Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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Web-Based Monitoring of Gas Emissions from Landfill Sites using Autonomous Sensing Platforms

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community 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, Community 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 STRIVE Programme 2007–2013

Web-Based Monitoring of Gas Emissions from Landfill Sites using Autonomous Sensing Platforms

(2010-ET-MS-10)

STRIVE Report

Prepared for the Environmental Protection Agency

by

Dublin City University

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DISCLAIMER

The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers 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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Executive Summary

Numerous initiatives that are policy driven by national, European and global agencies target the preservation of our environment, human society's health and our ecology. Ireland's *EPA 2020 Vision* outlines a mandate to prepare for the unavoidable impact of climate change, the reduction of greenhouse gas (GHG) emissions, the control of air-emissions standards, the sustainable use of resources and the holding to account of those who flout environmental laws. These strategies are echoed in the *Europe 2020: Resource-efficient Europe Flagship Initiative*, which also advocates the creation of new opportunities for economic growth and greater innovation. The promotion of research and technical development is central to each of these strategies – specifically the achievement of accurate environmental monitoring technologies that will inform policy-makers and effect change. This is described in the *EPA Strategic Plan 2013–2015* as the provision of 'high quality, targeted and timely environmental data, information and assessment to inform decision making at all levels'. Specific to landfills, the Environmental Protection Agency's (EPA) *Focus on Landfilling in Ireland* stipulates the management of landfill gas to eliminate environmental harm and public nuisance, to promote energy generation where possible and to avoid liabilities in site closure and aftercare. It was in this context that the EPA STRIVE programme granted funding for this research project on developing autonomous sensor platforms for the real-time monitoring of gases generated in landfill facilities.

Managing landfill gas is one of the crucial operations in a landfill facility, where gases (primarily methane [CH_4] and carbon dioxide [CO_2] generated from the decomposition of biodegradable waste) are extracted and combusted in a flare or preferably an engine (as biogas fuel). These gases, classified as greenhouse gases (GHGs), also pose localised hazards due to fire risk and asphyxiation, and are indicative of odorous nuisance compounds. Gas-monitoring on site is conducted to (i) ensure against gas migration into the local environment and to (ii) maintain the thorough gas extraction and optimum composition for combustion. This is becoming more relevant because of the numerous landfill closures brought by Europe-wide changes in waste-management policy. Even for landfills no longer actively receiving waste, substantial gas generation remains ongoing for years and even decades. Despite diminished financial resources and reduced manpower, management of this gas must be maintained.

Traditionally, monitoring involves taking manual measurements using expensive handheld equipment and requiring laborious travel over difficult and expansive terrain. Consequently, it is conducted relatively infrequently – typically once a month. These issues can be addressed by adopting distributed continuous monitoring systems. These low-cost remotely deployable sensor platforms offer a valuable complementary service to operators and the EPA. They enable easier adherence to their licence criteria, the prevention of expensive remediation measures and the potential boost in revenue from increasing energy production through the use of biogas. Challenges arise in terms of achieving a long-term monitoring performance in a harsh environment while maintaining accuracy, reliability and cost-effectiveness.

To meet these challenges, this project developed cost-effective autonomous sensor platforms to allow long-term continuous monitoring of gas composition (methane and carbon dioxide) and extraction pressure. The project's work represents one of the only developments of autonomous sensor technology in this space; the few other market alternatives tend to be expensive or difficult to implement for remotely deployable continuous monitoring. Beyond the development of a platform technology, the challenge was to apply this technology to the adverse environmental conditions.

The project delivered a total of 14 autonomous sensor platforms in deployments involving Irish landfill sites, a Scottish landfill site and a Brazilian wastewater treatment plant. The analysis and interpretation of acquired data, coupled with local meteorological data and on-site operational data, provided the translation from raw environmental data to meaningful conclusions that could inform decision-making. This report presents a number of case studies to illustrate this. Characteristics

of site gas dynamics could be identified; for example, it was possible to show if excessive gas concentrations in a perimeter well could be resolved by increasing the flare extraction rate for a particular well. Furthermore, the potential for quantifying methane generation potential at distributed locations within the landfill was identified in addition to diagnosing the effectiveness of the extraction network – hence aiding in field-balancing and landfill gas utilisation.

The extensive wealth of data enabled by this platform technology will help better-informed decision-making and improve operational practices in managing gas emissions. In landfills, this signifies alleviating gas migration with perimeter monitoring and enhancing flare/engine operation by evaluating gas quality at distributed locations within the gas field. While landfilling is becoming outmoded as a waste-management process, the need for continuous monitoring will be relevant for many years to come. Indeed, a number of existing facilities are considering retrofitting engines because of the significant potential for additional landfill gas utilisation being identified by Sustainable Energy Authority Ireland in 2010. Furthermore, the technology's low-cost and autonomous nature would benefit the hundreds of historical and legacy landfills if any were deemed to be problematic in terms of their environmental impact. Beyond landfills, this work pertains to other applications within the waste sector, as demonstrated by measuring emissions from wastewater treatment plant lagoons. With some further development, this technology could apply to efforts in dealing with climate change (e.g. in evaluating GHG inventories), where applications include managed peatlands (one case study is presented in this report and future efforts could also be targeted at carbon sinks/storage) and agriculture (Ireland's greatest contributor to GHGs). Further scope could also be pursued in air-quality monitoring, particularly relevant at present with 2013 being dubbed the 'Year of Air' by European leaders.

Throughout this project, the commercial prospect of this technology was affirmed with positive feedback from landfill operators, environmental regulators and private consultancies. Continual technical developments and refinements in mechanical/electronic design delivered a platform with expanded functionality and reduced price-point, thus becoming more viable for scaled-up deployments and commercial feasibility. Ultimately, this innovative development shows good promise as a high-potential commercial venture, with this work continuing under Enterprise Ireland's Commercialisation Fund.

1 Introduction

1.1 Background Context

Environmental monitoring has become increasingly significant in recent years, driven by the need for ecological sustainability and preservation of human health. Governmental agencies have stated that environmental metrics are to be considered at the heart of policy-making (EPA, 2012). Key to this is the implementation of monitoring technology capable of accurate and reliable quantitative measurements. With European leaders branding 2013 as the ‘Year of Air’ to resolve problems in pollution and air quality (Potočnik, 2011), the challenge of gas sensing is particularly relevant. This is further motivated by the need to reduce greenhouse gas (GHG) emissions as targeted in internationally derived agreements (United Nations, 1998; European Commission, 2008). This trend is set to continue with the European Commission Roadmap pointing towards an EU-wide GHG emission reduction of up to 80% by 2050 compared to 1990 levels (European Climate Foundation, 2010).

1.2 Landfill Gas

Landfill gas is comprised primarily of methane (CH_4) and carbon dioxide (CO_2) as produced from the decomposition of biodegradable waste in an anaerobic environment (Lou and Nair, 2009). Both of these gas types are classified as GHGs, with CH_4 being especially potent having a global warming potential 20 times greater than CO_2 (Galle *et al.*, 2001). GHG emissions are subject to international agreements and ongoing negotiation on reductions of emissions to the atmosphere. Ireland is party to these processes and has made a commitment to significant reductions in emissions by 2020. Furthermore, CH_4 can be, depending on other gas concentrations, explosive when present within in the 5–15% v/v concentration range in air and CO_2, being heavier than air, is an asphyxiation hazard in nearby enclosed dwellings (Christophersen and Kjeldsen, 2000). Other toxic gases can also be present at trace levels, including odorous gases that are a nuisance to local residents. Therefore, the emission of landfill gas can have critical implications on both a global and local scale.

In order to comply with environmental legislation, gas management is a crucial aspect of landfill operation (EPA, 2003). All landfill gases, as far as is practicable, should be collected and thermally oxidised (i.e. burned) to mitigate GHG emissions and localised pollution (e.g. odour, vegetation decay, ground-water contamination). Modern landfill facilities are constructed with a gas-extraction system consisting of a network of pipes running through the waste body, various stages of which are shown in Fig. 1.1. The extraction network connects perforated wells bored into the waste cells, where an

(a) (b) (c)

Figure 1.1. Stages of a landfill’s gas-extraction network: (a) borehole wells embedded in waste cells, (b) manifolds that connect wells, (c) the flare that the gas is drawn towards for thermal oxidation.

applied negative pressure draws the gases towards a flare or engine (EPA, 2000). The composition and flow-rate of the gas mix must be carefully controlled for effective combustion by means of the adjustment of flow from different waste cells; this operation is called 'field-balancing'. For consistently high methane concentrations (typically exceeding 45% v/v), the gas can be used as fuel to run engines for electricity generation (Themelis and Ulloa, 2007), representing a financial advantage in recuperating costs by exporting electricity to the national grid; otherwise, the gas must be burned in a flare. To ensure thorough effectiveness of the extraction system, gas concentration levels are monitored at isolated borehole wells outside of the waste cells area, typically located around the site perimeter. This is to ensure against gas escaping from the collection system's zone of extraction and migrating into the surrounding soil. Gas concentration levels at these locations are subjected to trigger limits of 1.0% and 1.5% v/v for CH_4 and CO_2, respectively (EPA, 2004).

A number of complex factors can influence the rate of gas generation, including the type of waste material, the waste maturity, the effectiveness of gas extraction and the degree of gas containment within the landfill (Environment Agency, 2004; Lohila *et al.*, 2007). Additionally, meteorological dependencies can have a substantial effect on landfill gas behaviour (Cziepel *et al.*, 2003; Barry *et al.*, 2003; Scharff and Jacobs, 2006). Rainfall can reduce the permeability of the soil and inhibit surface emission, thus potentially increasing gas migration into the surrounding ground. Furthermore, prolonged rain can change the moisture content of the waste body, thus affecting the microbial methanogenic activity. A reduction in barometric pressure can induce a differential pressure between the upper and lower layers of the waste body, with this pressure gradient inducing a flux that results in an increase in gas migration. Tidal activity may influence gas migration in coastal landfill sites where rising tide heights may also induce a gas flux in the waste body. Given that meteorological effects are linked (i.e., a decrease in barometric pressure is often accompanied by rainfall), the resulting effect of weather on gas migration can be complex and difficult to define.

Current practices for monitoring landfill gas predominantly involve manual measurements, typically using a portable sensing device such as the GA5000 device (Geotechnical Instruments Ltd, UK). However, the procedure is labour intensive, requiring travel over difficult terrain and the manual recording of gas-concentration readings at a range of sampling locations. As a result, measurements have been taken at extended intervals – typically once a month during the operational stages of the landfill. While the need for a more continuous monitoring system has been recognised (EA, 2010), the enabling technologies are yet to proliferate.

