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A STRATEGY FOR EMISSIONS BASED REGULATION OF LANDFILL GAS

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SUMMARY: The Environment Agency (the Agency) is responsible for the regulation of landfill sites in England and Wales. Since its formation, the Agency's regulatory strategy for landfill gas has been to require operators to demonstrate best practice. However, this approach does not allow environmental outcomes from site-specific landfill gas management to be easily illustrated or quantified. Greater clarity is now given to these environmental outcomes by augmenting best practice regulation of landfill gas with emissions-based regulation. This will require a "step change" in the management of landfill gas. However, it will enable the operator and regulator alike to respond to public concerns regarding landfill gas, including increasingly complicated health-related issues.

1. INTRODUCTION

The Environment Agency is the leading public body for protecting and improving the environment in England and Wales, a responsibility that includes the regulation of landfill sites. The major legislative requirements relevant to landfill gas at permitted landfill sites are the Waste Framework Directive (Council of the European Communities, 1975), Landfill Directive (Council of the European Union, 1999) and the IPPC Directive (Council of the European Union, 1996).

From the perspective of a regulator, landfill gas is a "waste" that results from the landfilling of waste. Mature landfill gas from biodegradable waste is a mixture predominantly made up of methane and carbon dioxide and small amounts of hydrogen. It also contains varying amounts of nitrogen and oxygen derived from air that has been drawn into the landfill. Landfill gas will also contain a wide variety of trace components. Over 550 trace components have been identified in landfill gas (Environment Agency, 2002a), and together they normally comprise no more than 1% of the gas by volume.

In 2000, it was estimated that approximately 660 thousand tonnes of methane from UK landfills were released, accounting for 27% of the total UK emission of methane (NETCEN, 2002). There is an increasing level of concern about the uncontrolled release of landfill gas in the UK. This concern is reflected by the significant number of complaints relating to landfill gas that the Agency received from the general public. In 2002, the Agency received over ten thousand complaints related to odour, the majority of which related to landfill sites. Indeed the most significant of these cases result in a number of "landfill gas-related" prosecutions by the Agency every year. This concern has been exacerbated by the increased awareness of the potential health impacts of landfill gas.

Several epidemiological studies conducted around landfill sites have indicated an association between adverse health outcomes and the proximity to landfill (e.g. Dolk *et al.*, 1998), although no causal link has been established. In another recent example, a draft report by the United States Department of Health and Human Services on the Nant-y-Gwyddon Landfill site in Wales (*pers comm,* 2002) concluded that it was likely that off-site exposure to landfill gas had caused an increase in reporting of short-term health conditions such as respiratory ailments, severity of asthma attacks, headaches and skin rashes.

Historically, the Agency's strategy for the regulation of landfill gas has been based upon a "best practice" approach. However, this approach is limited because regulating the engineering doesn't easily allow site-specific outcomes associated with landfill gas management to be clearly demonstrated, particularly to local residents. There is also a need to increase the quantity of landfill gas that is currently collected and/or treated from many landfill sites in the UK, partly as a result of implementing the Landfill Directive and as a result of the UK Renewables Obligation Order (2002).

2. EMISSIONS BASED REGULATION

The Agency's approach to the future regulation of landfill gas is based upon a strategy of "environmental outcomes" and follows the principle of "emissions-based regulation". It takes the view that if you cannot monitor "it" you cannot manage "it". Historically, landfill gas has been a difficult emission to manage and regulate because of the variability in composition and rate of production. In addition, landfill gas is generated as an area source and limited toxicological information is available for many of the trace components present within the gas.

The strategy augments existing best practice methods with the concept of emissions-based regulation. The strategy is designed to achieve a balance in reducing global emissions without incurring the expense of increased local impact. Emission standards are introduced as minimum requirements to be met at all landfill sites, whilst requiring site-specific risk assessment to identify additional parameters or more stringent standards. The strategy provides for a step change reduction in the quantity of landfill gas that is uncontrolled and an improvement in the ability of the operator and regulator alike to directly respond to the concerns regarding landfill gas. It is recognised that many modern engineered landfills already have gas control systems that are capable of meeting the emission standards. Such systems are not off the shelf packages and they must be adequately maintained.

