 MW to 10 MW.) One site added 3 new engines in 2008 but these have not yet been connected to the national grid and therefore are not included in the calculations of landfill gas utilisation. Five of the sites have flares to supplement or to provide backup to the engines. Landfill gas utilisation plants in Ireland are owned and operated by Bioverda Power Systems Ltd (BPS). Typically, BPS operates the plants as separate entities to the landfill sites and is responsible for:

- Operating and maintaining the engines and flares in their compounds;
- Recording flaring and utilisation data;
- Supplying the landfill operator with details of engine runtimes and landfill gas throughput on request.

3.1 Technical Data

Each of the sites with a landfill gas utilisation plant in Ireland responded to the survey. The total volume of landfill gas utilised in Ireland from 1996–2007 was calculated from the following information collated from each site:

Operation and management:

- Number of engines on site 1996–2007;
- Recording methods.

Recorded parameters:

- Average flow rate (m^3/hr);
- Average gas quality (CH_4, CO_2 and O_2);
- Average runtime (hrs/day);
- Engine rated power output (kW);
- Actual engine power output (kW).

Table 3.1 shows the types and numbers of engines used in Ireland in 2007.

Table 3.1. Types and numbers of engines used in Ireland, 2007.

Landfill site	Model	Unit rated power capacity	Operational engines 2007	Total rated power capacity
		kW	No.	kW
Arthurstown*	Jenbacher JMS420 GS-B.L	1,415	7	9,905
Arthurstown	Deutz 1250 kW	1,250	1	1,250
KTK	Deutz** 620	1,250	3	3,750
Dunsink		1,250	1	1,250
Silliot Hill		1,250	1	1,250
Kinsale Road		1,000	2	2,000
Balleally		1,000	5	5,000
Ballyogan		1,000	2	2,000
Total				**26,405**

* Three additional engines have been installed on site and are awaiting grid connection from the Electricity Supply Board (ESB).

**It should be noted that many of the engines used in Ireland have been reported in this survey as Deutz 620. It is not clear whether this model name refers to the output of the engine, although it appears from the reported data that it does not.

Table 3.2. Volume of CH_4 utilised for energy generation, 1996–2007.

Year & Licence No.	W0012-02	W0004-03	W0009-02	W0081-03	W0127-01	W0015-01	W0014-01	Sum m³/yr	Sum m³/hr
1996	950,400	0	1,895,400	0	7,581,600	4,001,400	0	14,428,800	1,647
1997	3,801,600	0	3,790,800	0	7,581,600	4,001,400	0	19,175,400	2,189
1998	3,801,600	0	6,633,900	0	7,581,600	4,001,400	0	22,018,500	2,514
1999	3,801,600	0	9,477,000	0	7,581,600	4,001,400	0	24,861,600	2,838
2000	3,801,600	0	9,477,000	0	7,581,600	4,001,400	0	24,861,600	2,838
2001	3,801,600	0	9,477,000	0	7,581,600	4,001,400	0	24,861,600	2,838
2002	3,801,600	0	9,477,000	0	7,581,600	4,001,400	0	24,861,600	2,838
2003	3,801,600	0	9,477,000	0	6,633,900	4,001,400	0	23,913,900	2,730
2004	3,801,600	10,206,000	9,477,000	0	4,738,500	4,001,400	*201,600**	32,426,100	3,702
2005	3,801,600	12,852,000	9,477,000	2,421,900	3,790,800	4,001,400	*403,200**	36,747,900	4,195
2006	3,801,600	17,898,300	9,477,000	6,054,750	2,843,100	4,001,400	*302,400**	44,378,550	5,066
2007	3,801,600	21,612,150	9,477,000	6,660,225	1,579,500	4,001,400	*67,200**	47,199,075	5,388
2008	3,801,600	25,439,400	9,477,000	6,054,750	1,579,500	4,001,400	0	50,353,650	5,748
								390,088,275	44,531

*Values in italics are estimated.

Table 3.3. Power output (measured from annual individual engine outputs).

Year & Licence No.	W0012-02	W0004-03	W0009-02	W0081-03	W0127-01	W0015-01	W0014-01	MW
1996	0.49	0	0.74	0	3.55	1.41	0	6.19
1997	1.97	0	1.48	0	3.55	1.41	0	8.41
1998	1.97	0	2.59	0	3.55	1.41	0	9.52
1999	1.97	0	3.70	0	3.55	1.41	0	10.63
2000	1.97	0	3.70	0	3.55	1.41	0	10.63
2001	1.97	0	3.70	0	3.55	1.41	0	10.63
2002	1.97	0	3.70	0	3.55	1.41	0	10.63
2003	1.97	0	3.70	0	3.11	1.41	0	10.18
2004	1.97	3.66	3.70	0	2.22	1.41	0.05	13.01
2005	1.97	4.76	3.70	0.95	1.78	1.41	0.10	14.66
2006	1.97	6.70	3.70	2.44	1.33	1.41	0.07	17.62
2007	1.97	8.12	3.70	2.95	0.74	1.41	0.02	18.90
2008	1.97	9.58	3.70	2.60	0.74	1.41	0	20.00

The total volumes of CH_4 utilised and total power output were calculated based on data returned by licensees. Values were calculated as follows and are shown in Tables 3.2 and 3.3 respectively:

- Total CH_4 utilised (m^3) = total landfill gas throughput (m^3/hr) × average no. months operational × 30 (days) × average runtime (hrs/day) × average CH_4 content (%v/v);
- Total actual power output (kW) = actual power output (kW) × average no. months operational × 30 (days) × average runtime (hrs/day).

In 2007, an average of 5,388 m^3/hr of CH_4 was utilised for energy generation.

Licensees were also asked to report the total annual power output from each utilisation plant on an annual basis from 1996 to 2007. The total power output from each site is summed to give a national total in Table 3.4. These values differ slightly from those calculated from individual engine outputs (Table 3.3).

Table 3.4. Power output (sum of reported annual outputs from each utilisation plant).

Year	MW
1996	5.61
1997	8.98
1998	10.41
1999	9.45
2000	9.02
2001	8.61
2002	7.94
2003	8.30
2004	12.91
2005	11.75
2006	14.67
2007	17.99
2008	nr

3.2 Validation of Sustainable Energy Ireland Energy Balances

Sustainable Energy Ireland (SEI) has a lead role in developing and maintaining comprehensive national and sectoral statistics for energy production and end use. The principal source of information for sources of energy production and consumption in Ireland, SEI produces an annual national energy balance, which includes an estimate of the energy produced indigenously from landfill gas. Table 3.5 presents SEI results for the years 1996 to 2007. The information contained in the SEI energy balance reports is collated from Eirgrid, which operates and maintains the electricity transmission system.

The SEI reports energy balance data as kilo tonne oil equivalents (ktoe): 1 ktoe is equal to 11.63 gigawatt hours (GWh). Eirgrid was contacted during this study to clarify the methods used to give the values listed in Table 3.5. Eirgrid stated that, in 2007, 102 GWh of electricity were exported to the grid from landfill gas utilisation plants. This is the equivalent of 9 ktoe. SEI uses an efficiency rating of 36.67% for landfill generation plant, a figure provided to them in 2003 by Irish Power, now BPS. At 36.67% efficiency, SEI determined that the equivalent estimate of power generation fuelled by landfill gas was therefore 24 ktoe (278 GWh). Table 3.6 is a comparison of the SEI data and the survey data and is shown graphically in Figure 3.1.

Table 3.5. Energy produced from landfill gas as derived from annual Sustainable Energy Ireland energy balances.

Year	Energy generation per annum (ktoe)*
1996	7
1997	22
1998	21
1999	23
2000	24
2001	24
2002	19
2003	16
2004	20
2005	25
2006	25
2007	24

*As reported in each annual energy balance from SEI.

Table 3.6. Comparison of Sustainable Energy Ireland (SEI) data and survey data.

Year	Energy generation per annum (ktoe)[1]	SEI adjusted		Survey of engine outputs MWh	Survey of total plant power outputs MWh
		(ktoe)[2]	MWh		
1996	7	2.57	29,889	54,224	49,144
1997	22	8.07	93,854	73,672	78,665
1998	21	7.70	89,551	83,395	91,192
1999	23	8.43	98,041	93,119	82,782
2000	24	8.80	102,334	93,119	79,015
2001	24	8.80	102,334	93,119	75,424
2002	19	6.97	81,061	93,119	69,554
2003	16	5.87	68,268	89,177	72,708
2004	20	7.33	85,257	113,968	113,092
2005	25	9.17	106,647	128,422	102,930
2006	25	9.17	106,647	154,351	128,509
2007	24	8.80	102,344	165,564	157,592

[1] Values reported in SEI energy balances.

[2] Values adjusted by efficiency rating (36.57%) in accordance with information from SEI.

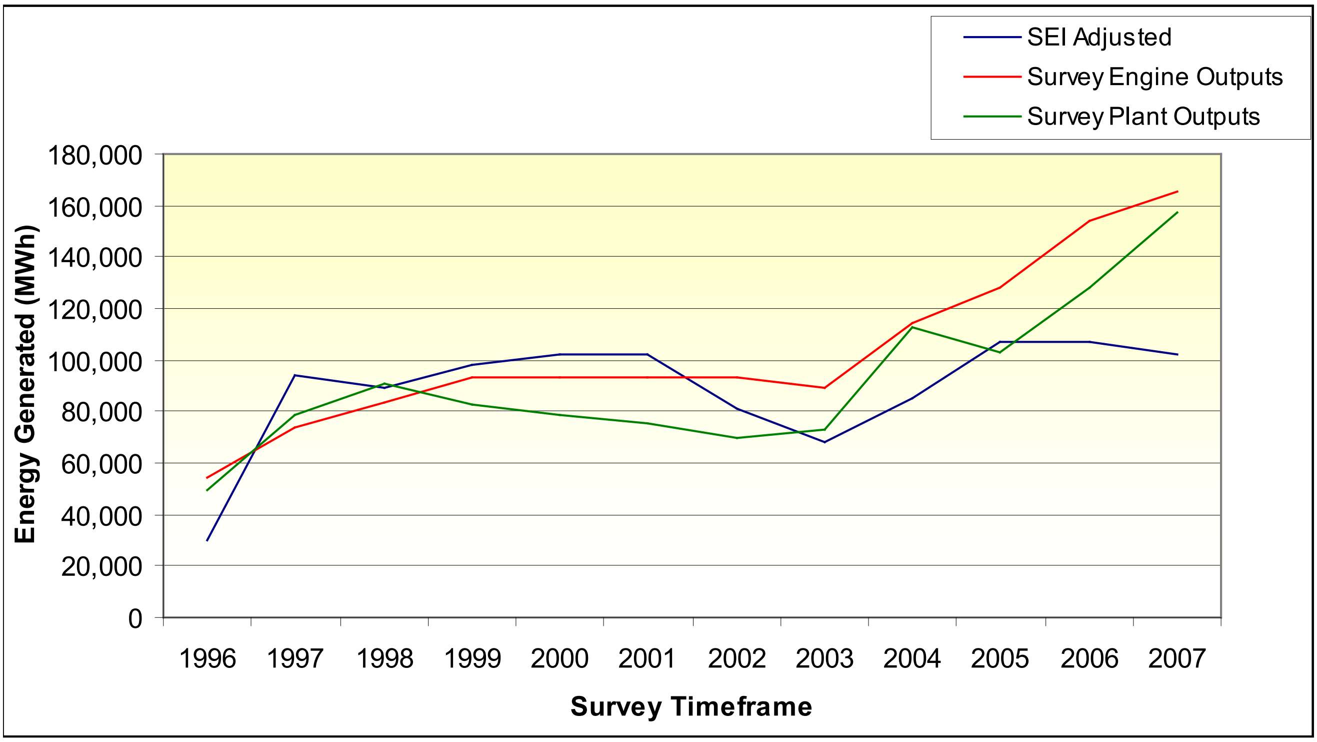

Figure 3.1. Comparison of Sustainable Energy Ireland and survey data.

The SEI-adjusted figure in Table 3.6 removes the efficiency assumption used by SEI to reflect the actual energy outputs from the plant to facilitate comparison of like with like.

This is necessary as the SEI figure defines the oil equivalent (which must accommodate engine inefficiencies), whereas the survey results examine only power outputs. Once this adjustment was carried out, a correlation between megawatts (MW) produced as defined in the survey and megawatt hours (MWh) exported to the grid from SEI figures was feasible.

The data in Table 3.6 shows that there is a good correlation in data for 1998–2005. The correlation for 2006 and 2007 data is not as good. The difference between the SEI value and the survey value for 2006 and 2007 is about 60%.