1.3 Motivation for Autonomous Gas Monitoring

Autonomous monitoring systems and wireless sensor networks (WSNs) are gaining increasing attention with regard to environmental monitoring. A wealth of environmental parameters can be measured because of the extended temporal and spatial resolution provided by distributed sensing nodes (Diamond, 2008). The emergence of medium and large-scale sensor networks has been evident in recent years; the first urban network for monitoring carbon dioxide was announced in Oakland, USA in 2012 (Cohen *et al.*, 2012), while air quality sensor networks have been deployed in urban centres in the UK since 2011 (Envirowatch, 2012). However, while WSNs are gaining more attention for use in environmental monitoring, they have yet to proliferate to their full potential. The principle obstacles to this proliferation are high costs and technological dependability. The extrapolation of current sensor and platform technology costs for scaled-up deployments is, for the most part, not economically viable. Furthermore, the deployment of a distributed network of sensors presents a challenge in terms of configuration, maintenance and the multiplication of technical issues.

The development of autonomous sensing platforms is ideally suited to the landfill application, given that a typical landfill gas-extraction system covers an expansive area of ground. Moreover, the nature of this terrain can be difficult to traverse, implying that remote sensors deployed *in situ* are better than the current infrequent manual sampling routines. Gas-composition monitoring would indicate the gas-generation potential of different waste cells as well as identifying fugitive gas emissions. Measurement of the extraction pressure could be used as a diagnostic tool to identify loss in flow caused by blockage or leakage. The distribution of autonomous sensing platforms in a networked configuration would enable more informed and precise field-balancing and gas management which, in turn, represents cost savings by promoting landfill gas utilisation and avoiding engine/flare downtime.

The substantial research challenge is to attain reliable and accurate sensing performance without incurring prohibitive expense. Typically, cost and performance are inherently linked – cheaper components fail to deliver adequate resolution, accuracy or in-calibration duration. Traditionally, long-term reliability is achievable only at a substantial cost. This is reflected in the prices of the current market leader Geotech Instruments, where their newest portable system (GA5000) retails for €6,000–10,000 and their fixed remote system (Automated Extraction Monitoring System, AEMS) costs in the region of €20,000 (Technology from Ideas, 2012). However, the price of electronics and sensors is continuously decreasing, driven by the ever-growing market of consumer technologies and optimised manufacturing processes. The integration of such technology into deployable platforms with remote telecommunications can fulfil the demand in industry for low-cost long-term sensing. However, market acceptance is only achievable if the sensing performance is validated and proven to work.

This project represents a progression of work from previous EPA STRIVE funding (Kiernan *et al.*, 2010). That work resulted in a prototype GEN1 system (Beirne *et al.*, 2010); proof of concept was demonstrated but it was not yet at a viable price-point that permitted multiple systems to be deployed. The second-generation GEN2 gas-monitoring system was subsequently designed and a single unit was fabricated in 2010. On the basis of the interest generated by these systems, this current project was granted funding to expand the number of deployments and to further develop the systems towards achieving a commercially viable technology.

1.4 Project Objectives

The objectives as per the original proposal were to:

1. Optimise the unit design for scale-up, targeting a 30% component cost savings in the next generation and achieve deployment times of six to twelve months maintenance free;
2. Optimise the power management of the unit to include energy-scavenging capabilities: for example, through coupling with a solar panel;
3. Build and laboratory validate 10 monitoring units, capable of sampling, measuring and communicating data in near real-time (five GEN2, five GEN3);
4. Deploy five units (GEN2) for at least nine months and the remaining five units (GEN3) for two to three months each at locations identified by the OEE/EPA;
5. Customise the communications, data-management and reporting modules for different sites with differing infrastructure;
6. Deploy pressure sensors at one or more locations, and to integrate data from these devices into the remote monitoring system in order to manage gas-extraction systems at these sites more effectively.

1.4.1 Objective 1

Objective 1 has been completed. Refinement of the GEN2 unit design has led to the construction of nine GEN2 systems. Deployment times of up to 12 months have been demonstrated with relatively few maintenance requirements. Optimisation of system hardware and software with a focus on reducing component cost, increasing functionality and facilitating more economical fabrication, have resulted in the GEN3 system at a 30% component cost savings. Field trial validation of the GEN3 systems has been carried out over a three-month period, where the potential for scaled-up deployments and commercialisation has been demonstrated.

1.4.2 Objective 2

Objective 2 has been addressed to the full extent enabled by GEN2 hardware. Optimisation of the microcontroller code operation has resulted in the system attaining a 10-week battery life. The successful implementation of solar chargers extends battery life indefinitely – allowing complete autonomous operation. In cases where a solar panel is not feasible (e.g. vandalism concerns), an auxiliary battery pack has been developed to extend the deployment duration. For GEN3, new microcontroller circuitry programmed with low power sleep routines has enabled a battery life of at least 10 weeks, with indefinite battery sustenance provided by solar charging.

1.4.3 Objective 3

Objective 3 was completed and indeed exceeded in terms of proposed quantities. Eight GEN2 platforms were constructed and validated both in the laboratory and in the field during the project duration. Additionally, five GEN3 systems have been built and laboratory validated.

1.4.4 Objective 4

Objective 4 has been concluded for nine GEN2 systems: five units at Kyletalesha landfill (twelve months), two units in Raheenmore bog (six months) and one unit in Auchinlea landfill in Scotland (two months). Furthermore, one of the Raheenmore units had prior deployments in Balleally landfill (eight months) and Dundalk landfill (10 months). In addition, one GEN2 unit was deployed in a wastewater treatment plant in São Paulo, Brazil (two weeks to date). Five GEN3 systems have been deployed in Ballydonagh landfill (two months to date). This deployment is being continued beyond the duration of this funded project into the next phase of commercialisation funding.

1.4.5 Objective 5

Objective 5 was continually addressed during system development: advancing from wired computer interfacing (GEN2) to wireless communications (GEN3); optimising transmission of compressed datasets by long-range telemetry, thus enabling a high temporal resolution of data without incurring high mobile network costs. Data management has been optimised by triplicate back-up: (i) onboard system memory (GEN3), (ii) on a Dublin City University (DCU) local server and (iii) on the cloud-based Internet server. Web-based access and visualisation of data was enabled via an Internet portal, where data can be accessed from any web browser, displayed in graphical form and filtered according to system, date or threshold levels.

1.4.6 Objective 6

Objective 6 was initially conducted in parallel with Objective 3, where two pressure-specific platforms successfully operated in Kyletalesha landfill since December 2011, acquiring approximately 33,000 readings to date. Subsequent development has resulted in the integration of both sensor types within the GEN3 systems, hence having the capacity to measure both pressure and gas composition within the one platform at independent sampling rates.

2 Technical Development

2.1 GEN2 System Development

The initial stages of this project involved the refinement of the GEN2 gas-monitoring system which was designed under previous EPA funding in 2010.

2.1.1 GEN2 Refinement

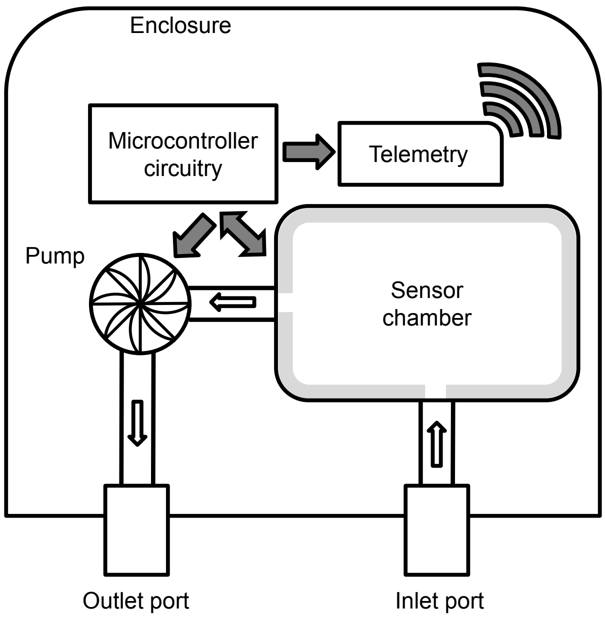
The GEN2 system assembly is shown in Fig. 2.1. Powered independently by battery, the monitoring operation was controlled by a custom-programmed microcontroller circuitry. Gas was extracted from the landfill well/pipe by an internal pump via quick-release sampling ports, whereupon gas concentration was measured by infrared gas sensors. All sample gas was recirculated back to the landfill such that no emissions were vented to atmosphere. Sampling was typically conducted at six- hour intervals. The data acquired from the sensors was transmitted via GSM to the DCU base-station in Dublin. Components were held together by a custom-designed sheet metal frame. The entire assembly was housed within a robust IP68-rated enclosure suitable for long-term outdoor deployment.

A number of refinements were implemented to the original GEN2 design with a focus on reducing costs, simplifying fabrication and increasing functionality. These refinements included the re-specification of the pump, modification of the sample chamber design, development of a pressure-sensing platform and the incorporation of solar-charging to sustain battery life.

The original pump was a component of a commercial air sampler device and as such was relatively expensive. A range of pumps was tested for their gas-flow capabilities in the lab, whereupon a lower-cost pump was selected based on achieving an acceptable flow-rate (approximately 0.6 L/min).

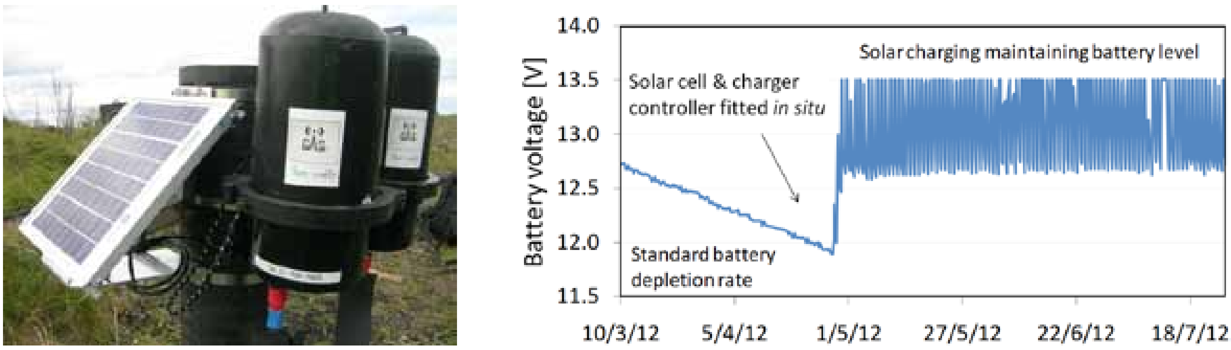
The sample chamber – the component housing the sensors to be exposed to the sample – was originally a micro-milled assembly in the initial GEN2 design. This fabrication process was quite labour intensive, particularly when considering scaled-up production. The chamber was initially redesigned for fabrication by lathe and milling-machine (in-house in DCU workshop), where the gas sensors were sealed with

(a)



(b)

Figure 2.1. GEN2 gas-monitoring platform: (a) systems as deployed, (b) internal schematic with components labelled.