Over the last three years the Agency has completed a significant research programme into landfill gas emission measurement. This research culminated in the production of a number of guidance documents and tools to enable the regulator and waste industry to deliver this strategy. Figure 1 lists the guidance, tools and underlying research projects that inform the delivery of this strategy.

At a fundamental level, the Agency's strategy for emissions-based regulation requires an understanding of landfill gas through the development of a gas management plan, developed as the result of an assessment of the risks posed by the site to human health and the environment. The core of the gas management plan is the monitoring and assessment plan, which includes the monitoring of:

- landfill gas composition at source, including quantification of trace components;
- engine emissions monitoring and compliance assessment;
- enclosed flare emissions monitoring and compliance assessment;
- surface emissions monitoring and compliance assessment; and
- air quality and meteorology.

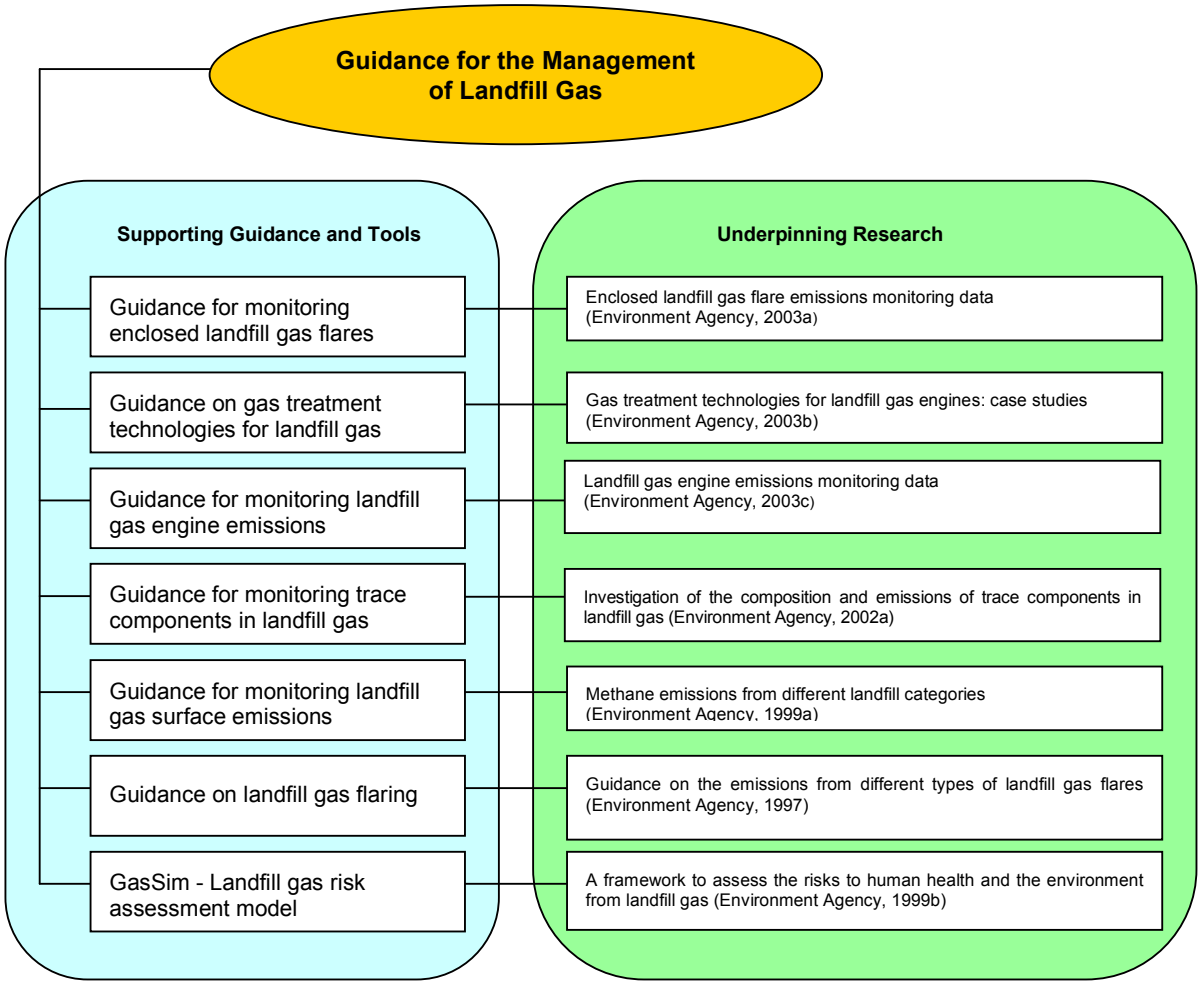

Figure 1. Relationship between the Agency's landfill gas guidance and supporting documents