Analysis suggests that both licensees and the operators have failed to accommodate down-time or generation of electricity that was not exported to the grid. Future surveys need to obtain an accurate assessment of megawatt hours exported to the grid. If a comparison is to be made between site data and SEI energy balance in the future, greater understanding of the losses in the systems are required along with accurate landfill gas utilisation figures and accurate energy generation values.

In order to compare SEI and licence data in future, it is advisable that the figure is sourced directly from Eirgrid/ SEI rather than from the energy balance.

3.3 Recommendations

It is clear from the findings of Sections 3.1 and 3.2 that there are inconsistencies in landfill gas-utilisation plant-output data.

It is recommended that the EPA liaise with SEI to ensure that accurate energy recovery data from landfill gas utilisation is reported. This data could then be used to verify figures reported by licensees.

Based on knowledge of current discrepancies, it is recommended that accurate information is sought and audited. This is achievable because:

- There is currently only one supplier of this service in Ireland;
- Electricity produced is recorded as it is sold to the grid;
- The majority of plants have control rooms with continuous data recording.

Difficulties to date may have been because:

- The utilisation plant provider operates as a separate entity to the licence holder; or
- There is no specific requirement or waste licence condition to obtain and maintain accurate records of landfill gas utilisation.

Section 4 presents a review of data-recording practices from landfill gas utilisation plants and makes recommendations for proposed reporting mechanisms.

4 Recording and Reporting Mechanism

This section of the report addresses Task 2 of the Brief to:

- Recommend a reporting mechanism for transfer of information from site to the EPA;
- Recommend a recording mechanism for the landfill operators on site.

This section of the report has been structured as follows:

- Introduction to recording and reporting;
- Existing recording practice:
  - Recording of waste inputs;
  - Recording of flare operations;
  - Recording of engine operations;
  - Required recording practices;
- Recommended recording and reporting practice:
  - Total landfill gas generation;
  - Total landfill gas recovered;
  - Total emissions.

4.1 Introduction to Recording and Reporting

The EPA (Office of Enforcement) currently has a mechanism that requires licensees to record data in the E-PRTR electronic Excel-based reporting tool. This is site specific and requires the operator to input emissions data on an annual basis. Currently, emissions to water, land, discharges to wastewater, off-site transfers of waste and emissions to air are recorded. The reporting tool is stored on the EPA website and the operators can download it annually, fill in the required information and upload it on completion. It is related to this project in that the form asks licensees to submit the mass of CH_4 flared or utilised in engines.

Fehily Timoney & Co. Ltd (FTC) has developed a recording and reporting mechanism to link into this existing automated reporting tool. The proposed reporting structure has been kept as succinct as possible. The questions and data required have been based on the results of the survey to ensure that the data is feasible to collate and report accurately.

To date, the EPA has been concerned primarily with recording the mass of CH_4 that is recovered at Irish landfills. This report recommends broadening the scope of emissions reporting in order to encourage an understanding of the potential impacts of landfill gas generation as a whole. It is proposed to develop an understanding of total landfill gas generation (see Equation 4.1 below) and to require reporting of as many aspects of it as possible.

Total landfill gas generation = total recovered (flaring and utilisation) + total emissions (Eqn. 4.1)

Landfill gas is made up of CH_4, CO_2 and trace gas constituents. Methane and CO_2 are greenhouse gases. A number of trace gas constituents are (i) harmful to the environment; (ii) harmful to human health; and (iii) odiferous nuisance components. During combustion of landfill gas, CH_4 is converted to CO_2. It is recommended therefore that CO_2 emissions are also reported.

Evidence from the survey undertaken as part of this report suggests that licensees do not manage landfill gas generation holistically. It appears that there is a focus on engine or flare operation that ignores fugitive emissions (i.e. the difference between landfill gas recovered and landfill gas generated). Survey returns indicate that a lack of understanding and non-prescriptive licence conditions may be instrumental in this.

The proposed reporting mechanism is designed to address poor management of gas-extraction systems by requiring the following information:

- Total landfill gas generation:
  - Landfill gas prediction model calibrated for recovery rates;
  - Accurate historical waste inputs (tonnage and characterisation);

- Total landfill gas flared:
  - Actual gas throughput, actual CH_4, CO_2 and oxygen concentration recorded on a regular basis;
- Total landfill gas utilised:
  - Actual gas throughput, actual CH_4, CO_2 and oxygen concentration recorded on a regular basis;
- Fugitive emissions[1] (surface emissions and below ground/lateral emissions).

Section 4.2 examines existing recording practice and Section 4.3 makes recommendations on how practices can be improved and subsequently reported to the EPA.

4.2 Existing Recording Practice

Existing recording mechanisms were surveyed and analysed in order to design a recording and reporting mechanism that accommodates site capabilities and is feasible to implement. The mechanism proposed has to be achievable. The findings and recommendations are summarised below.

4.2.1 Recording of Waste Inputs

Records of waste inputs are required to predict landfill gas generation accurately. This will be discussed in more detail in Section 4.3.1. Of the 58 surveys returned, a small number of sites made no estimate of historical landfilling rates. In these cases, and in the absence of supplementary information, FTC calculated an average landfilling rate from the total waste input divided by the number of years of operation.

Less than 25% of sites surveyed had accurate waste records for the lifetime of their facilities. The sites with accurate waste records are the newest sites. Approximately 50% of surveyed sites have accurate records of waste inputs in the latter years of operation from the late 1990s following installation of weighbridges on landfills. Prior to the late 1990s there are only subjective estimates of waste inputs. Approximately 25% of sites do not have any weighbridge records and all waste inputs have been estimated.

In the absence of weighbridge records, best practice would have been to undertake studies to best determine historical inputs using:

- Historical waste records, waste payment records, etc.;
- Void space analysis;
- Estimation of base of landfill by depth of wells, adjacent ground levels, etc.;
- Interviewing of previous staff;
- Economic and population growth in the area.

However, the survey suggests that operators, rather than making estimates using best practice, estimated average filling rates based on total waste landfilled averaged over the number of years of operation.

4.2.2 Recording of Flare Operation

According to the findings of the survey, 86 flares were operational in the period 1996–2008. As of 2008, there were 53 operational flares at Irish landfills (survey respondents).

Automated recording of flare operation is the preferred method of data capture as it provides a continuous and electronic record of flare performance. Table 4.1 details the extent of automated recording capabilities. According to the results of the survey, as of 2008, the majority of flares have automated recording capabilities. It is recommended therefore that the small number of flares without this capability be upgraded.

1 The Environment Agency in the UK requires monitoring of the rate of surface emissions from capped areas. Based on the results of this survey, emissions from uncapped or temporarily capped areas are likely to be greater than emissions from capped areas. It is proposed that measuring emissions from capped areas be postponed until there is a system in place to measure landfill gas recovery rates and estimate surface emissions from uncapped areas.

Table 4.1. Automated recording of flare operational data.

	Flares operational, 1996–2008				Flares operational, 2008			
	No. of flares		% of flares		No. of flares		% of flares	
	Yes	No	Yes	No	Yes	No	Yes	No
Gas Quality (Automated)	48	38	56	44	43	10	81	19
Runtime (Automated)	61	25	71	29	47	6	89	11
Throughput (Automated)	48	38	56	44	41	12	77	23

Table 4.2. Manual recording of flare operation.

	Flares operational, 1996–2008				Flares operational, 2008			
	No. of flares		% of flares		No. of flares		% of flares	
	Yes	No	Yes	No	Yes	No	Yes	No
Gas Quality (Manual)	66	12	85	15	46	3	56	4
Runtime (Manual)	47	25	65	35	37	8	47	11
Throughput (Manual)	53	22	71	29	39	7	49	9

Table 4.2 shows the extent of manual recording practices. In many cases both automated and manual recording are carried out. Manual recording is carried out using a number of methods. When monitoring landfill gas quality, the majority use a landfill gas analyser (60%).

In 30% of cases, the licensees reported that they take manual flare measurements of gas quality from the flare supervisory control and data acquisition supervisory control and data-acquisition (SCADA) system or landfill SCADA.

When measuring runtime and flow rate, the majority of manual measurements are taken from the flare SCADA or landfill SCADA (77% and 62% respectively). A small proportion of licensees keep a record of runtime themselves and flow rate is measured using an anemometer or a pitot tube in 24% of cases. Survey analysis suggests that the number of cases where flow rate is measured manually using a pitot tube is actually lower than reported. Just four operators are using an anemometer to measure flow rate.

On average, licensees record manual measurements of gas quality, runtime and throughput on a weekly basis at over half the flares operating in Ireland. Less than 20% are recorded monthly and 2% are recorded quarterly. The remainder do not carry out manual recording.

A summary of flares with neither an automated nor manual recording mechanism is shown in Table 4.3.

Table 4.3. Flares without data-recording mechanisms.

No recording capabilities for parameters	No. of flares, 1996–2007	No. of flares, 2008
Gas Quality	9	1
Runtime	17	2
Throughput	17	3

4.2.3 Recording of Engine Operations

There were 25 engines operating at different landfill sites in Ireland for differing periods during the timeframe 1996–2008. The maximum number of engines operating at any one time was in 2007 when 22 engines were in use. There were 21 operational engines in Ireland in 2008. Three additional engines were installed at the end of 2008 at Arthurstown Landfill but were not operational in terms of increasing CH_4 recovery until 2009. It is assumed that engines are re-used at different sites as required by BPS. Therefore, to avoid any double counting of engines, analysis has been carried out for 2007. When asked the question, ‘Is there automated recording of gas quality, runtime and throughput for each engine?’, licensees responded that all but 2 of the engines had the capability. These 2 engines are still operational and it is not clear from the answers given in the survey whether manual recording is being carried out. Runtime is being recorded automatically at the 2 engines. Automated recording data is shown in

Table 4.4 and manual recording data is shown in Table 4.5.

Table 4.4. Automated recording of engine operation.

	Engines operational, 2007			
	No. of engines		% of engines	
	Yes	No	Yes	No
Gas Quality (Automated)	20	2	91	9
Runtime (Automated)	22	0	100	0
Throughput (Automated)	20	2	91	9

Table 4.5. Manual recording of engine operation.

	Engines operational, 2007			
	No. of engines		% of engines	
	Yes	No	Yes	No
Gas Quality (Manual)	14	8	64	36
Runtime (Manual)	21	1	95	5
Throughput (Manual)	14	8	64	36

Manual monitoring of engines is carried out as shown in Table 4.6. Less than half of the engines are checked manually for gas quality at the inlet using a landfill gas analyser. Monitoring of flow at the input to the engines is carried out at one-third of the engines. Runtime is recorded manually in less than 10% of cases.

Table 4.6. Manual measurement methods of engine operation.

Manual measurement methods		No. of engines	% of engines
Quality	Using a landfill gas analyser	**10**	**45**
	From SCADA	**4**	**18**
Runtime	From SCADA	**17**	**77**
	From no. days running	**2**	**9**
Throughput	Anemometer	**8**	**32**
	From SCADA	**4**	**16**
	From no. days running	**2**	**8**

4.2.4 Required Recording Practices

Significant improvements in data management are required to allow accurate measurement of CH_4 recovery at Irish landfills.

An example of existing poor practice is outlined here:

- The flare screen recorded that the unit ran for a total of 274 hours in 2007. The operator estimates that average methane content was 34% v/v over the year and that the blower ran at approximately 50% on a 500 m^3/hr flare;
- The operator then estimates that 23,290 m^3/hr of methane was recovered in 2007 (500 × 50% × 274 × 34%).

The problems with the above are:

- The flare may record partial hours as a full hour or, unless it ran for 60 minutes, as zero hours so the 274 hours runtime may not be entirely accurate;
- The estimate of methane content is based on the landfill manager's estimate rather than recorded figures;
- Landfill gas throughput/flow is estimated rather than recorded.

Three critical parameters need to be recorded continuously to collate accurate records of CH_4 recovery:

1 Flare or engine runtime;

2 Volume of landfill gas throughput;

3 Quality of the landfill gas (concentration by volume of CH_4, CO_2 and oxygen).

All monitoring equipment should be calibrated and fit for purpose. The parameters should be recorded continuously to an electronic database where the licensee can call up a summary of 1 day, 1 week, 1 month etc. The outputs should be an accurate sum of the exact volume of CH_4 recovered in each individual flare or engine.

Currently flares and engines at landfill sites either have:

- An individual SCADA system; or
- An integrated landfill SCADA system; or
- No recording mechanism at all.

Flares with no recording mechanism tend to be older, or temporary, or acting as backup to another treatment mechanism. The majority of flares and engines have an independent SCADA system. Typically, landfill managers do not use these SCADA systems to populate an electronic database. Instead, snapshot readings are taken from the computer screen. Most commonly, the SCADA is programmed only to continuously record the sum of the runtime in hours.