(a) (b)

Figure 2.2. Solar-charging: (a) gas- and pressure-monitoring platforms as deployed with solar panels, (b) power levels during operation.

an internal O-ring and silicone sealant. This design still required significant labour time and so was ultimately replaced with a customised version of a commercially available pneumatic component which provided a tight tolerance fit for the gas sensors. The adaptation of this off-the-shelf component for the sample chamber enabled quicker assembly of multiple systems.

A version of the GEN2 platform was developed for sensing extraction pressure for in-line monitoring with the landfill extraction network. The GEN2 pressure system was an advancement of a GEN1 prototype (Fay *et al.*, 2012). At this stage of the development, the GEN2 pressure system was in a separate unit to the gas-sensing platform; the pair of systems can be seen in Fig. 1.1. In this case, the pressure sensor was connected directly to the inlet port for sampling in-line pressure.

The final incremental refinement of the GEN2 system involved implementing solar chargers to sustain battery duration (ten weeks on battery alone) and hence avoid system downtime and data loss. Photovoltaic panels with charge controllers were fitted to the gas-monitoring systems (solar-charging deemed unnecessary for pressure systems due to lower power consumption with no pump or power-intensive infrared [IR] gas sensors). As can be seen in Fig. 2.2(a), solar charging was found to acceptably sustain the battery level of the system even during dark winter months. This indicated an indefinite deployment period in terms of power requirements as these deployments were running throughout December to February. Note the 13.5V upper limit in Fig. 2.2(b) is not representative of the actual battery voltage but instead is the maxed-out voltage potential across the solar panel during daylight hours. A truer reading of the battery level is the night-time values – the daily minima in the latter stages of Fig. 2.2(b).

2.1.2 GEN2 Drawbacks

Overall, the GEN2 monitoring system exhibited a good performance, operating successfully under remote deployment for a total of 2,744 days, acquiring over 7,000 valid gas readings and over 33,000 valid pressure measurements. As with any prototype technological device, it was not without its drawbacks.

Firstly, the component cost remained relatively high, particularly because of the electronic components (microcontroller circuitry and telemetry module); these accounted for 35% of the total component cost. In addition, the microcontroller circuitry comprised 141 individual components that needed to be soldered manually, representing substantial labour time (or expense if outsourced).

Secondly, the ease of use of the system could be improved. The reprogramming of the microcontroller required a specialised and relatively expensive piece of hardware (approximately €200). Furthermore, the wired connection between the GEN2 platform and computer (e.g. for calibrating, debugging or initiating monitoring operation) was awkward for field work due to inaccessibility (difficulty, for example, in positioning the laptop within reach of the deployed system on site) and environmental exposure (open enclosure exposing sensitive electronics to rain and dirt).

Finally, some electronic components had become obsolete and discontinued. This was particularly problematic for the system's on-board flash memory integrated chips (ICs). While a range of alternative flash ICs was trialled with the microcontroller code modified for compatibility, a suitable replacement was not found. As a result, long-term data logging was not available in the GEN2 platform.

2.2 GEN3 System Development

The development of the GEN3 landfill monitoring system was motivated by a need to reduce component costs, to improve the system's fabrication process and to implement lessons learned from the preceding GEN2 deployments. The technical development of the GEN3 mainly involved the introduction of new electronics (microcontroller and GSM circuitry) and control programming. This re-specification of the electronics hardware resulted in a 30% reduction in overall component costs. Furthermore, a substantial reduction in labour costs was attained due to easier fabrication with substantially fewer soldered components on GEN3 compared to GEN2.

The redesign of the circuitry also solved the problem of the obsolescence of circuitry components (as had been the case with the GEN2 system). In addition to this, the re-specification enabled additional functionality to be achieved. Therefore, numerous design features of the GEN3 superseded those of the GEN2 systems. The implementation of new microcontroller hardware and custom-written control program allowed for the integration of both gas sensors and pressure sensors, thus enabling measurement of both parameters within the one platform. Programming of this microcontroller was simplified by using a standard USB connection rather than requiring separate hardware. On-board non-volatile memory chips on the system enabled the logging of acquired data with sufficient storage capacity for 12 months. A more cost-effective telemetry module was implemented for long-range wireless communications, while short-range communications for computer interfacing was enabled by an integrated radio transceiver. Despite being powered by a more compact battery, the battery longevity was maintained at 10 weeks' deployment. All components were arranged in a compact configuration in a redesigned sheet metal frame which was housed within a rugged environmental-proof enclosure. The smaller weight and dimensions of the GEN3, as demonstrated in Fig. 2.3, facilitated easier handling, installation and transit. Setting up the deployment on site also became more user friendly with independently powered time-keeping and options for automated initiation on power-up.

Figure 2.3. GEN3 monitoring systems as deployed in-line with the landfill gas-extraction pipework.

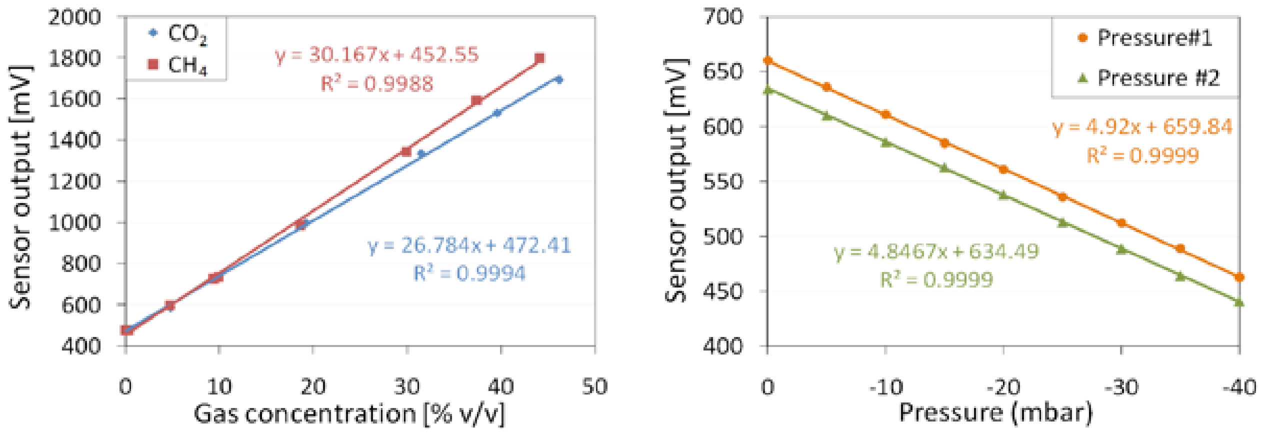


Figure 2.4. Linear calibration response for gas and pressure sensors.

2.3 Calibration and Performance of the Sensors

The performance and long-term accuracy of the sensors are crucially important to validate the remotely deployable monitoring platforms. To this end, reliable sensors were selected and a rigorous calibration procedure was carried out before and after deployment. Furthermore, numerous spot checks are conducted on site with the Geotech GA2000 Plus analyser and comparisons were made with the on site SCADA (System Control And Data Analysis flare software) where applicable.

Infrared CH_4 and CO_2 gas sensors were employed for gas-concentration monitoring. Their sensing capability is based on the IR absorbance characteristics of the target gas. The optical nature of IR sensors circumvents issues experienced by sensor types based on a chemically active surface, where the exposed surface can be coated (biofouling) or poisoned, thus resulting in drift or loss of sensitivity. These sensors contained internal circuitry to provide a linear output with temperature compensation. The pressure sensor was selected on the basis of good performance in the author's previous work (Collins, 2011). This sensor type also contained internal circuitry to provide an amplified linear output.

Before deployment, all sensor platforms were calibrated relative to standardised equipment as displayed in Fig. 2.4. The IR gas sensors were calibrated against a reference calibration gas (50/50 CO_2/CH_4 mixture, Air Liquide). Using nitrogen as a diluent, the percentage gas concentration was varied using mass flow controllers (Mass-Stream D-6300, M+W Instruments) to achieve incremental steps in the sensing range of the IR sensors (0–20 %v/v for perimeter well deployments, 0–100 %v/v for deployments in-line with extraction system). A Geotech GA2000 Plus analyser was used to verify the concentrations of the gas dilutions. The pressure sensor was calibrated under vacuum (typically 0 to -100 mbar) against a standard digital pressure gauge (Digitron PM-10).

In order to evaluate the long-term accuracy of the sensors, the calibration procedure was repeated on all systems when retrieved from deployment. An example of this is shown in Fig. 2.5, with the sensors in question belonging to a GEN1 system retrieved from deployment after 13 months. Post-deployment baseline drifts of approximately 4% and 7% deviation from the original calibration were found for the CO_2 and CH_4 sensors, respectively. Considering the long duration of the deployments, the IR sensors proved to be acceptably accurate and reliable, thus confirming their suitability for autonomous gas-monitoring platforms.

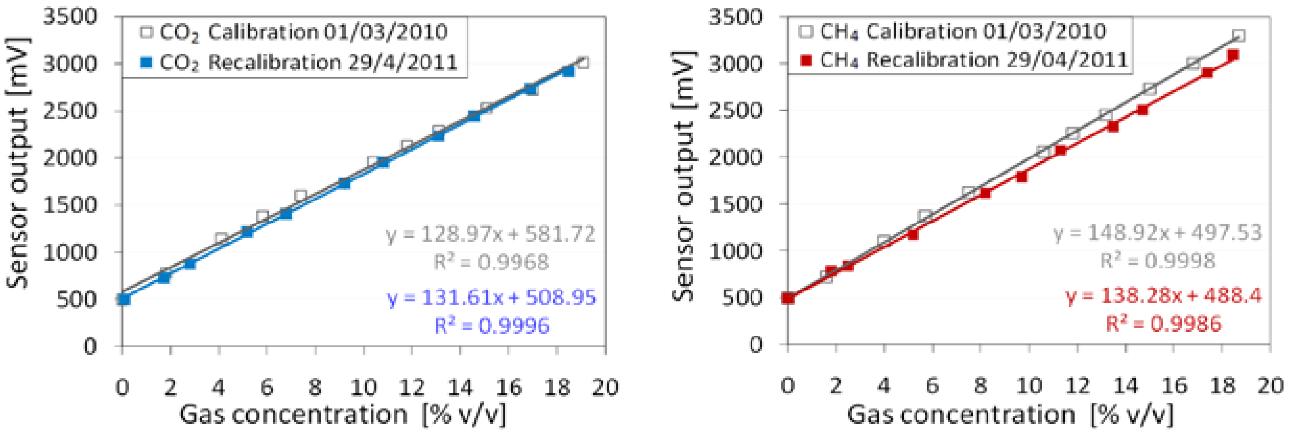


Figure 2.5. Comparison of calibration data for IR gas sensors after 13-month deployment.