3. THE MANAGEMENT OF LANDFILL GAS

The Agency guidance on landfill gas management (Environment Agency, 2002b) is an overarching document that sets out a structured approach to the management of landfill gas. This involves the assessment of the impacts, the implementation of control methods and the monitoring required to demonstrate proper performance of those controls. The gas management plan provides a framework within which the methods, procedures and actions for the control of landfill gas are provided.

The guidance also sets out a number of landfill gas management principles that the Agency expects landfills to adopt.

- A structured approach to the assessment of the risks posed by the landfill to health, environment and amenity. A tiered approach to the risk assessment should be adopted where the level of effort is proportionate to its magnitude and complexity. Tier 1 is risk screening using a basic semi-quantitative assessment. The other two tiers, identified as simple and

complex risk assessments, consist of quantitative calculations using deterministic and probablistic techniques respectively.

- All elements of the landfill gas control system are to be subject to Construction Quality Assurance, including the completion of validation reports following completion of all works.
- The establishment of a landfill gas management hierarchy (Figure 2) which encourages the utilisation of landfill gas and excludes passive venting of landfill gas.
- Maximisation of landfill gas collection, with an annual collection efficiency of 85% identified as a target.
- The provision of assessment criteria to determine when utilisation of landfill gas on site is feasible (Environment Agency, 2000). The criteria specified are (i) size of landfill (ii) geometry of landfill (iii) gas flow rate (iv) waste composition and (v) site location.

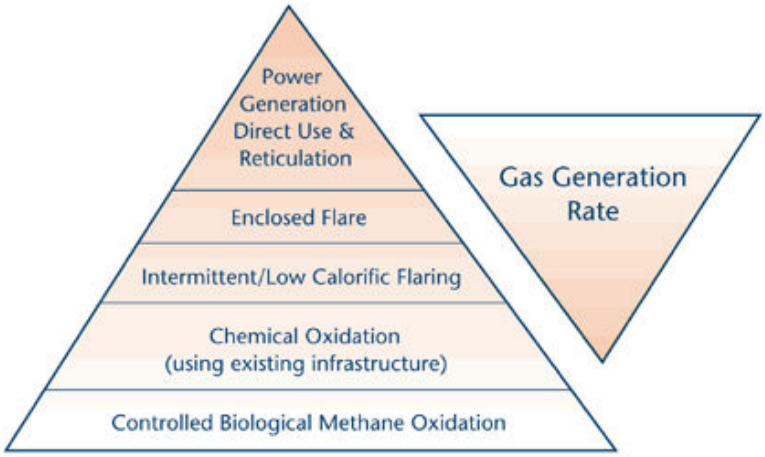

Figure 2. The Agency's landfill gas management hierarchy

4. MONITORING TRACE COMPONENTS IN LANDFILL GAS

Knowledge of the source-term trace gas composition at a landfill site provides vital information for the development of the Gas Management Plan. The Agency has developed a method for ranking the significance of individual substances based on the potential health or odour impacts of landfill gas (Environment Agency, 2002a). A database of measured concentrations was created and from this, typical UK landfill gas concentrations were derived. Separate potential odour and toxicological importance ranking scores were produced. The ranking value took into account toxicity data, odour threshold concentrations and physical properties. These values were combined with a range of measured landfill gas component concentrations, obtained from the database to derive the potential significance score. This score has been used to prioritise the typical landfill gas components relative to one another and thus identified important trace components for possible emission reduction (Table 1).

In particular this information will:

- provide an integral part of the demonstration of compliance with the objectives of the Landfill Directive;
- assist in defining the source-term gas composition for use in a site-specific risk assessment of gaseous emissions and the initial gas management plan;
- provide compositional data to the annual review and refinement of an existing gas management plan; and
- contribute to the source-term for gas generation models that estimate the emissions of landfill gas and that are used to produce the Pollution Inventory of specified substances released from a permitted site (e.g. the Agency's landfill gas risk assessment model GasSim; Environment Agency, 2002h). This has been designed to meet the requirements of Article 15(3) of the IPPC Directive to produce an inventory of principal emissions.