These independent SCADA systems should be linked to the landfill SCADA system and programmed to record runtime, throughput, gas quality and pressure continuously against time, in order to provide an electronic database of flare and engine performance.

In the interim period, all parameter values should be noted daily and then entered into an electronic database. Licensees should also have a back-up recording procedure in place in case one or more of the automated monitoring instruments fail. It is recommended that licensees take manual measurements of gas quality, and throughput (flow and runtime) on a weekly basis. This data can be used to confirm that the automated instruments are recording correctly and in the event that an automated instrument fails, licensees should increase the frequency of manual monitoring to daily.

The manual measurement of gas quality and flow should be measured at the inlet to the flare. Interruptions to runtime should be recorded manually by date, time and hours offline. It is important to correlate runtimes to gas quality and throughput. It is not sufficient to record that the flare was down for 10% of the month or year.

Table 4.7 gives a recommended format for a dataset of manual recordings.

In the event that an automated instrument failed, this data could be used to make a reasonable estimate of CH_4 recovery that week. If licensees were obliged to chart CH_4 recovery on a weekly basis, it is believed that this would lead to an improved understanding of the process and therefore improved management and landfill gas recovery.

4.3 Recommended Recording and Reporting Practice

A reporting system has been designed to survey the following on an annual or monthly basis from licensees:

- Total landfill gas generation;
- Total landfill gas recovered;
- Total landfill gas emitted to the atmosphere.

The reporting sheet has therefore been set up for licensees to fill in in the following order:

- Theoretical gas production (LandGEM model), X;
- Actual gas recovery (measured gas-extraction flow), Y;
- Uncontrolled releases, Z:
  - landfill gas that is not captured by extraction, Z_1;
  - conversion of CH_4 to CO_2 during combustion, Z_2 (Equation 4.2).

$$X\text{-}Y=Z\ (Z_1 + Z_2) \qquad \text{(Eqn. 4.2)}$$

Every site will have uncontrolled releases. The proportion of uncontrolled releases to actual gas extraction from individual sites will be dependent on a number of factors. It is recommended that licensees are obliged to ensure that percentage recovery improves with time. For example, sites might aim towards an 85% capture rate for a fully engineered and capped site.

Table 4.7. Recommended recording of manual measurements.

Week	Downtime (hrs)	Flow (m^3/hr)	Pipeline pressure (mbg)	CH_4 (%v/v)	CO_2 (% v/v)	O_2 (% v/v)
Week 1	1	500	-20	45	30	4
Week 2	24	450	-18	43	31	5
Week 3	5	500	-20	44	29	3

4.3.1 Reporting Total Landfill Gas Generation

Based on the information collated in the surveys, landfill gas prediction modelling was carried out for 8 landfill sites using LandGEM and for 4 landfill sites using both LandGEM and GasSim Lite (the first 4 sites in this list):

- Arthurstown Landfill, Co. Kildare (South Dublin County Council);
- KTK Landfill, Co. Kildare (Greenstar);
- Knockharley Landfill, Co. Meath (Greenstar);
- Kinsale Road Landfill, Cork (Cork City Council);
- East Galway Residual Landfill, Co. Galway (Greenstar);
- Gortadroma Landfill, Co. Limerick (Limerick County Council);
- Pollboy Landfill, Co. Galway (Ballinasloe Town Council);
- Ballydonagh Landfill, Co. Westmeath (Westmeath County Council).

Sites were chosen where good landfill gas recovery data was available and also to represent:

- Different moisture conditions east and west of the country; and
- Various sizes of landfill.

The following steps were followed when modelling each site:

- The volume of gas reported as flared and or utilised (gas-extraction flow rate) was tabulated;
- A collection efficiency of 70% was assumed for each of the sites modelled (because none are fully capped);
- The volume of theoretical gas production was calculated by adjusting the recorded gas-extraction flow rate upwards by 30%. The data was graphed and labelled as 'Actual Landfill Gas Production';
- A LandGEM model was prepared using the recorded waste inputs from the site survey. This produced a predicted landfill gas production curve, which was graphed against the 'Actual Landfill Gas Production' curve;
- The predicted landfill gas prediction curve was calibrated by adjusting the following model parameters to fit the predicted curve as closely as possible to the actual gas recovery curve. The parameters that can be adjusted are:
  - CH_4 generation rate;
  - Potential CH_4 generation capacity;
  - Non-methane organic compound concentration;
  - CH_4 concentration.

This was repeated for each site and average parameters for CH_4 generation rate and potential CH_4 generation capacity for the east of Ireland and the west of Ireland were calculated. Table 4.8 gives these model parameters.

Table 4.8. LandGEM parameters/factors for Irish landfills.

Averages	CH_4 generation rate, k (year^{-1})	Potential CH_4 generation capacity, Lo (m^3/Mg)
East	0.32	112
West	0.30	131

Following this exercise, a LandGEM model was prepared for each of the licensed landfills that participated in the survey,[2] employing the use-defined parameters for the CH_4 generation rate and for the potential CH_4 generation capacity, as shown in Table 4.8.

It is proposed to issue the model to each of the sites and for the licensees to take ownership of, and update it annually, with the tonnage of waste landfilled in the preceding year. An instruction on using the model will be included in the reporting tool. It is proposed to ask licensees to make a proposal to the EPA justifying any intended changes to the model – for example, to improve estimates of waste inputs where weighbridge records are not available. The output from the model will give a predicted volume of landfill gas generated

2 A model has been prepared for each of the 58 sites that responded to the survey. Accurate historical waste inputs and projected waste inputs until closure would be required to model the remaining sites. Once that data is available, the models can be completed in a short timeframe.

for the preceding reporting year. This value has to be inserted by the licensee into the reporting sheet.

4.3.2 Reporting Total Landfill Gas Recovered

Total landfill gas recovered is represented by the value Y, where X-Y=Z (Z_1 + Z_2). This is the sum of landfill gas flared and/or utilised and is measured in cubic metres per annum (m^3/p.a.). It is proposed to request that licensees compile the data on a monthly basis to improve accuracy. Table 4.9 is a sample of the proposed table that a licensee will be asked to complete for each and every flare and engine operated on site. The tool will sum the total CH_4 and carbon recovery rates from each flare and engine to provide a total value for the site, the value Y, where X-Y=Z (Z_1 + Z_2).

4.3.3 Reporting Total Emissions

Total emissions are represented by the value Z. Z is equal to Z_1 plus Z_2, and it represents the proportion of gas that is released to the atmosphere.

Total emissions are summed from:

- Z_1, volume of landfill gas that is not collected by the extraction system, i.e. emissions from:
  - The active face;
  - Uncapped areas;
  - Temporary capped areas;
  - Accidental releases from capped areas, e.g. venting wells;
  - Migration from unlined areas.
- Z_2, volume of CO_2 released during combustion (in flares and engines);
- During combustion CH_4 is converted to carbon dioxide and water (Equation 4.3).

  $$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad \text{(Eqn. 4.3)}$$

  98% of CH_4 is combusted and is converted to CO_2. This results in emissions of CO_2.

Box 4.1 gives an example of a calculation of total emissions from a landfill. The calculation is included in the reporting tool and will be based on inputs of predicted landfill gas generation X and total recovered landfill gas Y. It will automatically calculate total emissions including:

- Total mass of carbon emitted;
- Total mass of carbon recovered;
- E-PRTR report format:
  - CH_4 emissions (kg/yr)
  - CO_2 (kg/yr).

Table 4.9. Reporting format for landfill gas recovery.

Month	Method	Recorded landfill gas throughput	Average CH_4	Average CO_2	Average CH_4	Average CO_2
	M/C/E	m^3	%v/v	%v/v	m^3	m^3
January		279,000	35	30	97,650	83,700
February		279,000	35	30	97,650	83,700
March		279,000	35	30	97,650	83,700
April		279,000	35	30	97,650	83,700
May		279,000	35	30	97,650	83,700
June		279,000	35	30	97,650	83,700
July		279,000	35	30	97,650	83,700
August		279,000	35	30	97,650	83,700
September		279,000	35	30	97,650	83,700
October		279,000	35	30	97,650	83,700
November		279,000	35	30	97,650	83,700
December		279,000	35	30	97,650	83,700
m^3/year		**3,348,000**			**1,171,800**	**1,004,400**
kg/year					**840,181**	**1,988,712**

Box 4.1 Example of calculating total emissions for an average sized lined landfill with a capped area, an uncapped area and an active face.

There is a gas-extraction system in the capped area and a temporary system in the uncapped area and the active face. The gas prediction model output for predicted landfill gas generation for the year is 3,500,000 m^3/yr. There is one landfill gas flare on site, it is a 500 m^3/hr flare and it operates continuously at approximately 50% capacity.

Total measured landfill gas recovery at the flare for the year was 2,100,000 m^3/yr, of which 1,050,000 m^3 was methane and 1,050,000 m^3 was carbon dioxide; 98% of the methane recovered in the flare was combusted to produce carbon dioxide.

Emissions from this site are calculated as the sum of methane and carbon dioxide not captured by the landfill gas-extraction system and the sum of recovered non-combusted methane, recovered carbon dioxide and carbon dioxide created during combustion.

A carbon dioxide example is shown in Table 4.10.

The reporting tool carries out these calculations for each site based on data entered for X and Y and reports them as shown in Table 4.10. Emissions are calculated in m^3/yr and converted to kg/yr in line with the E-PRTR reporting format. Emissions greater than 100,000 kg/yr of CH_4 and 100,000,000 kg/yr of CO_2 must report under the E-PRTR.

Table 4.10. Calculation method for emissions.*

		Estimated gas generation (m^3)	Tonnes CH_4	Tonnes CO_2	Tonnes C
Landfill Gas Generated	LandGem prediction	3,500,000			
	CH_4	1,750,000	1,252	26,299	
	CO_2	1,750,000		3,436	
Landfill Gas Recovered	Landfill Gas	2,100,000			
	CH_4	1,050,000			
	CO_2	1,050,000		2,062	
	Combustion Recovered Gas				
	Combusted CH_4	1,029,000			
	Uncombusted CH_4	21,000	15	316	
	CH_4 converted to CO_2	1,029,000		2,020	
Not Captured	Landfill Gas	1,400,000			
	CH_4	700,000	376	7,890	
	CO_2	700,000		1,031	
Reporting	Total Emissions to Atmosphere			13,318	3,629
	Total Recovered			16,417	4,473
	E-PRTR Reporting				
	CH_4 (kg)	375,718			
	CO_2 (kg)	2,064,731			

* The CO_2 equivalent of CH_4 is 21. Carbon equivalent calculated based on molecular weight of carbon versus CO_2.

5 Efficiency of Methane Capture – Management Practices

The aim of Task 4 of the Brief is split into two sections:

- Assess existing landfill infrastructure and management systems with regard to efficiency of CH_4 capture and utilisation;
- Identify cost-effective changes in technology and management practice which would maximise the mitigation of CH_4 emissions whilst addressing the ongoing need to meet other environmental protection objectives.

This section of the report addresses management practices and how they relate to CH_4 capture.

The key element of managing landfill gas successfully is management of the landfill gas-extraction system. This is often referred to as 'balancing' or 'tuning' the landfill gas field. The volume, nature and composition of gas in a landfill changes constantly: balancing therefore should be carried out on a regular basis. The frequency of balancing is specific to each site – an active landfill may require weekly or monthly balancing, whereas a closed landfill may require only monthly or quarterly balancing. The required frequency of balancing decreases as waste decomposition progresses.

A review of management and operational practices was undertaken. The following management practices were surveyed:

- Landfill gas management:
  - Field audits;
  - Extent of monitoring;
- Management/control philosophy;
- Operational management of flares and engines.

Following a review of the above, recommendations on how to improve gas-extraction efficiency were made.

5.1 Guidance and Waste Licences

In order to minimise environmental emissions from landfill gas (in particular CH_4 because of its global warming potential), landfill operators are conditioned by the waste licence[3] to either utilise landfill gas or flare it.

There are 16 waste licensed sites operating without an active landfill gas-extraction system in Ireland (all are closed). Of them:

- Two have conditions in their licence to install and operate a landfill gas-extraction system and a flare;
- Five have conditions making reference to a landfill gas collection infrastructure but with no specific reference to a flare;
- Two have conditions to install passive venting stacks;
- Six of the licences have no condition regarding landfill gas collection infrastructure or flares;
- One licence conditioned a review of the feasibility of landfill gas collection and treatment but the status of this is unknown.

The EPA (EPA, 2003) states that, within the waste body,

> The monitoring of collection wells and associated manifolds is undertaken to determine the effectiveness of the gas extraction and collection system and to facilitate the balancing of the extraction and collection system. Collection well monitoring is necessary for the efficient management of an extraction system.