2.4 Data Access and Visualisation

Data from the remotely deployed systems were received at a base-station in DCU, whereupon the transmissions were decoded to segment sample date, time, CH_4, CO_2, pressure readings and battery level. By using the transmitter phone number as an identifier, this information was parsed into a local database via MySQL software. Additionally, averaged data was uploaded onto an online portal for web-based access.

Three options were explored for web-based data access and visualisation. The first option was the kspace portal, a past collaborative development with the DCU computing department (Fig. 2.6(a)), which was used for the GEN1 proof-of-concept deployments

Figure 2.6. Options for web-based accessibility and visualisation of data: (a) kspace portal, (b) CLARITY portal and (c) Google Drive data hosting and graph display.

before the current project. This web page featured a secure login, a simple graph display and data download. However, this site was designed specifically for perimeter well monitoring and so could not support the display of negative pressure values. The second option was the CLARITY portal (Fig. 2.6(b)), which was developed for environmental and electricity monitoring across a range of CLARITY projects. However, this portal was rejected because of lack of password protection. The third option was to use Google Drive graphing tools. This option was implemented as it delivered intuitive operation, customisable display and data download, simple filtering of data for viewing certain dates/threshold breaches, secure login and the ability to annotate specific data-points for event identification. Furthermore, this service provided reliable cloud-based data back-up and faster access speed via Google servers.

3 Field Validation Deployments

A total of 14 autonomous monitoring platforms (9 x GEN2, 5 x GEN3) were deployed on seven separate locations worldwide over the course of this project as shown in Fig. 3.1. Each deployment is discussed in the following sections and, where available, analysed with respect to on-site SCADA measurements (provided by landfill operators) and local weather conditions (derived from local met stations). In some cases, the analysis is quantified by means of correlation coefficients ("*correl*"), where values approaching ±1.0 indicate a stronger positive or negative correlation.

3.1 Perimeter Well-monitoring (GEN2, Balleally Landfill)

3.1.1 Aim of Deployment

To monitor and to help identify contributory factors leading to excessive gas levels in a perimeter borehole well.

3.1.2 Location and Configuration

A single GEN2 gas-monitoring system deployed on the GA5 perimeter borehole well on Balleally landfill facility. The system extracted the sample from a 1 m depth within the borehole well and returned the sample to the top of the headspace.

3.1.3 Duration

Eight-month deployment, February 2011 to October 2011, comprised of 881 gas readings.

3.1.4 Discussion and Analysis

To observe the full monitoring duration as a whole, as shown in Fig. 3.2(b), it is evident that the high gas concentration levels (> 50% v/v CH_4) disappeared towards the latter half of monitoring. Similar behaviour, where substantially high levels of landfill gas had appeared and subsequently disappeared, had been noted by regulatory checks on this borehole well in

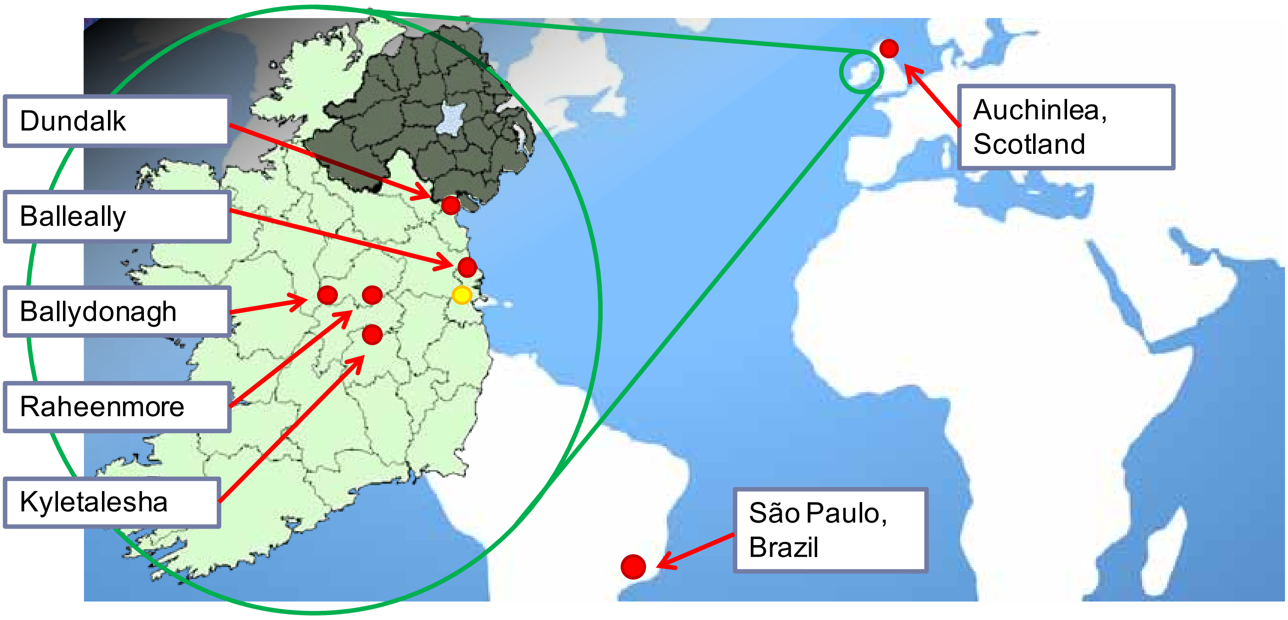


Figure 3.1. Deployment locations of Dublin City University (DCU) gas-monitoring systems throughout project duration.

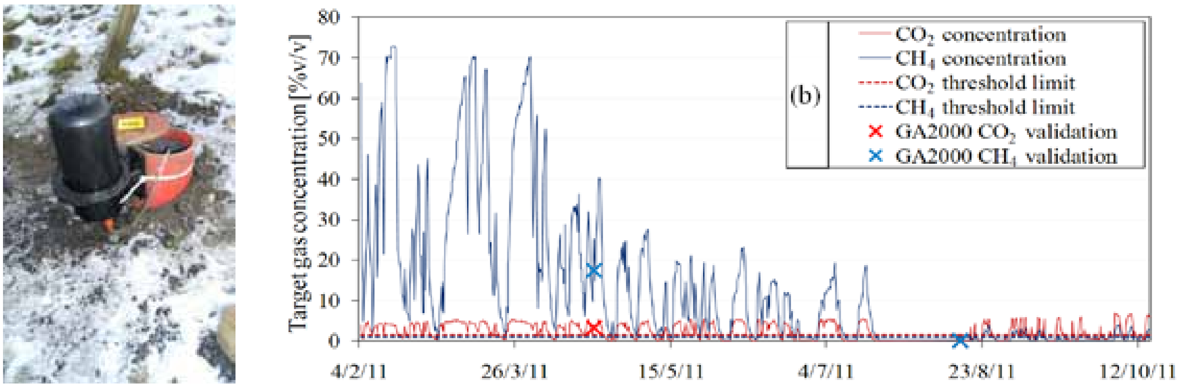
(a) 

Figure 3.2. GEN2 gas-monitoring system (a) as deployed on borehole well, (b) full deployment dataset.

previous years (Fingal County Council, 2010). This led to this study being commissioned on behalf of the EPA, with a particular interest in identifying the environmental conditions that influence landfill gas fluctuations.

Given the extensive time duration of this analysis, a one-month subset of the data is displayed in Fig. 3.3. Over the dataset duration, CO_2 does not exceed much over 5% v/v while CH_4 reaches as high as 70% v/v.

Both CH_4 and CO_2 levels had a highly fluctuant nature: rapid changes in concentration were observed. In general, both gases were approximately synchronised, that is, they rose and fell together at similar times. This suggested that the variation in gas level was related to the flare extraction-rate, that the change in extraction rate reduced the volume of gas migration, thus decreasing both components of CO_2 and CH_4 simultaneously. Ideally, this should not be the case; the borehole well should be isolated from the extraction system, where the gas content represents that which was not captured in the extraction system to be processed by the flare/engine. This is evident for the most part – for the majority of events, there is no correlation between borehole gases levels and SCADA CH_4. However, on occasions such as events 'B' and 'C' shown in Fig. 3.3, a link between borehole

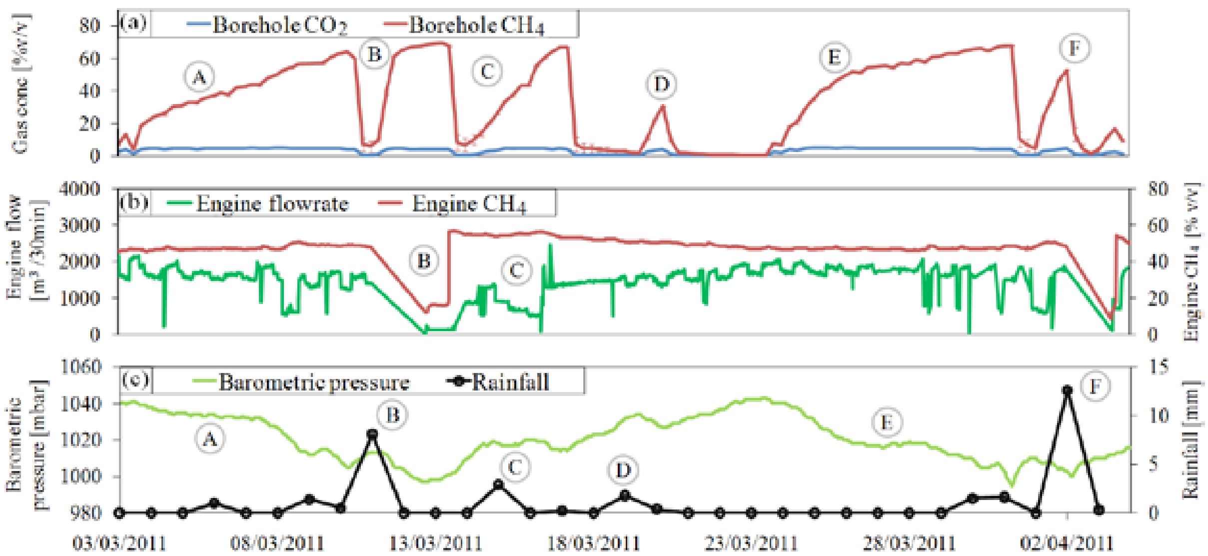


Figure 3.3. Comparative analysis of gas activity with respect to on-site and environmental conditions: (a) borehole CH_4 and CO_2 gas levels, (b) CH_4 and flow-rate at engine inlet, (c) atmospheric pressure and rainfall as measured on site. Specific events are annotated A–F.