This Agency guidance (Environment Agency, 2002c) also recommends a suite of sampling and analytical methods that could be used to monitor these significant trace components in typical landfill gas. The guidance indicates that the priority trace components should be monitored annually as a minimum frequency, subject to site-specific circumstances e.g. significant changes to the gas management system or waste composition.

Table 1 - Priority trace components to be monitored in landfill gas

SIGNIFICANT TRACE COMPONENT	SAMPLING METHOD	ANALYTICAL METHOD
Chloroethane	Dual solid sorbent	ATD-GC-MS[1]
Chloroethene (vinyl chloride)	Dual solid sorbent	ATD-GC-MS
Benzene	Dual solid sorbent	ATD-GC-MS
2-butoxy ethanol	Dual solid sorbent	ATD-GC-MS
Arsenic (as As)	Solid sorbent	ICP-MS/AAS[2]
1,1-dichloroethane	Dual solid sorbent	ATD-GC-MS
Trichloroethene	Dual solid sorbent	ATD-GC-MS
Tetrachloromethane	Dual solid sorbent	ATD-GC-MS
Methanal (formaldehyde)	Reactive sorbent	HPLC[3]
Hydrogen sulphide	Direct on site measurement of raw gas	Hand-held instrument
1,1-dichloroethene	Dual solid sorbent	ATD-GC-MS
1,2-dichloroethene	Dual solid sorbent	ATD-GC-MS
Carbon disulphide	Dual solid sorbent	ATD-GC-MS
Methanethiol	Dual solid sorbent	ATD-GC-MS
Butyric acid	Solid sorbent	GC-FID[4]
Ethanal (acetaldehyde)	Reactive sorbent	HPLC
Ethyl butyrate	Dual solid sorbent	ATD-GC-MS
1-propanethiol	Dual solid sorbent	ATD-GC-MS
Dimethyl disulphide	Dual solid sorbent	ATD-GC-MS
Ethanethiol	Dual solid sorbent	ATD-GC-MS
1-pentene	Dual solid sorbent	ATD-GC-MS
1-butanethiol	Dual solid sorbent	ATD-GC-MS
Dimethyl sulphide	Dual solid sorbent	ATD-GC-MS
1,3-butadiene	Dual solid sorbent	ATD-GC-MS
Furan	Dual solid sorbent	ATD-GC-MS

[1] Automatic thermal desorption - gas chromatography –mass spectrometry
[2] Inductively coupled plasma mass spectrometry/atomic absorption spectrometry
[3] High pressure liquid chromatography
[4] Gas chromatography with flame ionisation detection

5. MONITORING LANDFILL GAS ENGINE EMISSIONS

To minimise the risks associated with landfill gas, it should be collected and combusted either in a landfill gas engine or enclosed flare. Currently in the UK, there are approximately 200 landfill sites generating electricity for the national grid. Landfill gas as a resource is estimated to be equivalent to around 6.75 TWh per year, around 2 % of the current UK electricity demand. However, as concerns over the potential global impacts of raw landfill gas have been addressed by combustion of the gas, this itself has led to concerns about the potential local impact from these emissions.

In response to these concerns the Agency has produced guidance (Environment Agency, 2002d), which specifies emissions standards for landfill gas spark-ignition engines. This provides a tiered approach where the generic emission standards are based on best practice, but are combined with stricter, site-specific, risk-based standards where appropriate. The emission standards are set in the light of research undertaken by both the Agency and the waste management industry. It has demonstrated that the operational emissions are achievable with a well-constructed, maintained and operated landfill gas spark-ignition engine of a particular age (Environment Agency, 2003c; Biogas Association, 2002). The proposed emission standards are given in Table 2.

The waste management industry in the UK is keen to develop a type approval system. Under this system, specific landfill gas flare and engine plant could be shown to be capable of meeting the emissions standards set by the Agency and could be demonstrated to do so reliably in the field, when operated at optimum conditions. The Agency would be supportive of a move towards this approach, as it may lead to less expensive but more frequent monitoring of landfill gas combustion equipment, in the knowledge that its emissions standards were being met.

Table 2 - Proposed emission standards for landfill gas engines and flares.