The EPA *BAT Guidance Note* (2003) on landfilling activities makes reference to landfill gas-extraction system management. One of the best available techniques 'is to regularly monitor landfill gas-extraction wells and balance gas-extraction wells'.

5.2 Existing Landfill Gas-Management Practices

5.2.1 Overview

The survey shows that the typical practice on Irish landfills is to balance landfill gas-extraction flows in relation to available CH_4 and oxygen to facilitate operating criteria for generation plant and flaring units. For example, enclosed flares typically require a minimum of 25% v/v CH_4 to ensure a temperature of 1,000 ^{o}C for a retention period of 0.3 seconds and may not be able to operate

3 This condition is not included in some of the older licences.

if oxygen exceeds 6.5% v/v. Utilisation engines have more onerous operating criteria.

These operational criteria often result in landfill gas migration and odour problems because the combined extraction capacity of generation plant and flares may be lower than the total landfill gas production from different sources within the waste body. Problems are further compounded as the characteristics of gas production change – for example, when new cells are brought on-line with low CH_4 and high oxygen concentrations or when CH_4 production and quality from old cells falls off after capping due to ageing waste and reduced moisture.

Fehily Timoney & Co. recommends that, where feasible, a flow- (as opposed to an oxygen and methane) based extraction philosophy is used to manage and balance landfill gas extraction. The aim of this is to extract gas at or near the rate at which it is being generated.

The primary gas-extraction management objectives at any site should be (in the following order of priority):

- Prevent gas migration by extracting gas at a flow rate equal to or approaching that which is being produced in the landfill body;
- Develop a negative pressure gradient towards the centre of the waste body to mitigate the risks of offsite migration;
- Manage landfill gas quality to facilitate CH_4 recovery by efficient operation of landfill gas flares (and/or engines on larger sites);
- Manage CH_4 recovery by biological means or similar on site with small CH_4 emissions;
- Provide conditioning, using carbon filters, wood chip or similar to mitigate the impacts of fugitive gas emissions that cannot be managed by the primary extraction systems.

5.2.2 *Management Practices*

In order to survey landfill gas field management practices at Irish landfills (open and closed), licensees were asked the following questions:

1. Is auditing/balancing of the landfill gas-extraction system carried out?
2. If so, by whom?
3. Which parameters are measured?
4. Where is balancing carried out?
5. What parameter is balancing based upon?
6. Are the results recorded and in what format?
7. What is the key function of each flare on your site?

A summary of the answers to each question follows.

5.2.2.1 Auditing/Balancing of Landfill Gas-Extraction System

According to the survey respondents (Table 5.1), all open landfill sites with a landfill gas-extraction system are audited. One new site does not have an active extraction system due to insufficient waste volumes.

Of the 33 closed landfill sites that responded to the survey:

- 17 have an operating landfill extraction system and are being audited;
- 16 have no extraction systems and are not being audited.

Table 5.1. Auditing/balancing of landfill gas field.

Audits	Yes (%)	No (%)	No. sites surveyed
Open Sites	96	4	25
Closed Sites	52	48*	33

*Of sites with active gas collection systems.

The frequency of auditing[4] is good, as Table 5.2 shows.

Table 5.2. Frequency of auditing/balancing.

Frequency of audits	No. sites	%
Weekly	14	34
Monthly	22	54
Quarterly	2	5
Biannually	3	7

The majority of sites are audited by the licensees themselves. In some cases the flare or plant operators also audit the field.

5.2.2.2 Parameters Monitored

A summary of parameters monitored is presented in Table 5.3.

Ideally, landfill gas should be extracted at the same rate at which it is generated. In order to understand extraction rates, flow is a critical parameter in landfill gas balancing. It is possible, however, on smaller older sites, when only flaring is possible, that CH_4 and oxygen are likely to become more important control parameters than flow.

Flow (calculated from velocity measurements in gas-extraction pipelines) is monitored during 32% of audits, rising to 42% during audits of active landfills. This represents 10 sites in Ireland.

Gas quality is monitored during each audit. The licensees reported that pressure and temperature are measured at 93% and 51% of sites respectively. Most landfill gas analysers measure atmospheric temperature and pressure since both are important parameters for perimeter well monitoring. Landfill gas analysers with instrumentation to measure borehole pressure and temperature are less common. It was a flaw of the survey that 'borehole pressure and temperature' were not specified instead of 'pressure and temperature'. It is likely that the percentage of licensees measuring borehole pressure and temperature is less than shown in Table 5.3.

Carbon monoxide is a determinant of a potential landfill fire, and is monitored in less than 50% of audited sites. The temperature of the landfill gas is also important in detecting the potential for landfill gas fires.

The landfill gas analysers do not measure the volume of nitrogen in the gas; rather, it is displayed as the balance remaining. Nitrogen levels in the landfill indicate the volume of air in the waste body. The fire risk increases if air is drawn into the waste body.

Table 5.3. Parameters monitored.

Parameter	All sites (%)	Open sites (%)
Velocity in pipelines (flow)	32	42
Pressure*	93	92
Methane	100	100
Carbon dioxide	100	100
Oxygen	100	100
Nitrogen (air balance)	39	46
Carbon monoxide	41	46
Temperature	51	50

*Error in survey (survey did not specify borehole pressure).

5.2.2.3 Where Balancing Is Carried Out

Licensees were asked where balancing is carried out and what is the order of importance in relation to key control points for balancing. The survey identified wellheads, manifolds, flare and/or specified control points[4]. Table 5.4 is a summary of results.

Controlling/balancing the field from manifolds is the most common method according to the survey.

Of 41 sites audited, 27 of the licensees listed the control points in order of importance. The remaining 14 placed equal importance on one or more control points.

It is noted that some sites do not have access to wellheads as they are buried within the cap.

Table 5.4. Control points for balancing.

Main control point	All sites (%)	Open sites (%)
Wellheads	46	46
Manifolds	56	67
Flare	24	29
Other specified control points	7	13

5.2.2.4 What Parameter Is Balancing Based Upon?

Licensees were asked to list the key balancing parameters for their gas fields (a summary of responses is shown in Table 5.5). None of the licensees listed flow as the single most important parameter for landfill gas field balancing at their site. A small number of licensees listed it as a key parameter, giving it equal status to one or more other parameters.

A small percentage of licensees balance the field based on pressure. This is considered to be the second most important parameter to ensure a negative pressure gradient towards the centre of the waste body.

The majority of licensees are balancing their fields based on CH_4 content. This practice is generally derived from the perception that maintaining flare and engine

4 Wellhead is defined as the top of a vertical extraction well. Ideally, there is a dip port, gas quality taps/pressure ports and a control valve. A manifold is a point in the landfill gas-extraction system where several wells are connected into one collection pipe. It usually has a gas quality/pressure port and a valve at the inlet from each well, and a valve on the main collection line. Specified control points may be for example connection points for separate gas zones or the active face collection system, etc.

operation is of key importance. Of critical importance is environmental protection. Flaring and gas utilisation facilitate environmental protection but they should not take precedence over management of the gas field.

Balancing of the gas field based on CH_4 content is suitable for smaller older landfills.

Balancing based on oxygen content is a clear sign that the sole focus of landfill gas management is to keep the flare going. It is an important parameter as elevated oxygen can indicate problems in the waste body or with infrastructure. Elevated oxygen levels could be indicative of air ingress and can increase the risk of fire. Flare and engines will not operate above specific oxygen thresholds.

Table 5.5. Key balancing parameter.

Balancing philosophy	Listed as key parameter (may be more than 1 key parameter) (%)	Listed as most important parameter (%)
Flow	12	0
Pressure	17	5
Methane	78	61
Oxygen	27	15

5.2.2.5 Recording Audits

All except 2 sites keep records of audits. Just over half of the audits are recorded electronically; the proportion is slightly higher (66%) on active landfills. Record keeping is summarised in Table 5.6.

Table 5.6. Record keeping.

Recording of audits	Manually in notebook	Electronically to PC	No physical record kept
Open Sites	22	16	0
All Sites	36	22	2
% of all sites	88	54	5

5.2.2.6 Flare Management

A series of questions was included in the survey pertaining to flare management. Tables 5.7 to 5.10 give a summary of findings.

As of 2008, 41% of flares can be restarted remotely. The majority of licensees with flares have received training on flare operation. Table 5.7 shows data on flare training.

Table 5.7. Flare operation training.

	Yes	No
Training provided (%)	83	17
	Training provider:	
In-house (%)	11	
External/other (%)	72	
Not applicable (%)	17	

There is a very mixed view across licensees of the function of a flare as shown in Table 5.8. There was no single consensus. The primary function of 36 flares (42%) is considered to be odour control. The next highest grouping was to run the flare as per licence conditions.

While taking into consideration that there may be more than one flare on site and that smaller flares can operate in specific roles – such as odour control from an active face – the overriding function of every flare should be to extract gas at a rate similar to generation for environmental protection. However, there is no specific licence condition for this.

Table 5.8. Function of the flare.

Which of the following functions of the flare is considered most important at your site? (%)	
To control odours	42
To run flare 24/7 as per licence	29
To extract gas at its generation rate	19
To prevent migration	6
Extraction from uncapped areas	2
None of the above	2

Table 5.9 is a summary of flare control criteria. The licensees were asked which parameter was of primary importance and of secondary importance in relation to the control of each flare. There was a mixed view across licensees. Methane was or is considered to be the primary flare control criterion for 38 flares (44%). Of the total number of flares surveyed, oxygen was considered

to be the second most important flare control criterion for 44% of flares. However, in the case where CH_4 was chosen as the primary parameter, oxygen was chosen as the secondary parameter in 84% of cases.

This is similar to the practice of balancing gas fields, where the majority of licensees use CH_4 and oxygen as the criteria upon which to make decisions.

Of the 14 flares that are predominantly controlled by flow, 8 listed pressure as the secondary control criterion. These flare operators show a good understanding of the purpose of the flare.

Odour was selected as the primary flare control criterion for 13 flares (15%) in the period 1996–2007, but this dropped to 4 flares in 2008. In some cases, a flare is a useful mechanism for controlling odours – a small flare can be employed at the active face to do this. This was not the case with each of the 4 flares in 2008.

Table 5.9. Flare control criteria.

Flare control criterion	Primary (%)	Secondary (%)
Methane	44	17
Flow	16	7
Max runtime	16	0
Odour	15	5
Oxygen	14	44
Pressure	3	12
Other	1	2
None	0	12

Table 5.10 shows that there are many reasons for flare downtime. There is no single issue. Grouping by gas quality shows that 27% of flares stop running due to high oxygen, low CH_4 or a combination of both.

It is highly likely that more than 5% (3 flares) of flares since 1996 have stopped running because of insufficient gas volume. It is presumed that this has been misunderstood by the operators as a result of poor gas quality.

Table 5.10. Flare downtime.

Main cause of flare downtime	% of flares surveyed (86)
N/A, flare runs continuously	37
High O_2	14
Low CH_4	10
Servicing issues	5
Combo. high O_2 and low CH_4	3
Insufficient landfill gas volume	5
Condensate	2
Problems with restart	2
Other	9
No. of issues	9
Don’t know	4

The majority of reasons for flare downtime listed under ‘servicing issues’, ‘other’ and ‘no. of issues’ were mechanical issues totalling 23%.

In terms of flare maintenance and servicing, the majority of call-outs are answered the next day, with the remainder answered within 7 days. The majority of licensees carry out minor flare repairs themselves (70%) and the majority keep spare parts on site (69%). There is or has been a flare maintenance contract in place for 71% of flares and there has been or is an operation and maintenance manual for 70% of flares. Table 5.11 summarises the servicing schedules.

Table 5.11. Servicing schedules.

Flare service schedule	% of flares serviced
Biannually	56
As required	30
Annually	7
None	5
Don’t know	2

5.2.2.7 Management of Gas post-Flaring and Utilisation

Licensees in each of the surveys were asked ‘What year is each engine on site expected to be no longer viable?’ The answers are shown in Table 5.12. Of 21 fully operational engines in 2008, a de-commissioning

Table 5.12. Engine de-commissioning dates.