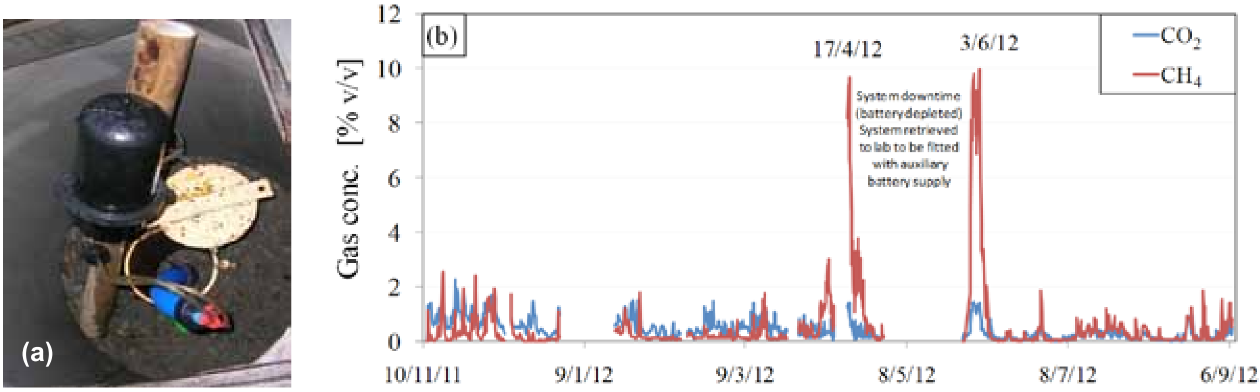


Figure 3.4. Inline well monitoring in borehole G6 in Dundalk landfill facility: (a) GEN2 system as deployed on borehole well, (b) gas levels for the 10-month deployment.

gases and abrupt changes in SCADA flow-rate becomes apparent: two rapid increases in SCADA flow-rate coincide with abrupt reductions in borehole gases (*correl* = -0.47). It is a reasonable assumption that the substantial increase in extraction reduces the overall volume of gas in the waste body, the flux of which could result in a reduction of gas in the borehole well. By the same reasoning, the low levels of SCADA flow-rate during event 'C' are conducive to increased borehole gas levels given that less extraction implies more gas is residing in the waste body.

An apparent link between borehole gas and meteorological conditions (Loftus, 2011; Met Éireann, 2011) could be seen. Strong correlations could not be expected given the complex interaction between weather and landfill structure (e.g. water run-off, soil soakage and permeability, water table height, etc.). There appeared to be an inverse relationship between barometric pressure and borehole gas levels, as evident in events 'A' and 'E' where gas levels behaved inversely with respect to barometric pressure (*correl* = -0.72). However, this was not always consistent. For example, increases in borehole gases in events 'C' and 'D' were observed during increasing barometric pressure although this may have been compromised by rainfall occurring at the time. Borehole gas levels tended to increase during or shortly after heavy rainfall (see events 'B', 'C', 'D' and 'F').

In summary, two significant factors appeared to contribute to the gas behaviour in the perimeter borehole well in question. Firstly, an abrupt increase in extraction flow-rate tended to reduce borehole well gas levels, thus suggesting that gas migration was occurring in the vicinity of the well. Secondly, an increase in borehole gas levels tended to be associated with a rapid decrease in barometric pressure and/or heavy rainfall.

3.2 In-line Well-monitoring (GEN2, Dundalk Landfill)

3.2.1 Aim of Deployment

To investigate the contribution (if any) of tidal effects on gas concentration levels in an in-line well in Dundalk landfill, given that this site was adjacent to an estuary.

3.2.2 Location and Configuration

A single GEN2 system, formerly deployed at Balleally landfill (see Section 3.1), was refitted and calibrated with new 0–20% range sensors. The system was fitted to the G6 in-line well in the Dundalk landfill facility, a disused landfill with a single flare in operation. This well was enclosed by a concrete surrounding and padlocked manhole cover as security was forewarned as being an issue. The sampling rate was increased to a three-hour period at the request of EPA officer Eamonn Merriman in order to increase the time resolution of the acquired data.

3.2.3 Duration

Ten-month deployment, November 2011 to September 2012, 1119 valid readings.

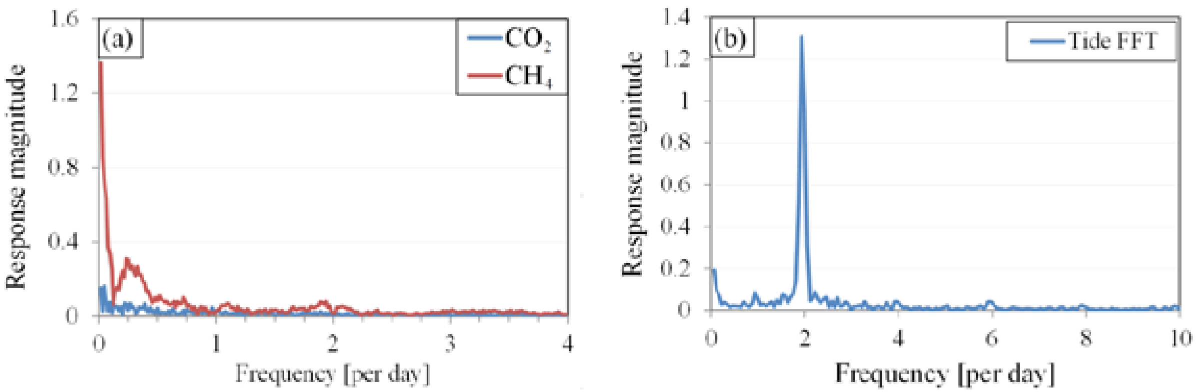


Figure 3.5. Frequency analysis of: (a) borehole gas levels and (b) tidal height.

3.2.4 Discussion and Analysis

Gas levels remained relatively low (<3% v/v) for the majority of the deployment period with two notable exceptions in April and June (see Fig. 3.4(b)). On these occasions, CH_4 levels were observed to increase abruptly to approximately 10% v/v, midway within the explosive range. Unfortunately, a blackspot in acquired data coincided with this period of time due to battery depletion; an auxiliary battery pack was developed and installed thereafter (a solar panel was not a viable option given vandalism concerns on site). Discussions with site personnel and analysis of SCADA data determined that the increases in gas levels were associated to flare downtime due to maintenance (Wilson, 2012). Lesser magnitude peaks in the CH_4 levels on 9 April and 6 June were also found to correspond to abrupt changes in extraction flow-rate of the flare. The landfill management was surprised at the extent of gas concentrations accumulating in the well when the flare was not under normal operation, an insight into the site's gas behaviour that had previously been unknown.

Outside of these extreme occurrences, the data was analysed with respect to tidal height and weather conditions. Frequency analysis of the gas data, as shown in Fig. 3.5(a), showed no dominant frequencies in the CO_2 data and a minor cluster of frequencies in the region of 0.25 (representing the peaks in CH_4 recurring every three to five days as seen in the early stages of data in Fig. 3.4). In contrast, equivalent frequency analysis of local tidal data in Fig. 3.5(b) shows a peak at 1.93, indicating just under two tides per day (as expected, typically two tides every 25 hours). Therefore, there were no periodic frequencies in the gas data associated with tidal frequencies. The lack of association between the gas levels and tidal conditions was further reinforced by a negligibly low correlation being calculated (*correl* = 0.04). Analysis with respect to data from local weather station (Carrickmacross, 2012) revealed slight correlations between gas behaviour and atmospheric pressure (*correl* = -0.26) and rainfall (*correl* = 0.23).

In summary, there was no reasonable association between tidal conditions and gas behaviour on this particular site, although atmospheric pressure and rainfall magnitudes were identified as being minor contributory factors to gas fluctuations in the well. Furthermore, abrupt changes to the flare operation could manifest in wells further down along the extraction system as evidenced from substantial peaks in monitored data.

3.3 Peatlands Background Levels (2x GEN2, Raheenmore Bog)

3.3.1 Aim of Deployment

To determine background levels of CH_4 and CO_2 gas generation in virgin boglands (i.e. unaffected by peat harvesting or landfilling). With peatlands covering approximately 15% of the land area of the Republic of Ireland (Bórd na Mona, 2013) and a number of landfills being constructed on or adjacent to peatlands (e.g. Kyletalesha, Marlinstown), this study is to quantify the inherent generation of CH_4 and CO_2 gases due to natural vegetation decomposition rather than landfilling activities.

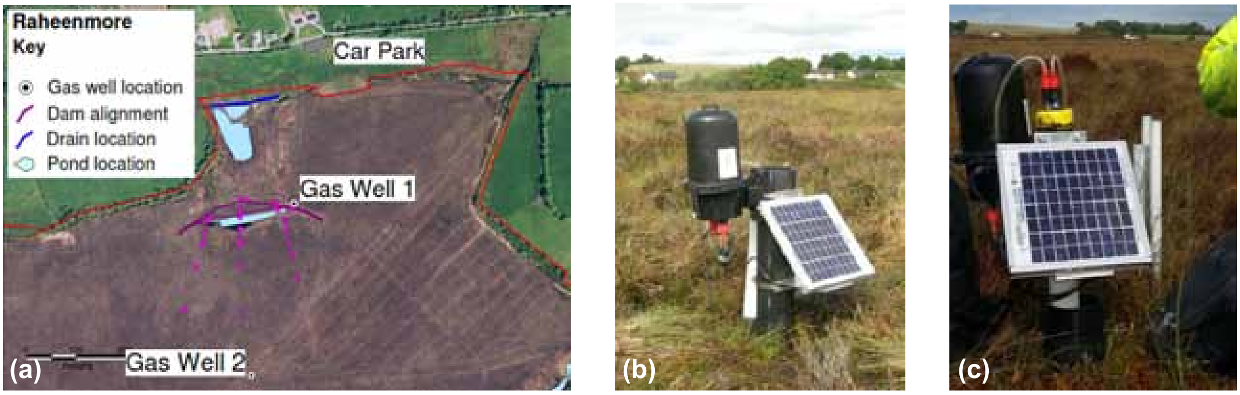


Figure 3.6. Peatlands deployment: (a) Raheenmore bog map, GEN2 systems deployed at (b) well #1 near bog perimeter and (c) well #2 in bog interior.

3.3.2 Location and Configuration

Two solar-charged GEN2 gas-monitoring systems were deployed on Raheenmore bog, an area of preserved peatlands outside Tyrrellspass, Co. Westmeath. Gas wells were installed in two locations, each comprising an unlined pipe sunk approximately 1.5 m below ground level with perforations for the lower 1 m. Their locations are shown in Fig. 3.6(a). The monitoring systems sampled from 1 m depth of the well, with a sample being recycled back into the enclosed headspace to be consistent with previous deployments on landfill borehole wells.

3.3.3 Duration

System #1 (new-build) on well #1: installed July 2012; 218 days with 848 valid readings. System #2 (formerly deployed in Dundalk): installed October 2012; 149 days with 544 valid readings.