Emission Parameter	Reference Method	Enclosed Landfill Gas Flares Emission Standards (Existing flare)* (mg. m^{-3})	Enclosed Landfill Gas Flares Emission Standard (Flare commissioned after Nov. 2002)* (mg. m^{-3})	Landfill Gas Engines commissioned between January 1998 & November 2004 Emission standard mg. m^{-3}**	Landfill Gas Engines commissioned after 1 November 2004 Emission standard mg. m^{-3}**
Nitrogen Oxides (NO_x)	ISO 10849: 1996	150	150	650	500
Carbon Monoxide (CO)	ISO 12039: 2001	100	50	1500	1400
Total Volatile Organic Compounds (VOCs)	BS EN 12619:1999*** BS EN 13526:2002****	10	10	1750	1000
Non-Methane Volatile Organic Compounds (NMVOCs)	BS EN 13649: 2002	5	5	150	75

Notes:

* These limits are based on normal operating conditions and load. (Temperature - 0^{O}C (273 K), Pressure - 101.3 kPa and Oxygen - 3 % (dry gas)

** These standards are based on normal operating conditions and load. (Temperature - 0^{O}C (273 K), Pressure - 101.3 kPa and Oxygen - 5 % (dry gas))

***At sites with low total VOC concentrations

**** At sites with low to moderate total VOC concentrations.

Site-specific considerations may necessitate a stricter emission standard based on risk, either in terms of the generic emissions standard stated (e.g. a reduction of NO_x from 500 to 400mg/m^3) or in terms of additional parameters. These specific issues may include consideration of atypical raw landfill gas (e.g. elevated levels of chlorinated compounds), and assessment of dispersion modelling (e.g. a potential breach of a local air quality objective).

In addition to the numerical emission standards given in Table 2, the Agency's guidance also recommends that:

- discharges should be vertically upwards and unimpeded by cowls or any other fixture on top of the stack;
- sampling sockets should be fitted;
- crankcase emissions must be managed to minimise their release to the environment; and
- methane and the rate of flow of the inlet gas must be continually assessed.

For landfill sites where the engines are unlikely to meet the Agency's emissions standards, the Agency has produced separate guidance on the potential for pre and post combustion clean up based on a cost benefit appraisal (Environment Agency, 2002e).

6. MONITORING ENCLOSED LANDFILL GAS FLARES

Agency guidance on landfill gas flaring (Environment Agency 2002f) details combustion principles and provides indicative operating conditions required to meet emission standards. Recognition of the need to manage and regulate emissions from landfill gas flares has mirrored that of landfill gas engines.

Figure 3. Multiple-probe system for end of pipe sampling

Further Agency guidance (Environment Agency, 2002g) provides emission standards and associated monitoring protocol. The primary emission standards are a tiered requirement based on best practice and age of equipment, combined with a stricter, site-specific, risk-based standard where appropriate. The emission standards (Table 2) are based on data collected from ten operational landfill sites. This has been further informed by other data collected by the Agency

and the waste industry. In addition to the emission standards and monitoring protocols, the guidance sets out a number of additional principles/requirements:

- the phased removal of open flares from landfill sites;
- enclosed flares to include sufficient shroud to fully enclose the flame;
- installation of sample ports/ insitu probes for enclosed flares;
- sampling to be undertaken downstream of the flame; and
- sampling to consist of multi-point sampling.

7. MONITORING LANDFILL GAS SURFACE EMISSIONS

Methane emissions through the cap of the landfill need to be monitored to identify faults and then to prioritise the remediation required. Additionally, the surface emissions must be quantified to estimate the emission of this important greenhouse gas. Agency guidance on monitoring surface emissions of methane applies to those phases of a landfill with permanent or temporary caps (Environment Agency, 2003d).

The monitoring of emissions through a landfill cap has two stages (Figure 4). During the preliminary stage the concentration of methane close to the surface is measured. This aids the identification of inadequacies in the gas containment and collection system. Only when these deficiencies have been remedied and the concentration of the gas above the surface is low, is it appropriate to begin a quantitative survey of surface flux. During the regular survey stage, the flux of methane emitted through the intact cap is measured using flux boxes. These quantify the total release of methane from the capped zones and identify any zones where the gas flux exceeds the Agency's emission standards (Table 3).