Engine no. on site	Landfill	Expected de-commissioning date
1	Arthurstown Landfill	2011
2	Arthurstown Landfill	2011
3	Arthurstown Landfill	2012
4	Arthurstown Landfill	2012
5	Arthurstown Landfill	2013
6	Arthurstown Landfill	2014
7	Arthurstown Landfill	Don't know
8	Arthurstown Landfill	Don't know
1	KTK (Brownstown and Carnalway)	Don't know
2	KTK (Brownstown and Carnalway)	2015
3	KTK (Brownstown and Carnalway)	2012
1	Dunsink	Don't know
1	Kinsale Road Landfill	Engine provider will decide
2	Kinsale Road Landfill	Engine provider will decide
1	Balleally Landfill	Don't know
2	Balleally Landfill	Don't know
3	Balleally Landfill	Don't know
4	Balleally Landfill	Don't know
5	Balleally Landfill	Don't know
1	Ballyogan	2012
2	Ballyogan	Don't know
1	Silliot Hill	no longer operational

date is known for less than half the engines (9 in total). Licensees with utilisation plants on site were asked whether there is a plan in place for when utilisation on site is no longer a feasible method of landfill gas treatment. One of the sites has carried out a detailed study of this topic and has a plan for replacing engines with flares; 3 sites gave a brief response to say that gas would be flared; 2 sites did not provide a response.

One-third of open sites with an active gas-extraction system have a plan in place to manage landfill gas once flaring is no longer possible. Less than 20% of closed sites with an active gas-extraction system have a plan in place to manage landfill gas once flaring is no longer possible.

5.2.2.8 Overview of Landfill Gas Balancing

An overview of landfill gas balancing in Ireland has been taken from Sections 5.2.2.1 to 5.2.2.6. Although every site with an active gas-extraction system is being audited on a regular basis, the quality of the auditing procedure needs improvement. Flow and borehole pressure are not monitored as a matter of course, and balancing is carried out at manifolds and is primarily based on CH_4 and oxygen content. Half of the audits are being recorded electronically. Training on flare management has been carried out in 83% of cases. The single largest consensus (42% of cases) for the function of a flare on site was odour control.

5.3 Recommendations to Improve Efficiency of Landfill Gas Extraction

5.3.1 Landfill Gas-Management Plan

It is recommended that the EPA prioritise landfill gas management at Irish landfills in order to improve the efficiency of CH_4 recovery.

The UK Environment Agency (EA) requires licensed sites to have a landfill gas-management plan. The plan is updated annually and reviewed and audited by site inspectors. There are less onerous requirements for closed licensed sites.

Closed licensed sites are required to prepare a conceptual model of gas management for the site. A conceptual model is defined as a textual or graphical representation of the relationship(s) and receptor(s) developed on the basis of hazard identification and refined during subsequent phases of assessment.

This should identify all possible sources (S), pathways (P) and receptors (R) as well as the process that is likely to occur along each of the source-pathway-receptor (S-P-R) linkages and uncertainties.

If the review of a closed site determines site-specific risks, then the licensee has to propose an improvement programme. The EA set a date by which all of those improvements must be carried out. (This date in 2009 was 5 years, following the publication of the guidance document.)

A gas-management plan for active sites should demonstrate that the gas control systems are appropriate for landfill conditions during:

- Site development;
- Site operations;
- Closure period;
- Aftercare period.

It is important that the plans are live documents that are updated annually. This is essential for fine-tuning respective gas-management plans with time.

The EA has a framework for what each plan should include:

- Section 1 Risk Assessment;
- Section 2 Control Measures;
- Section 3 Operational Procedures;
- Section 4 Monitoring Plan;
- Section 5 Action Plan;
- Section 6 Aftercare and Completion Plan.

It is recommended that the EPA adopt a similar approach to the EA and require active sites to prepare and maintain a gas-management plan and require closed sites to carry out a review of gas emissions. If risk is determined, licensees should be required to mitigate the same before final sign-off by the EPA.

It is recommended that odour-management plans be kept as a separate document to the gas-management plan but that both plans should reference the other.

5.3.1.1 Section 1 Risk Assessment

Typically, risk assessment of landfill facilities with respect to gas is not carried out in any routine or structured format in Ireland. Like all other aspects of the plan it would be reviewed annually.

5.3.1.2 Section 2 Control Measures

Control measures are in place at Irish landfills but there is potential for improvement. This includes planning for gas control throughout the lifetime of the facility and the entire gas curve. Figure 5.1 is a sketch of a typical landfill gas curve showing the feasibility of existing management options employed in Ireland. As can be seen in Figure 5.1 there are areas of the graph where traditionally gas has been allowed to vent. Section 5.2.2.7 of the report showed that there is a significant lack of planning for gas management post-utilisation and post-flaring.

This information would be sought as part of a gas-management plan, including;

- Modelling of landfill gas generation;
- Engine feasibility assessment;
- Flare feasibility assessment;
- Financial planning for purchase of and in the case of utilisation plant engines;
- Standby flares and replacement flares;
- Planning for lead-in times; and
- Iterative methods of mitigating the impact of gas with CH_4 concentration < 25% v/v.

An annual review of control measures would be very beneficial.

5.3.1.3 Section 3 Operational Procedures

Operational procedures with respect to landfill gas management are not commonplace at Irish landfills, yet are critical for good management. It is recommended that licensees should include the following:

- A drawing pack including as-built drawings of all gas collection systems;
- An overview of how each of the phases, where applicable, of a landfill gas system are connected;
- Well logs and specs including borehole and casing, length of slotted section, depth of well;
- O&M manual for flares;
- Landfill gas field balancing procedure (discussed in further detail at the end of this section);
- Audit methodology and reporting system for inspection and balancing of gas collection system.

5.3.1.4 Section 4 Monitoring Plan

Typically in Ireland, licensees would have a monitoring plan for perimeter wells, flares and engines in place. Improvements are required: for example, with regard to landfill gas monitoring, the UK EA requires a methodology for data storage, retrieval and presentation. In general, gas monitoring results in Ireland are presented in tabular format representative of one month. Historical data or trends are not included as a matter of course. Licensees should be encouraged to interpret monitoring results in the light of historical trends and in conjunction with adjacent wells, etc.

5.3.1.5 Section 5 Action Plan

This is a comprehensive plan for dealing with abnormal events and failures of control systems. The existing emergency plan for the site should refer to this section of the gas-management plan. The EA recommends that the plan sets out the actions to be taken by the licensee as a result of:

- Any abnormal changes observed in collected monitoring data;
- All identified operational problems or failure of the gas control system established as part of the routine inspection or maintenance programme;
- A reported event, e.g. an odour complaint;
- Scenarios identified during the risk assessment.

5.3.1.6 Section 6 Aftercare and Completion Plan

As mentioned previously, the licensee should plan for the point when it is no longer viable to flare landfill gas. An aftercare and completion plan should be site specific to determine how emissions will be monitored and controlled until the waste body has stabilised.

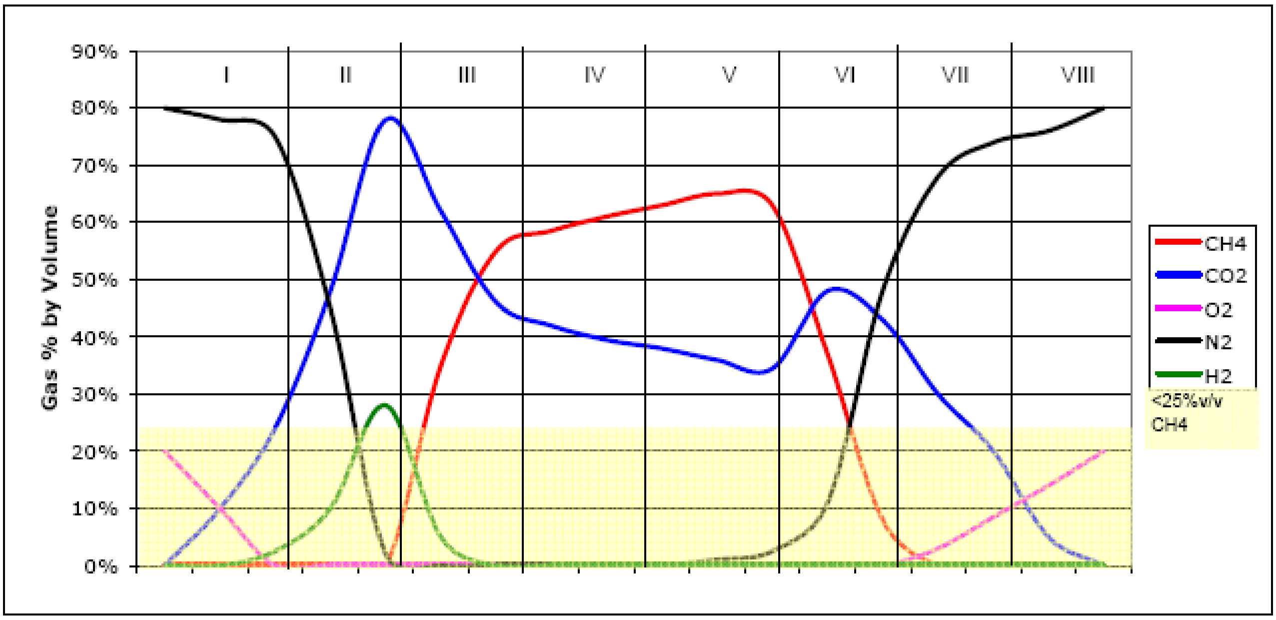

Figure 5.1. Typical landfill gas generation curve. (Source: Christiansen and Kjedsen (1989)).

5.3.2 Landfill Gas Balancing

Section 3 of this report makes reference to the need for a detailed balancing methodology to demonstrate an understanding of the concept that landfill gas generation equals emissions plus recovery. Based on the age and size of the landfill, licensees should be asked to propose a flow-based or CH_4-based extraction system. The plan should look at the expected viability of flares and engines into the future so that the landfill management can plan for landfill gas management post-utilisation and subsequently post-flaring.

Balancing should be carried out at a frequency suitable to gas production. Monthly balancing of all sites is recommended until the licensee demonstrates that another frequency is more suitable.

Table 5.13 shows the recommended parameters to be monitored and recorded in order to make informed decisions about balancing.

Data gathered during balancing and subsequent changes made to the field should be recorded in order to assess the effectiveness of balancing. A methodology for data storage, retrieval and presentation should be included in the plan by the landfill operator.

It is recommended that a training course on landfill gas balancing be run for all stakeholders (licensees, inspectors, flare and engine operators, consultants). Consideration should also be given to including guidance from the EPA. Elements that should be included in the course are:

- Understanding of landfill gas generation (what drives it, risks, environmental impact);
- Flow-based extraction philosophy versus a CH_4 -based extraction philosophy;
- Balancing procedure (equipment required, parameters, interpretation, data management);
- Understanding of the volume of gas being extracted from each well and all zones of the site. This is to reduce the risk of over or under extracting from specific zones;
- Function of a flare;
- Function of a utilisation plant;
- Impacts of alternative landfill gas-extraction system designs.

5.3.2.1 Recommended Landfill Gas Balancing Procedure

The following landfill gas balancing procedure is recommended:

1 Define recommended operating criteria;

2 Measure and record flow and pressure in the gas-extraction system pipe work;

3 Measure and record the following parameters at wellheads and manifolds:

- Pressure;
- Methane;
- Carbon dioxide;
- Carbon monoxide;
- Hydrogen sulphide;
- Nitrogen (balance);

4 Enter all measurements into a database with trending capabilities;

Table 5.13. Recommended balancing parameters.

Location	Wellheads	Manifolds	Carrier pipelines	Inlet to flare(s) or engine(s)
Parameter				
Velocity of gas (flow)	x	✓	✓	✓
Pressure (of gas)	✓	✓	✓	✓
Methane, carbon dioxide, oxygen	✓	✓	✓	✓
Hydrogen sulphide, carbon monoxide	✓	✓	✓	✓
Temperature (of gas)	✓	✓	✓	✓
Nitrogen* (balance)	✓	✓	✓	ü

* Nitrogen cannot be measured on a landfill gas analyser – it reads as the balance. Atmospheric pressure and temperature should be recorded at every audit.

5 Interpret the data;

6 Make changes to the field slowly and in isolation (i.e. do not change several things at once or you will not be able to assess the impact);

7 Let the field stabilise, examine and record the impact of the changes. Use trends to understand the impacts of specific actions;

8 When first commencing balancing of a field, repeat the audit regularly. The operator will develop a sense of how the field reacts, when and where issues arise and how often auditing should be carried out. An active landfill will require more frequent auditing than an old capped site.

6 Efficiency of Methane Capture – Infrastructure

This section of the report addresses the infrastructure element of Task 4:

- Assess existing landfill infrastructure with regard to efficiency of CH_4 capture and utilisation.

An assessment of existing landfill infrastructure was carried out based on the data collated in the survey with regard to the efficiency of CH_4 capture and utilisation. According to industry opinion, a fully engineered and capped landfill may achieve 85% recovery of landfill gas[5]. The following data was gathered to categorise sites in terms of infrastructure:

- Extent and type of cap 1996–2007;
- Uncapped areas;
- Diameter, spacing, age and number of extraction wells in capped and uncapped areas
- Flares and engines;
- Data-recording capabilities.