3.3.4 Discussion and Analysis

As Fig. 3.7 shows, appreciable levels of gas, particularly CO_2, were observed in both wells. Gas behaviour was more fluctuant in well #1, with varying levels of CO_2 and no presence of CH_4 in this location. Higher absolute levels of both gases were observed in well #2 although with a lesser extent of variation in gas concentrations. The disparity in gas behaviours between the two wells may be attributed to the difference between the two well locations. Well #1 was near the edge of the bog and hence less stabilised in terms of moisture content (this was indicated visually in visits to the site, where the surrounding ground was intermittently flooded and dry). Conversely, well #2 in the bog interior appeared to be at a consistent level of ground moisture content at all times. A logical observation was that there would be less likelihood of drainage due to its location being almost 1 km deep into the bog area.

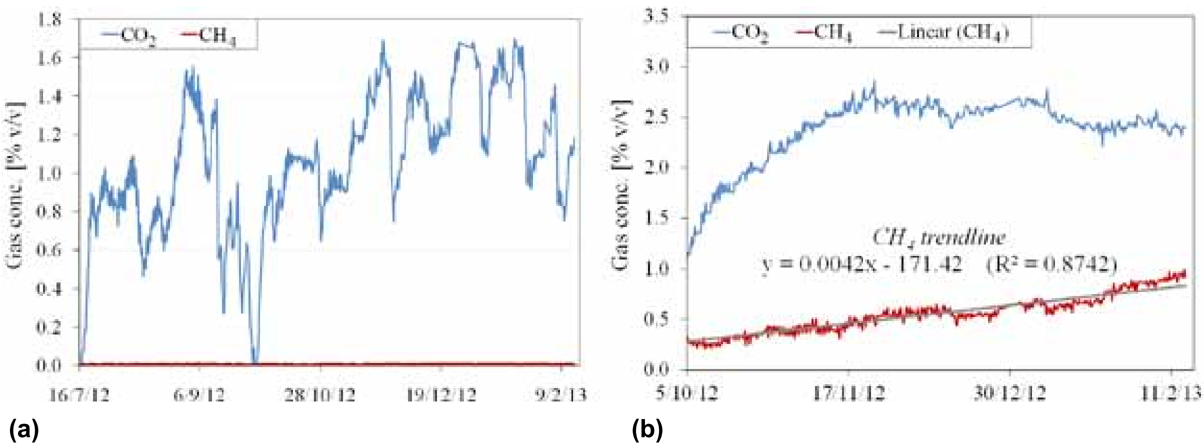


Figure 3.7. Gas activity in peatlands: (a) system #1 near bog edge, (b) system #2 in bog interior.

Carbon dioxide was the more dominant gas present in these particular wells, with maxima of 1.7% v/v and 2.9% v/v recorded in wells #1 and #2, respectively. These elevated levels call into question the 1.5% threshold limit for CO_2 in landfill perimeter wells, given that this limit has been exceeded because of natural peatland activity. Therefore, the validity of this universal regulation for landfill should be considered in the context of the substrate upon which the landfill has been constructed.

As Fig. 3.7(b) shows, CH_4 levels were observed to slowly accumulate in well #2. This gradual increase was almost linear ($R^2 = 0.874$). One consideration to bear in mind is that the sample was recycled back into the well headspace, thus implying that the gas levels were an integrated measurement. The near-linear increase in CH_4 indicates that the rise was likely due to a build-up in the headspace over time, with an average increase of 0.0042% v/v per day. Deviations from the linearity of the CH_4 increase may be caused by weather/seasonal variations. To gain some insight into the factors affecting the gas behaviour, both datasets were analysed with respect to weather data acquired from nearby weather stations (Garrymore, 2013; Killucan, 2013). Table 3.1 lists the correlation coefficients.

Unlike previous analyses of gas in landfill perimeter wells, there were no evident links between the peatland gas data and atmospheric pressure or rainfall. The largest correlation values found, though relatively low at 0.51 and under, were those pertaining to ambient air temperature. Caution is advised against drawing any conclusions here, given that a negative correlation could be expected because of incrementing gas levels (integrated readings caused by sample recirculation into the well headspace) and temperatures falling as the season of winter advances. As Fig. 3.8(b) shows, this is particularly true for data from well #2; the inverse similarity in the air temperature trend and the CO_2 in this well are most likely coincident with no conclusive evidence of a causal relationship. There may be more merit to the correlation coefficient calculated from well #1 (near bog edge), with discrete changes in CO_2 levels coinciding with peaks and troughs in the temperature data as seen in Fig. 3.8(a). That said, this does not necessarily point to a direct correlation; it merely suggests an association between gas generation and temperature or affiliated conditions (humidity, evaporation rate, etc.). This suggestion agrees with the appreciable correlation coefficient found for humidity and the DCU team's observation of varying ground moisture content surrounding well #1.

Table 3.1. Correlation coefficients of peatlands gas levels relative to meteorological conditions.

		Atm pressure	Precipitation	Temperature	Humidity
System #1	CO_2	0.002	-0.158	-0.511	0.380
	CH_4	0.004	-0.048	-0.201	-0.082
System #2	CO_2	0.076	-0.004	-0.384	0.282
	CH_4	0.046	0.129	-0.371	0.392

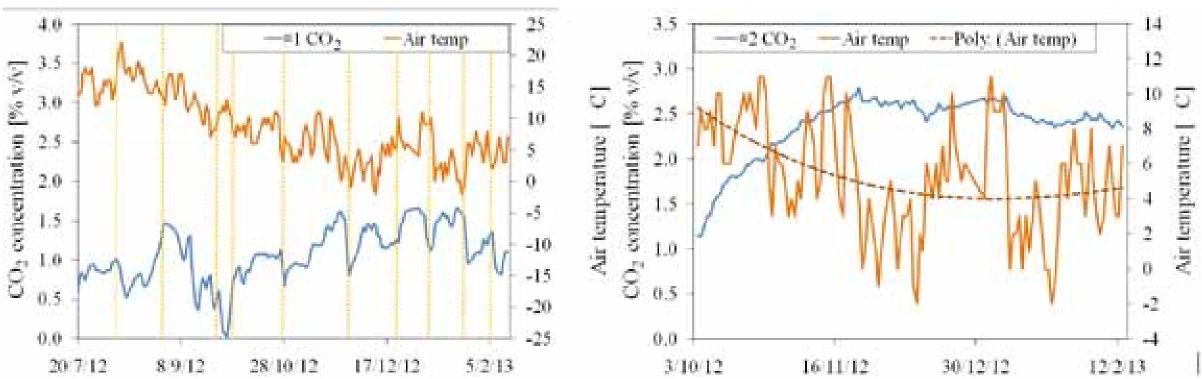


Figure 3.8. Comparison of peatlands CO_2 activity and air temperature for (a) system #1, (b) system #2.

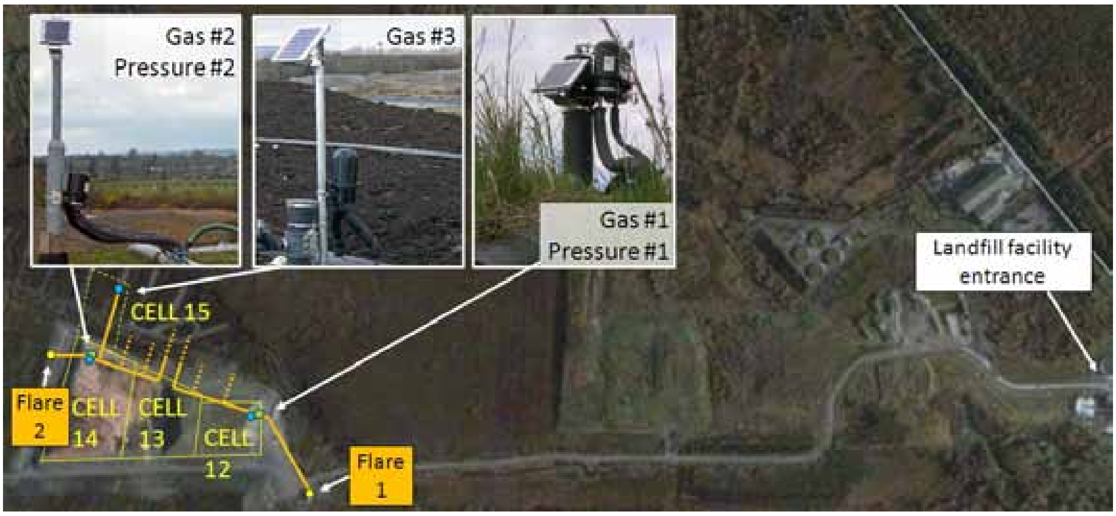


Figure 3.9. Configuration of deployed GEN2 systems on Kyletalesha landfill facility

In summary, low but appreciable quantities of gas were found to emit naturally from peatlands, particularly CO_2 in this case. The time-dependent gas behaviour was found to differ between the sampling locations (near bog edge compared to bog interior) – this may be attributed to the bog interior being more stabilised in terms of ground moisture content. Levels of CO_2 were shown to exceed the threshold limit defined for landfill perimeter wells, thus indicating that these levels could be surpassed in a landfill site depending on the inherent properties of the substrate material. Therefore, the underlying ground material should be considered when measuring low gas concentrations in landfill perimeter wells in order to identify whether the emissions are arising from natural (peatland vegetation decomposition) or anthropogenic (landfill waste decomposition) sources.

3.4 In-line Monitoring Network (5 x GEN2, Kyletalesha Landfill)

3.4.1 Aim of Deployment

To deploy multiple gas and pressure monitoring systems in-line with the landfill gas-extraction network. This deployment represented the first effort of its kind to deploy a wireless sensor network on an Irish landfill facility.

3.4.2 Location and Configuration

Five GEN2 platforms were deployed on Kyletalesha landfill facility, an active landfill facility outside Portlaoise. Two configurations of GEN2 platform were deployed: three gas-concentration-sensing units and two pressure-sensing units. Two pairs of gas and pressure platforms were deployed in-line with the extraction pipes leading to each of the two flares on site (locations #1 and #2 in Fig. 3.9). A third gas-monitoring system was deployed in a newly capped cell (location #3 in Fig. 3.9) to monitor the contribution of the gas from this cell to the adjacent flare.

3.4.3 Duration

Twelve-month deployment in total, December 2011–December 2012, valid readings total over 3,000 and 32,000 for gas concentration and pressure, respectively. Deployment details for individual platforms are shown in Table 3.2.

Table 3.2. Deployment details of GEN2 systems on Kyletalesha landfill facility.