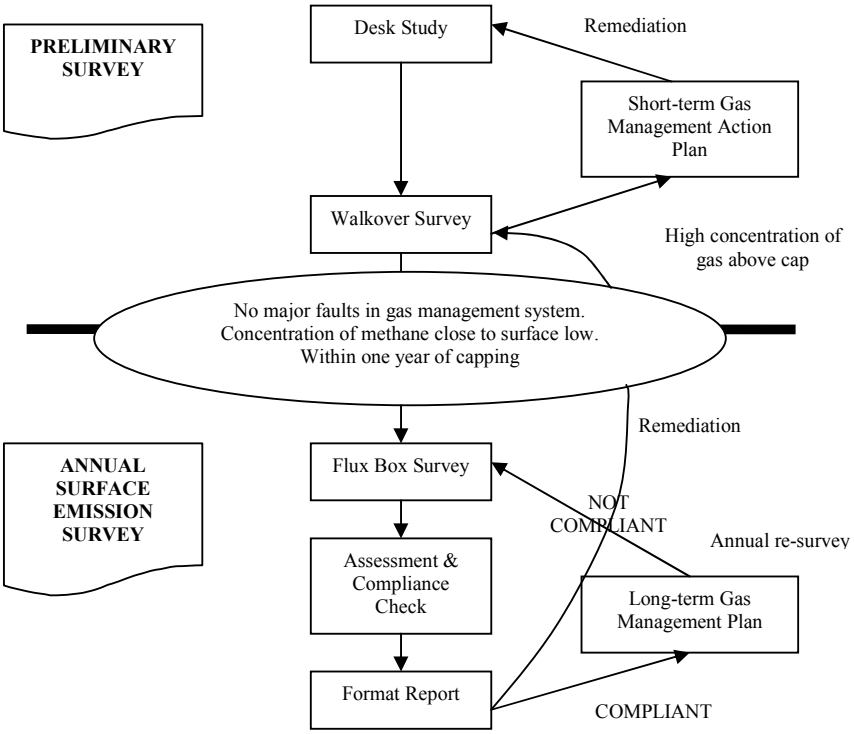

Figure 4. Phased approach to surface emissions monitoring

The preliminary stage involves a desk study and walkover survey using a Flame Ionisation Detector to scan the surface of the cap for significant concentrations of methane. This survey should be systematic and give semi-quantitative ranking of the emissions from various features. These data will be used within the gas management plan to remedy inadequacies in active control of the landfill gas. After any remedial work the cap should be resurveyed to identify further features that may need to be rectified.

The survey will not normally proceed to the regular monitoring stage until the concentration of methane in the air is:

- less than 100 ppmv immediately above the surface on the main zones of the cap; and
- less than 1000 ppmv close to any discrete feature.

The regular survey of methane emissions through the surface of an intact cap should use an array of flux boxes. The capped area is categorised into zones (an extensive area of landfill cap that is generally uniform and homogeneous) in which there may be individual features (a discrete area or installation from which emissions are higher than in the surrounding zone).

The flux boxes are sealed on the surface at a number of sampling locations within each zone and feature. It is important to ensure that the individual sampling locations must be representative of the area under investigation. The emission rate for a zone or feature is estimated by aggregating the rates measured by flux boxes at these representative monitoring points.

Field research in the UK (Environment Agency, 1999a; Environment Agency, 2001), showed that a low surface flux of methane can be achieved by following current best practice for site capping and gas abstraction systems. The Agency's proposed standards for methane gas emissions from a landfill surface are detailed in Table 3.

Table 3 - Proposed emission standards for landfill gas surface emissions

Permanently capped zone	$1x10^{-3}$ $mg.m^{-2}s^{-1}$
Temporarily capped zone	$1x10^{-1}$ $mg.m^{-2}s^{-1}$

8. CONCLUSION

The management and control of landfill gas requires a co-ordinated and holistic approach to monitoring all the main emissions of the raw gas and its combustion products. It is anticipated that the development of the Agency's strategy for emissions-based regulation of landfill gas will provide for a step change in the regulation and management of landfill gas in England and Wales. Significant improvements in landfill gas collection and emissions reduction are anticipated, which in turn should deliver reassurance to the public that the Agency and the waste industry are responding to the increased concerns associated with landfill gas.

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