Methane capture is dependent on a landfill gas-extraction system with treatment. Landfill gas extraction is most effective where the waste body has been capped.

6.1 Extent and Type of Landfill Caps

As noted above, licensed sites are described in this report as either 'active' or 'closed' – an active site accepts waste material for deposition, and a closed site is one that has ceased accepting waste material for deposition.

The *Landfill Manual*: *Landfill Site Design* (EPA, 2000) defines a landfill cap as 'covering of a landfill, usually with low permeability material'.

The extent and types of cap installed at Irish landfills was surveyed. Capping details were submitted by 57 of the licensees[6].

5 An extraction efficiency of 85% for a fully capped landfill has been referred to in Guidance on the Management of Landfill Gas, Environment Agency 2004 as feasible. There are no hard and fast rules with landfill gas and thus there are no proven efficiency rates. A lot of guidance is rule of thumb, requiring site-specific refining.

6 58 licensees returned surveys. One site did not include details of capping.

Survey results showed that:

- 40% of sites are fully capped (23 sites);
- Of the 33 closed sites, 23 are fully capped (70%). The remainder of closed sites have a temporary cap. There are no uncapped areas on surveyed closed sites;
- Of the 25 active sites, none are fully capped. 3 of the sites have no uncapped areas, having been temporarily capped. The remainder have uncapped areas ranging from 0.2 ha to 22 ha.

A description of cap types is given below:

- 30 sites have a synthetic cap (more than half of all surveyed sites);
- 10 sites have a cohesive cap;
- 12 sites have a bentonite cap;
- 2 sites have a granular cap.

The survey did not query what materials are used as daily cover but experience shows that uncapped areas typically have an intermediate cover material comprising either:

- Soil (cohesive or granular);
- Woodchip;
- Compost.

The area of waste on active landfills is 235 ha. It comprises:

- 13% uncapped waste;
- 26% temporary capped areas.

The remainder is fully capped. The uncapped and temporary capped areas on active landfills total 91.7 ha.

The area of waste on closed sites is 336 ha. It comprises:

- 4% uncapped waste;
- 19% temporary capped areas.

The remainder is fully capped. The uncapped and temporary capped areas on closed landfills total 76.4 ha.

There are two gas-management practices for uncapped areas of waste:

- Practice 1 is to vent landfill gas directly to atmosphere. A layer of soil, compost or woodchip on top of the waste mitigates the impacts of odiferous emissions to some (small) extent.
- Practice 2 is to install a temporary (vertical or horizontal) gas-extraction system(s). These systems can be combined with soil cover, compost or woodchip. This practice is an improvement on direct venting in terms of environmental protection. However, it can be difficult to manage gas extraction due to the risk of air ingress/high oxygen levels in the landfill gas leading to subsequent management difficulties at flares or engines and an increased fire risk.

Tables 6.1 and 6.2 show the proportion of uncapped areas at active and closed landfills with gas-extraction systems respectively. Table 6.3 shows uncapped areas at closed landfill sites that do not have an active gas-extraction system.

Closed sites with an active gas-extraction system constitute 286 ha, of which 4.5% is uncapped and 17% temporarily capped. Approximately 20% of closed sites with no permanent cap have an active gas-extraction system. Closed sites with no gas-extraction systems constitute 50.3 ha, of which less than 1% remains uncapped and 31% is temporarily capped.

Table 6.1. Active landfill sites – uncapped and temporarily capped areas.

Licence no.	Active landfill sites	Uncapped area 2008 (ha)	Temporarily capped area 2008 (ha)	Proportion site uncappped (%)	Proportion of site with temporary cap (%)
W0012-02	Kinsale Road Landfill	6	2	26	9
W0146-01	Knockharley Landfill	5.3	3	64	36
W0066-02	Rampere Landfill	3.64	1.62	60	27
W0021-02	Derrinumera Landfill Facility	2.2	0	59	0
W0029-03	Derryclure Landfill	2	0	100	0
W0067-01	Rathroeen Landfill	1.2	1.2	19	19
W0025-02	Powerstown Landfill Site	1.2	0	12	0
W0165-01	Ballynagran Residual Landfill	1.1	1.5	42	58
W0068-02	Youghal Landfill	0.98	0	14	0
W0191-01	Holmestown Landfill*	0.87	0	100	0
W0017-03	Gortadroma Landfill Site	0.86	0	7	0
W0024-03	Ballynacarrick Landfill Site	0.83	2.26	12	31
W0089-02	Derryconnell Landfill	0.62	0.52	20	17
W0060-02	Whiteriver Landfill Site	0.56	1.75	6	20
W0109-01	Ballyduff Beg	0.55	0.55	12	12
W0074-02	Donohill Landfill	0.51	2.78	10	51
W0059-02	Ballaghaderreen Landfill	0.5	0	11	0
W0081-03	KTK (Brownstown and Carnalway)	0.5	15.5	3	97
W0020-02	Scotch Corner Landfill	0.45	2.43	8	45
W0178-01	East Galway Residual Landfill Site	0.4	1.5	10	36
W0028-02	Ballydonagh Landfill	0.2	4.7	4	96
W0004-03	Arthurstown Landfill	0	17	0	53
W0009-02	Balleally Landfill	0	1.6	0	3
W0030-02	Dunmore Landfill	0	1.37	0	21
W0078-02	Ballaghveny Landfill**	no data	no data	no data	no data

*Holmestown commenced waste activities in May 2008. There is not sufficient waste for a gas-extraction system currently.

** Insufficient information on capping was returned in this survey.

Table 6.2. Closed landfill sites with gas extraction with uncapped and temporarily capped areas.

Licence no.	Closed landfill sites	Uncapped area 2008 (ha)	Temporarily capped area 2008 (ha)	Proportion site uncappped (%)	Proportion of site with temporary cap (%)
W0034-02	Newry Road/Dundalk Landfill	10.5	0	57	0
W0022-01	East Cork Landfill Site	2.24	0	25	0
W0002-02	Ballyguyroe Landfill Site	0	0	0	0
W0010-02	Basketstown Landfill	0	0	0	0
W0011-01	Ballymurtagh Landfill Facility	0	0	0	0
W0018-01	Kilbarry Landfill Site	0	0	0	0
W0023-01	Raffeen Landfill Site	0	0	0	0
W0027-02	Pollboy Landfill	0	0	0	0
W0031-01	Doora Landfill Site	0	18.7	0	100
W0033-01	Drogheda Landfill	0	1	0	9
W0071-02	Marlinstown Landfill	0	2	0	22
W0127-01	Dunsink	0	0	0	0
W0026-02	Kyletalesha Landfill	0	0	0	0
W0015-01	Ballyogan	0	26	0	62
W0070-01	Benduff Landfill	0	0	0	0
W0016-02	Killurin Landfill Site	0	0	0	0
W0014-01	Silliot Hill	0	0	0	0

Table 6.3. Closed landfill sites without gas extraction – uncapped and temporarily capped areas.

Licence no.	Closed landfill sites without gas extraction	Uncapped area (ha)	Temporarily capped area (ha)	Proportion site uncapped (%)	Proportion of site with temporary cap (%)
W0062-01	Churchtown Landfill	0	9.6	0	100
W0170-01	Lisdeen Recycling Centre and Transfer Station	0	3.2	0	100
W0090-01	Balbane Landfill Site	0	2.95	0	100
W0063-01	Drumabodan Landfill Site	0	0	0	0
W0076-01	Longpavement	0	0	0	0
W0091-01	Bailieborough Landfill	0	0	0	0
W0092-01	Belturbet Landfill	0.2	0	36	0
W0093-01	Ballyjamesduff Landfill	0	0	0	0
W0125-01	Glenalla Landfill Site	0	0	0	0
W0126-01	Muckish Landfill Site	0	0	0	0
W0065-01	Mohill Landfill	0	0	0	0
W0064-01	Carrick On Shannon Landfill	0	0	0	0
W0087-01	Caherciveen Transfer Station	0	0	0	0
W0072-01	Coolcaslagh	0	0	0	0
W0086-01	Kenmare WTS	0	0	0	0
W0069-01	Milltown	0	0	0	0

6.1.1 Landfill Gas-extraction Wells

A determination of the effectiveness of vertical landfill gas-extraction wells in capped areas was made based on the diameter of the wells, the age and spacing.

6.1.1.1 Spacing Closed Sites

On closed landfill sites with active gas-extraction systems, the average well spacing is 35 m and the average age is 3 years. Exceptions include 2 sites with large well spacings of 80 m and 90 m (Dunsink and Pollboy).

Some licensees had reported well spacings as low as 15 m; however, based on calculations of a capped area divided by the number of wells, the average spacings are closer to 40 m.

6.1.1.2 Spacing Active Sites

On active landfill sites with capped areas, the average well spacing is 35 m. The largest spacing is 55 m.

6.1.1.3 Well Diameter

Information from surveys was inconclusive in relation to well diameter as some respondents defined the well annulus, while others defined the pipe diameter.

6.1.1.4 Well Longevity

According to the survey responses, the average age of extraction wells is 3 years. The oldest wells (10 years) are at Dunsink Landfill. The consultants' experiences outside the survey has shown the average lifespan of an effectively managed vertical extraction well varies between 10 and 15 years subject to extraction rate and waste type. However, over extraction, poor well installation, unsuitable well diameters, certain waste types such as sludges etc. can shorten well lifespan to less than 5 years on some sites.

6.1.1.5 Miscellaneous

Survey results suggest that licensees view the functions of wells differently to the professional designers of gas-extraction systems. Accordingly, attached are a few anecdotal comments that may assist the reader in comparing survey results with the following typical design philosophies:

- Experience suggests that wells founded (typically gabions) on the stone drainage layer are more suited to odour control and are less likely to develop a radius of influence. Unless designed and managed appropriately, these wells are also more likely to be conduits for oxygen when cells are not full or if side-slope drainage envelopes are not isolated from the atmosphere.
- If gabion wells are used for primary extraction, it is important that they are founded on a minimum of 5.0 m above the basal drainage layers and have a bentonite plug isolating them from the underliner gas-collection system. These measures are required in order to prevent short-circuiting of the wells via either the basal stone drainage or the underliner gas-collection layer.
- If wells are placed too close together, accurate flow control is required to mitigate the zones of influence of each well overlapping and fighting against one another.
- Wells with small diameters are likely to have a limited life. For sites with flow rates less than 15 m^3/hr, 300 mm to 450 mm diameter annulus may be acceptable. For higher extraction rates, 600 mm annulus wells are recommended.
- Sludge if placed adjacent to wells will reduce longevity.
- A well's life will be reduced if a well is used for condensate drain-off.
- Wells are designed to facilitate a negative pressure gradient within the site to mitigate the risk of fugitive emissions.

6.2 Recovery Infrastructure

Table 6.4 shows active recovery capacity in relation to gas generated.

Nationwide, there is sufficient recovery capacity in Ireland. However, this assessment should be carried out on a site-by-site basis to determine if the infrastructure is appropriate for prevailing CH_4 concentrations. This information is available for analysis within the dataset collected for this study.

Table 6.4 shows that less than half of the total treatment capacity was used in Ireland in 2008. According to the findings of the survey, approximately two-thirds of all gas generated was collected for treatment.

Table 6.4. Recovery capacity vs gas generation.

	2008 m^3/hr	2008 m^3/yr
Rated Capacity of Flares	64,100	561,516,000
Rated Capacity of Engines	15,900	139,284,000
Total Rated Treatment Capacity	80,000	700,800,000
Total Landfill Gas Generated (modelled)	56,719	496,854,160
Total Landfill Gas Recovered (acc. survey)	37,506	328,553,065

Details of passive recovery infrastructure were not queried in the survey. A small number of sites are venting passively. The most appropriate passive infrastructure is appropriate soil cover to oxidise fugitive emissions from the waste body and/or biological filters using a combination of soil, woodchip compost or similar.

6.3 Recommendations

To mitigate the impact of CH_4 on the environment, it is necessary to:

- Evaluate the efficiency of existing systems and their ability to recover methane;
- Oxidise the CH_4;
- Review waste decomposition models;
- Define appropriate objectives and operating criteria;
- Collect the landfill gas;
- Implement appropriate collection and oxidation systems for respective landfill sites.

A review of waste decomposition models is discussed in this section as opposed to elsewhere because it has significant implications on infrastructure design.

6.3.1 *Efficiency of Existing Systems*

Survey results suggest that basic infrastructure on Irish landfill sites is compliant with guidelines as defined in the *Landfill Manual: Landfill Site Design* (Carey et al. (2000)).

This report has recommended that:

- The EPA requires licensees to update AER-EPRTR with gas-management data;
- Licensees develop a gas-management plan;
- Licensees review gas emissions in relation to gas production flow rates and gas-extraction flow rates in order to clearly understand the extent of fugitive emissions.