System	Location	Duration (days)	Battery life	Valid readings
Gas #1	Cell 12	370	Indefinite (solar)	1,200
Gas #2	Cell 14	368	Indefinite (solar)	1,270
Gas #3	Cell 15A	281	Indefinite (solar)	824
Pressure #1	Cell 12	360	6-month duration	16,574
Pressure #2	Cell 14	360	6-month duration	16,532

3.4.4 Site-specific Issues Rectification

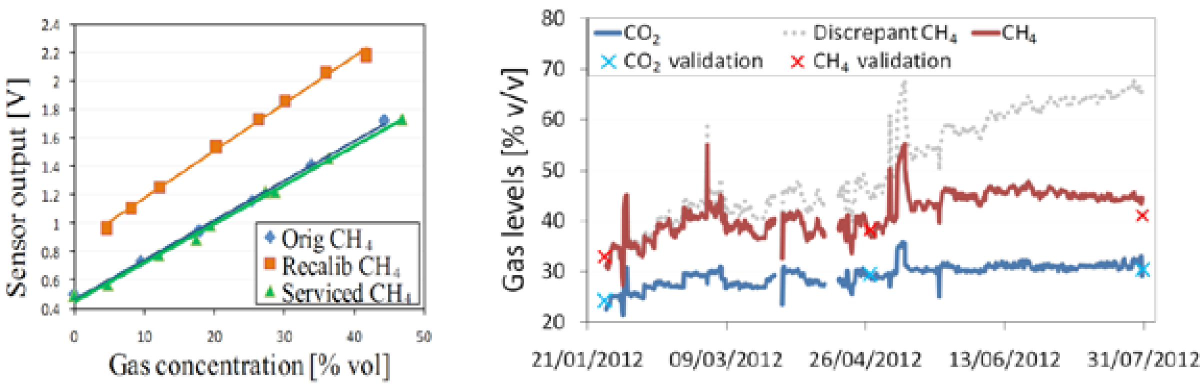
A number of issues specific to this site were identified and resolved in the early months of the deployment.

Due to natural conditions and on site working activity, there were two instances encountered where the sample tubing became disconnected. The first instance involved the sample tubing for gas unit #1 shrinking due to an abruptly warm weather spell as shown in Fig. 3.10(a). The second instance was where the landfill pipe collapsed from its support ridge due to the weight of excessive leachate, thus rending the connections for gas unit #3 on a number of occasions, see Fig. 3.10(b). Given that this was a newly capped cell, remedial construction works were ongoing to stabilise the pipe. In both instances, the issue was quickly identified from observing discrepancies in the online data and addressed by travelling on site to repair, with contingencies in place to avoid a repeat occurrence.

When the EPA advised the team of high-moisture content in the gas within the landfill's extraction pipes, this highlighted that there was a risk of condensate forming within the sampling tubing; this is evident in Fig. 3.10(c). The configuration of the systems' installation was adjusted to minimise the formation of condensate and to prevent the inhibition of gas intake. Besides blocking the sampling of the gas, condensate formation could also cause a leak to develop because the pump was acting upon a constriction. This was experienced in the gas unit #1 system in the early stages of its deployment, where the issue was identified by observing discrepant values for the CH_4 sensor readings. Retrieval of the system confirmed that the discrepant values were caused by the drift in sensor readings from their original calibration due to ambient air seeping into the sensor chamber. This was confirmed by the sensor readings reverting to agree with their original calibration upon resealing the unit, as shown in Fig. 3.11(a). The extent of the discrepancy was calculated to form a mathematical model that was applied to the preceding field readings; interestingly, this retrospective data adjustment then brought the readings into good agreement with independent validation readings taken during that period (see Fig. 3.11(b)).

(a) (b) (c)

Figure 3.10. On-site issue rectification: (a) tube shrinkage, (b) connection breakage due to pipe collapse, (c) condensate blockage.



(a) (b)

Figure 3.11. Rectification of readings discrepancy arising from sampling leak in system #1: (a) CH_4 calibration data, (b) corrected field deployment data.

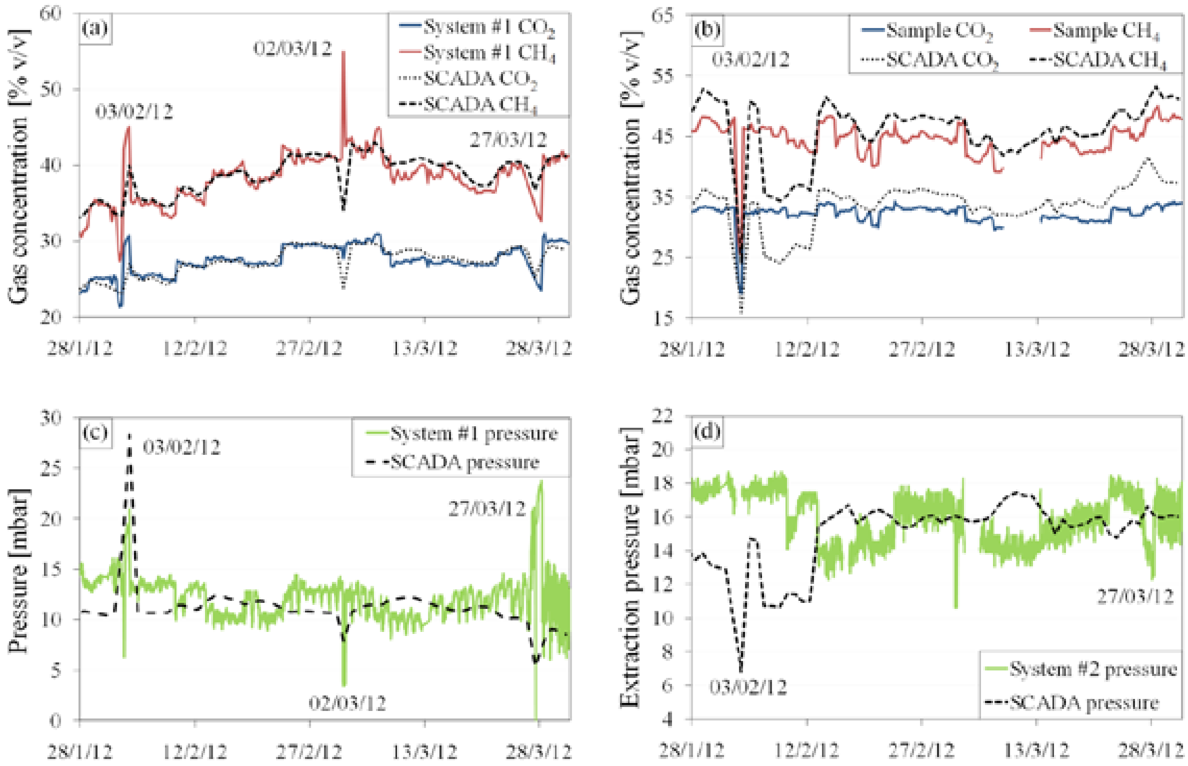


Figure 3.12. Subset of data indicating correlation between deployed platforms and SCADA: (a) location #1 gas levels, (b) location #2 gas levels, (c) location #1 pressure levels, (d) location #2 pressure levels.

Periodic spot checks conducted to all other systems on site (gas systems #2 and #3 and both pressure systems) found that they remained within calibration during the deployment period, thus ensuring sensor accuracy.

3.4.5 Discussion and Analysis

Distinct 'events' are clearly seen in the overall datasets, coinciding in both the gas concentration and pressure values. Variations in the constituent gas levels tended to be time synchronised, that is CO_2 and CH_4 tended to rise and fall at the same time. This signified that the gas activity was predominantly controlled by a singular factor affecting the entire volume of the gas – most likely the extraction rate towards the flare. This is confirmed by the reasonably strong correlation between the deployed systems and their respective SCADA measurements at the flare, as shown in Fig. 3.12 and Table 3.3. Reasonably strong correlations (*correl* ≥ 0.6) were found for both monitoring locations and their respective SCADA measurements, particularly for gas concentration values. This validated the gas data collected by the deployed platforms. The correlations in gas concentration levels were marginally higher for location #1 compared to location #2 (0.73 vs. 0.62 averaged), most likely due to separate unmonitored gas inlets into flare #2 from different cells. The lower correlation values for pressure readings (*correl* < 0.4) was somewhat to be expected given the dynamic variability of extraction pressure due to fluctuating barometric pressure and varying levels of condensate in the landfill pipes. However, as seen in Fig. 3.12, distinct events are clearly observable in both the SCADA and systems' datasets, implying that changes in the extraction pressure and flow-rate manifest further down the extraction network within the landfill. Therefore, the distributed monitoring systems allow the quantification of the effectiveness of the flare extraction.

It can be seen that, at times, CH_4 experienced a greater differential change than CO_2. This is evident from Fig. 3.12 and also confirmed by the lesser correlation seen between the CH_4 values and SCADA flow-rate compared to that of CO_2 (0 vs. 0.1 for location #1; 0.36 vs. 0.5 for location #2). One point to note (which

Table 3.3. Correlation analysis of deployed systems and SCADA (System Control And Data Analysis) measurements.

Deployed platforms		SCADA			
		CH_4	CO_2	Pressure	Flow
#1	CH_4	0.72	-	-0.024	-0.005
	CO_2	-	0.736	0.059	0.107
	Pressure	-	-	0.065	0.218
#2	CH_4	0.649	-	0.195	0.358
	CO_2	-	0.592	0.337	0.505
	Pressure	-	-	0.376	0.307

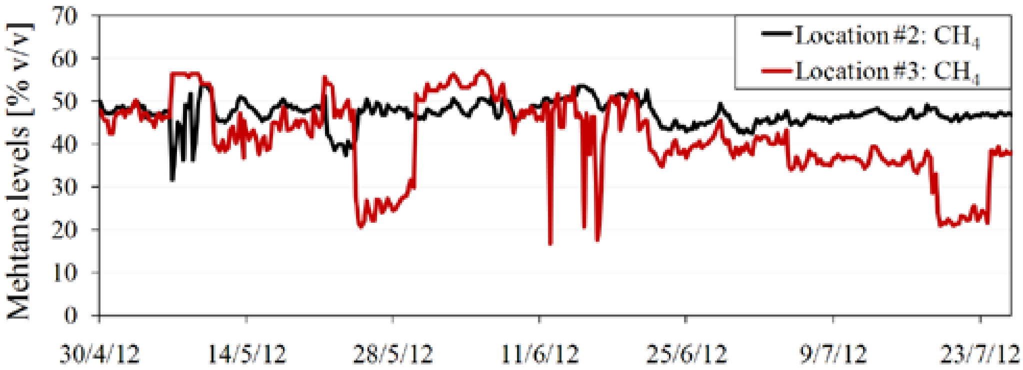


Figure 3.13. Methane readings acquired from locations #2 and #3.

would reduce the correlation values) is that the gas concentration correlation was not consistently positive: for example, negative correlations in gas levels on 2/3/12 and in pressure on 27/3/12 as seen in Fig. 3.12(a) and (c). It is difficult to ascribe variations in a system as complex as a landfill gas field to a specific source; one possibility is differing levels of methanogenic activity in the waste body according to varying conditions of waste decomposition. Unlike previous perimeter well-monitoring deployments, local weather conditions were found to have no direct contribution to gas behaviour, with the dominant factor instead being field-balancing actions (opening and closing of wells/manifold valves to enrich the methane content flowing to the flare). Unfortunately, documentation of the field-balancing activity on site was handwritten and hence unavailable for correlation analysis.