These management tools however may not necessarily define how efficient the installed systems are in recovering CH_4 and when infrastructure needs to be upgraded or changed.

A typical example illustrates this point. Whilst a system may have wells at the required spacing, it is not possible to determine how effective they will be at extracting landfill gas or how effective CH_4 recovery is unless the following parameters are assessed:

- Waste composition, moisture content, age and depth;
- Well depth;
- Well annulus diameter;
- Leachate level within well;
- Screened area;
- Slot sizes;
- Pressure at well-head;
- Resultant flow;
- Gas composition at respective flow rates;
- Gas composition at flaring or engine compound;
- Details of bentonite plugs and proximity to basal liner;
- Pressure under the cap between wells;

- Impact on trigger monitoring boreholes of extraction;
- Extraction capacity and constraints;
- Oxidation capacity and constraints;
- Condensate management.

If wells are not extracting the landfill gas at the required flow rate, it is not possible to accurately calibrate the landfill gas prediction model. Therefore, there is a requirement for landfill sites to be audited technically at regular intervals. Whilst data may be provided if sites are managed as recommended by this report, interrogation of said data needs to be carried out by suitably qualified staff.

> It is recommended that all staff responsible for landfill gas management attend a specialised training course, dedicated to the management of landfill gas.

> It is recommended that spot assessments by the EPA or EPA-appointed specialists be carried out during programmed audits. The basis for audit could be taken from the gas-management plans or an EPA guidance document.

6.3.2 *Methane Oxidation*

Methane is oxidised traditionally using three methods:

- Engines;
- Flares;
- Biological oxidation:
  - Daily cover;
  - Soil cap;
  - Biological filters.

This section makes recommendations on these three methods and other alternatives.

6.3.2.1 Engines

Engines are designed to produce energy through combustion of landfill gas. As with flaring, combustion converts CH_4 to CO_2 and destroys harmful and odiferous trace components. Engines for large developments are only viable for CH_4 concentrations > 45% v/v.

> Engines have stringent emission targets. The most contentious one at present is NO_x in relation to greenhouse gases, but this is outside the scope of this study and as such will not be discussed further.

In addition to oxidising methane, engines also have the advantage of providing power. Accordingly, they are more effective than flares at CH_4 recovery.

6.3.2.2 Flares

Flares are used to combust landfill gas, converting CH_4 to CO_2 and destroying harmful and odiforous trace components. To ensure combustion and the destruction of odiferous compounds, a temperature of 1,000 °C for a retention period of 0.3 seconds is specified by the EPA. Under most licence conditions in Ireland this is achieved using a flare within an enclosed stack. In order to achieve and maintain this temperature, CH_4 must typically be > 25% v/v. Open flares were permitted in the early days of landfilling but are no longer allowed due to their inability to combust trace components of landfill gas.

When there is insufficient CH_4 to sustain a flame at 1,000 °C for a retention period of 0.3 seconds (i.e. CH_4 concentrations < 25% v/v) the following management options are available if the appropriate infrastructure is in place:

- Mix poor quality gas (CH_4 < 25% v/v) with good quality gas to enable flaring in an enclosed stack;
- Downsize the flare to facilitate turn-down ratios.

However, these options are feasible on sites only where there is a sufficient volume of CH_4 available. If sufficient CH_4 gas is not available, then there is great difficulty in recovering CH_4 at concentrations < 25% v/v.

Figure 5.1 above shows that within a typical landfill gas curve there is a significant volume of poor quality gas. Globally, this contributes to greenhouse gas emissions. Locally (i.e. adjacent to the site), this can cause odours.

Options for managing poor quality landfill gas may require some changes to current EPA guidance. It is recommended that the following options be considered on a site-by-site basis when the licensee can demonstrate that there is no alternative:

- Use of alternate flare designs, e.g. Bekeart has flares which work with CH_4 down to 15% v/v;
- Programming enclosed flares to run in recovery mode with a pilot to facilitate combustion allows enclosed flares to operate down to 14% v/v methane;
- Use of open flares which is essentially the same as the previous alternative;
- Biological filters;
- Other technologies (e.g. thermal oxidisers): however, these are unlikely to be cost effective.

6.3.2.3 Biological Oxidation

In the absence of a synthetic barrier, fugitive CH_4 emissions can be oxidised by methanotrophic bacteria. The bacteria use the CH_4 as a source of carbon in a process called CH_4 oxidation. Oxidation tends to be higher in free-draining granular soils.

Biological filters, whether daily, intermediate or permanent caps, are typically suited to landfills without a synthetic barrier layer. Soil cover will accommodate only low landfill gas emissions in caps where settlement is unlikely to create preferential pathways.

Soil cover is clearly suited to historical landfill sites; however, effective use of this method to recover CH_4 may cause other problems. Because it is preferable to have a free-draining medium, the risk of deep percolation inputs increases and this may not be acceptable on unlined sites.

If soil cover is used to recover methane, then soil may benefit from inoculation with compost, woodchip or similar.

Where liners on sites are present, landfill gas would need to be extracted and passed through a biological filter in order to recover methane.

6.3.3 Review Waste Decomposition Models

The available models are:

- Traditional landfill;
- Entombment;
- Anaerobic bioreactor;
- Aerobic bioreactor.

6.3.3.1 Traditional Landfill

Traditional landfills were essentially ‘dilute and disperse’ systems. The disadvantages to this approach were that groundwater contamination risks and fugitive emissions to the atmosphere were high. The primary advantage was that the waste-degradation process was allowed to continue by allowing moisture to percolate through the waste body and facilitate biological activity.

6.3.3.2 Entombment

Entombment is currently advocated by the EPA as the most appropriate approach to landfill. The main objective of entombment using a lining system is to protect the surrounding environment. Best practice is that waste is entombed between a high density polyethylene (HDPE) basal liner and a linear low density polyethylene (LLDPE) capping barrier. The basal liner protects underlying soils and groundwater by containing leachate, controlling ingress of groundwater and mitigating landfill gas migration. The capping liner:

- Minimises infiltration of water into the waste, thereby minimising the production of leachate;
- Helps control gas migration; and
- Provides a physical separation between waste and plant and animal life.

This philosophy presents challenges for optimal landfill gas management over the entire period of waste decomposition. The plastic envelope prevents moisture ingress into the waste body. Once entombed, waste decomposition slows and the management period is extended. Once liners eventually break down and water is allowed to enter into the waste body the degradation process will restart and pose management problems for future generations and CH_4 emissions will recommence.

6.3.3.3 *Anaerobic Bioreactor*

There is potential to accelerate waste decomposition and to reduce the management period by introducing moisture into the entombed waste body. This is normally carried out for economic reasons to facilitate utilisation of gas to produce power.

Anaerobic bioreactors are entombed waste bodies that have water or leachate applied to increase the moisture content of the waste and accelerate waste degradation.

Current practice in Ireland encourages leachate recirculation once a cap is in place if cells have a basal liner. This is not considered to be appropriate by the authors of this report because, for bioreactors to work effectively, it is essential that water content within the waste body is both high and uniform. Waste at depths of 15 m or greater becomes increasingly impermeable and to try and change moisture content beyond this depth is not cost effective.

For a bioreactor to work cost effectively, moisture content additions need to take place as the waste is being landfilled. It is recommended that the EPA consider this approach to allow landfills to derive benefit from:

- Increased void space;
- Accelerated waste degradation;
- Improved control of landfill gas:
  - More concentrated volume of high CH_4 landfill gas;
  - More efficient CH_4 recovery rates;
- Reduced aftercare period.

6.3.3.4 *Aerobic Bioreactor*

Waste can be broken down aerobically within landfills. This requires high energy inputs and there is also an increased fire risk. This approach, at present adopted by the Landfill Directive (Directive 1999/31/EC), is to encourage such breakdown outside of landfill body and landfill inert materials. It is not possible to comment on this option in relation to CH_4 recovery without more detailed studies, which are outside the remit of this study.

6.3.4 *Define Landfill Gas-Extraction Objectives and Operating Criteria*

Section 5.2.1 defined the landfill management objectives. These are replicated below for convenience.

To facilitate CH_4 recovery, it is recommended that the EPA require operators to:

- Prevent gas migration by extracting gas at a flow rate equal to or approaching that which is being produced in the landfill body;
- Develop a negative pressure gradient towards the centre of the waste body to mitigate the risks of offsite migration;
- Manage landfill gas quality to facilitate CH_4 recovery by efficient operation of landfill gas flares (and/or engines on larger sites);
- Manage CH_4 recovery by biological means or similar on site with small CH_4 emissions;
- Provide conditioning, using carbon filters, wood chip or similar to mitigate the impacts of fugitive gas emissions that cannot be managed by the primary extraction systems.

The preferred option for CH_4 recovery is clearly to oxidise landfill gas in an engine or similar to produce power. Thereafter, when CH_4 is not sufficient for engine operation, typical EPA licences require landfill gas to be oxidised in an open flare.

The environmental conflict will occur when:

- Oxidation by flaring at reduced CH_4 concentrations may cause odours; and
- Conventional enclosed flaring is no longer possible.

When available, CH_4 begins to compromise operations at the landfill (i.e. in Phases I, II, VI, VII and VIII as shown on Figure 2.2), a decision is required by the EPA to define the priority and rating operating criteria and priorities in relation to utilisation, CH_4 recovery, odour management or off-site migration, etc.

To illustrate one such example of the potential conflicts, it is worth considering the typical current licence requirements to utilise and/or oxidise landfill gas in an enclosed flare. Each has a minimum viable CH_4 concentration: in simple terms, if a closed flare requires 25% v/v CH_4 gas and the available average

CH_4 quality is 24% v/v CH_4 then it is not possible to run the flare. If, however, some parts of the site deliver 45% CH_4 v/v and this gas is segregated at source, it may be necessary to supplement the poor-quality gas with additional CH_4 and oxidise some if not all of the CH_4 in the poor gas, albeit that the possibility of utilisation may be compromised. To facilitate segregation of different gas qualities for alternate treatment options, a twin gas collection system is recommended. Such a system would facilitate separation of landfill gas at groups of wells.

Once a gas collection system is installed, it is essential that appropriate operating criteria are implemented in relation to gas extraction and the balancing of the gas field.

> Once operating criteria have been established, the sites need to be managed and audited. It is recommended that the EPA provide guidance on the facility objectives, operating criteria and reporting format and that the licensees propose site specifics in a gas-management plan.

Further details on gas-management plans are included in Section 5.3.

6.3.5 Implement Appropriate Collection and Oxidation Systems for Respective Landfill Sites

In addition to the twin pipe-work systems discussed above, other collection systems may be required to manage gas extraction. These may include – but will not be limited to – horizontal gas-collection systems, vertical odour-control systems, and vertical gas-extraction systems and cover designs to manage fugitive emissions.

Traditionally in Ireland a cell is designed. Thereafter, it is handed over to the operator to place waste in. When ready for capping, it is passed over to third parties for cap designs. This system of working is inappropriate. Operations to mitigate fugitive CH_4 emissions and to recover CH_4 need to have extraction systems implemented from day 1 of waste inputs and operational staff who are fully conversant with the gas-management systems. It is recommended that this requirement could be addressed in a gas-management plan.

> The design of extraction and management systems needs to complement and be contiguous with operations. Gas-collection systems also need to be designed to manage landfill gas over the life of the facility, meaning both low CH_4 emissions and high CH_4 emissions.

Recommendations to improve the efficiency of CH_4 recovery are discussed under the following headings:

- Active landfill sites;
- Closed landfill sites with active gas extraction;
- Closed landfill sites without active gas extraction.

6.3.5.1 Active Landfill Sites

Active landfill sites are defined as those that are accepting waste materials. On active landfills sites, landfill gas-collection systems and CH_4 oxidation are essential for CH_4 recovery.

To facilitate recovery in active landfill sites, operators need to define current and projected waste streams and the potential they have to produce CH_4 in the short and long terms under differing waste-management models.

Conceptual gas-management plans need to review the impact of respective waste-management models on CH_4 production in the short and long terms. Following this conceptual review, system designs for alternative models should be prepared. Once all the options have been defined, an evaluation needs to be carried out and a conceptual gas-management philosophy developed. This should then be passed to the EPA for approval.

The critical issue in relation to CH_4 recovery will be, as stated previously, Phases I, II, VI, VII and VIII as shown on Figure 2.2. It is essential that operators define how they propose to recover CH_4 from landfill gas emission in these phases.

The key questions that will need to be addressed are:

- Is the waste body to be developed as a bioreactor?
- How will fugitive emissions from the waste face be oxidised?
- How will fugitive emissions from the surface be oxidised in the short, medium and long terms?
- How will CH_4 recovery be effected in Phases VI, VII and VIII as shown on Figure 2.2?
- What is the odour-management philosophy?
- How will poor CH_4 from historical waste be dealt with?
- How will poor CH_4 from future waste streams be dealt with?
- SEW design details in relation to capping, active extraction, well spacing, well annulus, pipe-work systems, active recovery mechanisms?
- What is the projected engine and/or flaring replacement schedule?
- What is the projected well replacement policy?
- What are the key receptors in relation to gas migration?
- What is the CH_4 recovery target as a percentage of annual gas projections?
- What is the gas-management philosophy in relation to balancing, auditing and reporting?

6.3.5.2 Closed Landfill Sites with Gas Extraction

There are 37 closed licensed landfills in Ireland; surveys were returned from 33 of them. The figures quoted in this section are based on those 33 returns.

The area of closed landfills with active gas-extraction systems in 286 ha. Approximately 20% of this area has not been permanently capped, 4.5% remains uncapped and 17% is temporarily capped. It is recommended that a review of emissions from closed sites be carried out to determine the potential or otherwise for CH_4 recovery.

Where insufficient CH_4 content prevents oxidation using enclosed flares, active extraction alternatives as discussed in Section 6.3.1 need to be reviewed.

Where sites have not been capped permanently, biological alternatives to recover CH_4 should be considered.

Where existing caps are in place and active extraction is no longer possible owing to lack of methane, active extraction should be considered with a view to passing the landfill gas through biological filters. It may be possible to use existing sub-surface drainage or to create organic filters using a mix of soil, wood chip and compost.

One potential problem area here will be the risk of explosion as the blowers may not be rated to operate in the explosive zone.

6.3.5.3 Closed Landfill Sites without Gas Extraction

The area of closed landfills without active gas-extraction systems is 50 ha, of which 0.4% is uncapped and 31% is temporarily capped.

It is recommended that a review of emissions from closed sites be carried out to determine the potential or otherwise for CH_4 recovery.

- *Uncapped areas*: The review should determine the scope of emissions and if appropriate generate a plan to manage emissions. It is recommended that the use of soil cover and/or independent biological filters be considered for oxidation of CH_4 in uncapped areas. Flux boxes or similar can be used to monitor effectiveness of cover materials and/or filters at containing and/or oxidising methane. Reviews should examine whether it is possible to use existing sub-surface drainage.

- *Capped areas*: Both synthetic and bentonite caps have been placed on closed sites with no gas-extraction systems. There is potential for lateral migration on these sites and therefore monitoring is essential. The EPA may need to allow venting from the site at specific locations to prevent migration. As above, the use of soil cover and/or independent biological filters should be considered for oxidation of CH_4 in capped areas and reviews should examine whether it is possible to use existing sub-surface drainage.

7 Project Outputs

Table 7.1. Completed project outputs.

Task output		**References from this report**
Task 1 Output	Identify the landfills where flares are used or have been used.	
	Determine mode and periods of operation for burners and other technical information relevant to gas consumption.	Not applicable.
	Quantify the CH_4 input to individual flares to compile the national total for all relevant years.	Table 2.3.
Task 2 Output	Use the information from Task 1 to elaborate a reporting scheme that would assist landfill operators in delivering the information necessary to produce the estimates of CH_4 used in flares in the future.	
Task 3 Output	Obtain technical information on the plants utilising landfill gas for electricity generation and on their landfill gas inputs in order to estimate the precise energy content and CH_4 consumption.	Tables 3.1, 3.2 and 3.3.
	Validate the available estimates of energy input from landfill gas to such plants for the years 1996–2007 as contained in the Sustainable Energy Ireland (SEI) energy balances for these years.	Table 3.4.
Task 4 Output	Assess existing landfill infrastructure and management systems with regard to efficiency of CH_4 capture and utilisation.	Sections 5 and 6.
	Identify cost-effective changes in technology and management practice which would maximise the mitigation of CH_4 emissions whilst addressing the ongoing need to meet other environmental protection objectives.	Sections 5 and 6.

8 Future Considerations

8.1 Future Waste Composition and Possible Impacts on Methane Recovery

In September 2008, the EPA published a consultation document regarding the pre-treatment of municipal solid waste (MSW) (EPA, 2008). Article 5 of the Landfill Directive (99/31/EC) sets out specific pre-treatment obligations for biodegradable municipal waste (BMW).

These biowaste diversion obligations are a sub-set of the waste treatment requirements, and have specific limitations in respect of the tonnage of biowaste that can be accepted at landfills. These limitations – which are tied to a 1995 statistical base year for waste production in Ireland – are staggered, with each iteration possessing a stricter obligation in relation to diversion. Ireland negotiated with the European Commission a 4-year extension to the first two compliance dates specified in Article 5 of the Directive (2006 to 2010, and 2009 to 2013 respectively). These obligations can be summarised as follows:

- By 1 January 2010 Ireland can only landfill a maximum 75% of the BMW generated in 1995, i.e. a national maximum of 967,443 t BMW can be landfilled. Based on current waste growth trends this, in 2010, will equate to a requirement that approximately 50% of all BMW accepted at a landfill facility for disposal must be biologically pre-treated (including diversion);
- By 1 January 2013 Ireland can only landfill a maximum 50% of the BMW generated in 1995, i.e. a national maximum of 644,956 t BMW can be landfilled. Based on current waste growth trends, this, in 2013, will equate to a requirement that approximately 70% of all BMW accepted at a landfill facility for disposal must be biologically pre-treated (including diversion);
- By 1 January 2016 Ireland can only landfill a maximum 35% of the BMW generated in 1995, i.e. a national maximum of 451,469 t BMW can be landfilled. Based on current waste growth trends, this, in 2016, will equate to a requirement that approximately 90% of all BMW accepted at a landfill facility for disposal must be biologically pre-treated (including diversion).

It is anticipated that waste will be expected to meet a biodegradability standard to prove adequate pre-treatment. This standard is currently in draft.

A reduction in the biodegradable waste fraction within the waste body will impact on landfill gas production. It is understood by the authors that the EPA intends to review the waste acceptance criteria for landfills in order to ensure biodegradable waste diversion. It is currently unclear how the EPA intends to apply the criteria for diverting BMW. It is essential that the EPA take potential landfill gas-management issues into consideration when applying waste acceptance criteria.

The manner in which biodegradable waste is diverted at the gate will dictate the management and design requirements for landfill gas and possibly waste placement.

If a landfill is required to reduce the BMW content of all waste accepted, then the overall gas production will be reduced. Depending on the size of the landfill, this may impact on engine and flare viability.

If a landfill is required to accept a certain proportion of total tonnage landfilled that has been treated to achieve the biodegradability standards, the remaining waste landfilled would be of a similar composition to that being landfilled currently.

> In this case, it may be pertinent to separate such waste inputs so that there would be one cell containing a waste fraction with very low gas production potential and another cell producing traditional landfill gas (60% methane, 40% CO_2). Potentially, gas extraction would not be required from the pre-treated cell. Operation of two discrete cells will present other issues.

8.2 Centralised Data Management within the EPA

It is recommended that information within the EPA in relation to gas management and CH_4 recovery be stored such that it is readily accessible by all EPA departments on central servers.

In the event that the E-PRTR recommendations in Section 4 are implemented and if a standardised auditing tool is promoted via the EPA, it is recommended that a web-based information and performance-assessment forum be established by the EPA to promote greater awareness and assistance between operators. It is recommended that access to the web-based network should be extended only to operators.

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Acronyms and Annotations

BMW	Biodegradable municipal waste
EA	Environment Agency, United Kingdom
EPA	Environmental Protection Agency
E-PRTR	European Pollutant Release and Transfer Register
gwh	Gigawatt hour
HDPE	High density polyethylene
ktoe	Kilotonnes of oil equivalent
LLDPE	Linear low density polyethylene
Mbg	Gauge pressure in millibars
MSW	Municipal solid waste
MW	Megawatt
MWh	Megawatt hour
NMOC	Non-methane organic compound
SCADA	Supervisory control and data acquisition
STP	Standard temperature and pressure
v/v	Volume per volume

Glossary

Open Flare Open flares burn landfill gas as open flames, though a windshield is normally fitted. If provided, combustion control is rudimentary. Open flares are also known as elevated flares.

Enclosed Flare Enclosed flares burn landfill gas in a vertical, cylindrical or rectilinear enclosure. Some means of combustion control is normally provided, and the enclosure is often insulated to reduce heat losses and allow operation at higher temperatures.

Capping The covering of a landfill, usually with low permeability material.

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

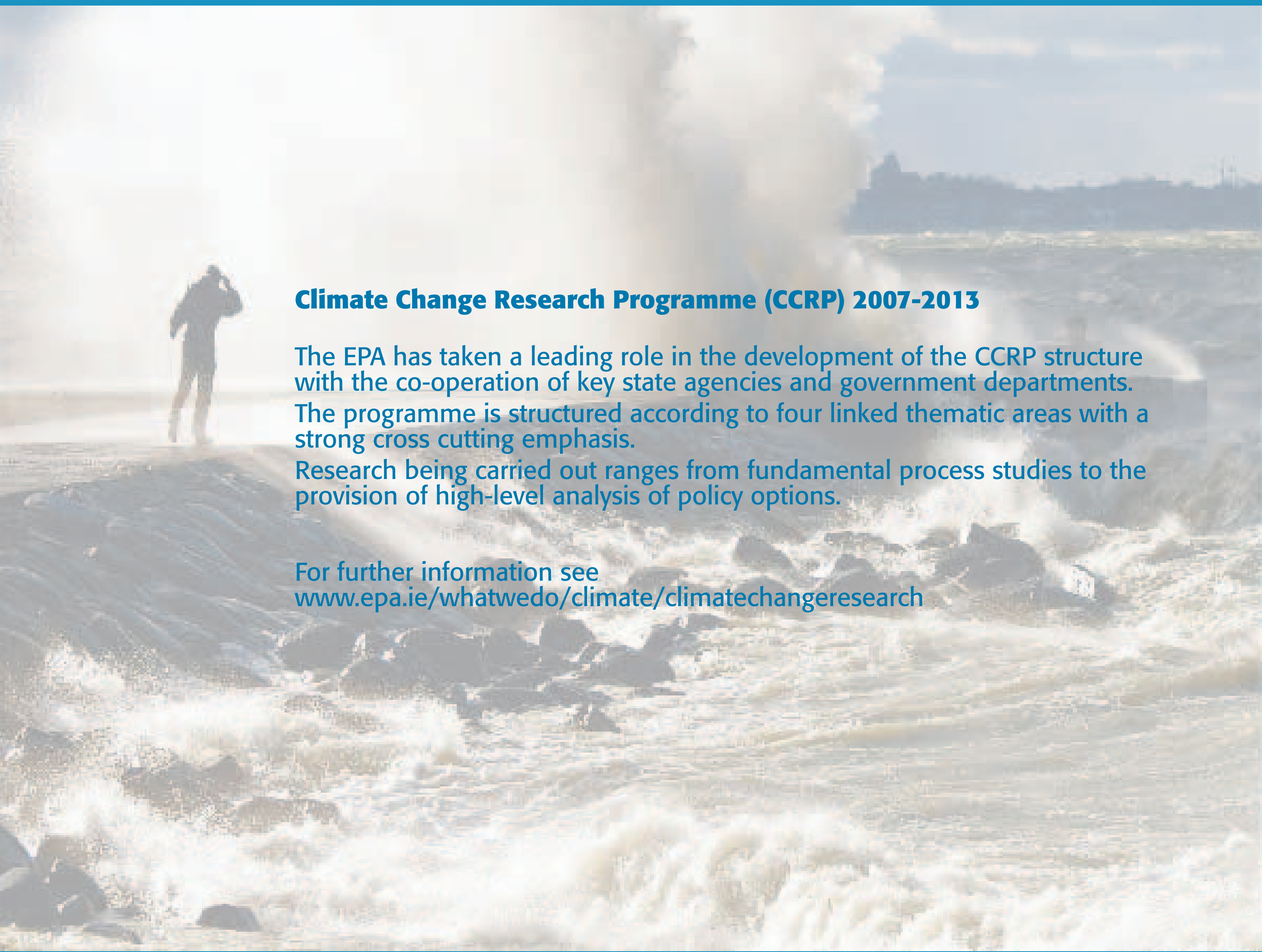
Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013



Climate Change Research Programme (CCRP) 2007-2013

The EPA has taken a leading role in the development of the CCRP structure with the co-operation of key state agencies and government departments. The programme is structured according to four linked thematic areas with a strong cross cutting emphasis. Research being carried out ranges from fundamental process studies to the provision of high-level analysis of policy options.

For further information see
www.epa.ie/whatwedo/climate/climatechangeresearch

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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