The simultaneous measurement of gas levels at different points along the landfill-extraction system was another advantage provided by distributed sensor platforms. Location #3 was situated on a tributary extraction line leading to the flare via location #2 as shown in Fig. 3.13 . A subset of the CH_4 data from both locations is displayed in Fig. 3.13. For the most part, CH_4 generation in location #3 is seen to be less than that in location #2; this may be expected for a new-capped waste cell where waste decomposition is not at a sufficiently advanced stage. The elevated CH_4 levels in location #2 indicate that the field is balanced from other cells to provide the appropriate gas composition for the flare.

In conclusion, consistent agreement with spot measurements and a reasonably good correlation with the flares' SCADA data indicated the validity of the data acquired by the GEN2 monitoring systems. This trial was useful in terms of demonstrating the capability of the monitoring, demonstrating the potential of quantifying gas levels further down the extraction system before issues manifest at the flare.

3.5 In-line Monitoring Network (5 x GEN3, Ballydonagh Landfill)

3.5.1 Aim of Deployment

To deploy multiple GEN3 monitoring (gas + pressure) systems in order to fully determine gas behaviour within a landfill extraction system.

3.5.2 Location and Configuration

Five GEN3 platforms were installed at five key locations (flare inlet and four principal manifolds) on Ballydonagh landfill facility (see Fig. 3.14).

3.5.3 Duration

Field trials commenced in December 2012 although a number of site-specific issues prevented consistent monitoring performance. Table 3.4 gives the deployment details for individual platforms. All systems are currently undergoing servicing and are to be redeployed in the near future.

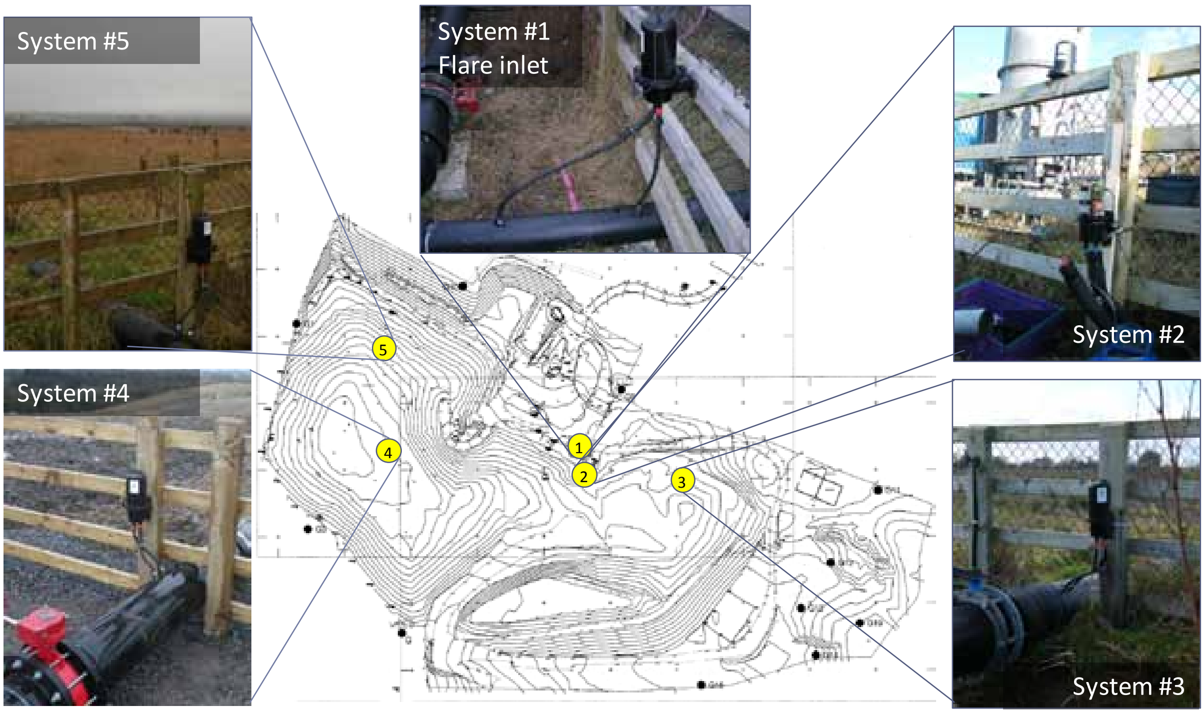


Figure 3.14. Deployment configuration for GEN3 platforms on Ballydonagh landfill facility.

Table 3.4. Deployment details of GEN3 systems on Ballydonagh landfill facility.

System	Location	Duration (days)	Gas readings	Pressure readings
System #1	Flare inlet	18	48	144
System #2	Manifold 1	7	30	90
System #3	Manifold 7	7	30	90
System #4	Manifold 8	14	18	54
System #5	Manifold 6	7	31	88

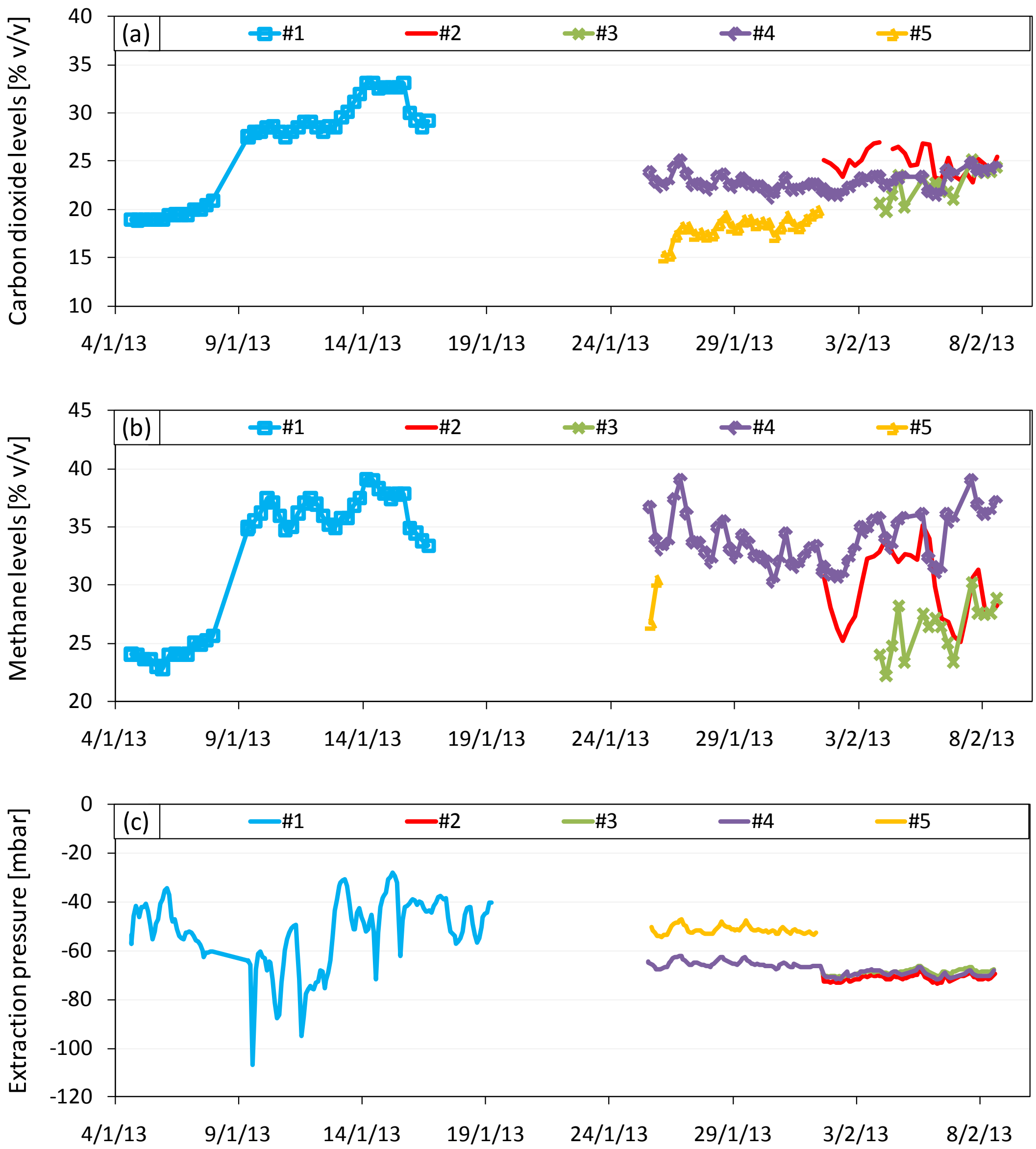


Figure 3.15. Data acquired from the five GEN3 systems deployed on Ballydonagh landfill: (a) CO_2, (b) CH_4, (c) extraction pressure.

3.5.4 Site-specific Issue Rectification

A number of issues manifested in the early days of deploying these GEN3 systems. Teething issues in implementing a new-generation technology were compounded by site-specific problems, which were suspected as arising from high-extraction pressure, water damage and the possible interference of corrosive hydrogen sulphide (H_2S) gas.

The extraction pressure within the landfill was higher than anticipated, ranging from -60 to -100 mbar whereas previous experience on other sites was typically in the region of -20 mbar. The initial attempt to deploy system #1 in December 2012 failed due to the pump's inability to work against the high pressure. The second attempt at deployment in January 2013 was more successful, though the water-trap was omitted as the pump could not draw against both the high extraction pressure and the water-trap constriction. Data from the subsequent monitoring operation was validated against readings taken on site by monitoring manager John Waldron. Unfortunately, the system's pump failed and erroneous sensor readings developed after 12 days. Subsequent analysis of the sensors in the lab revealed a calibration drift due to water damage arising from the lack of a water-trap. With newly tested pumps, the other GEN3 systems were deployed at their respective manifolds with water-traps fitted. Unfortunately, system #5 developed a fault in the CH_4 sensor readings; the next visit on site revealed water on the interior of the inlet tubing (beyond the water-trap), most likely arising from the heavy rainfall on the day of installation (despite all reasonable care being taken). Systems #2, #3 and #4 maintained correct operation, as validated by spot checks on site, though were later retrieved as a precaution pending full diagnosis of systems #1 and #5.

In the course of this diagnosis, H_2S levels were measured at the sampling locations on site. In this case, H_2S corrosion was ruled out as a factor contributing to these failures as relatively low levels were found at the problematic locations (105 ppm and 16 ppm at locations #1 and #5 respectively) compared to high levels found at locations where GEN3 systems operated without fail (397 ppm at location #4). Therefore, water ingress into both systems #1 and #5 was the most likely factor leading to faults in these systems' readings. These systems are in the process of being repaired and all systems are to be redeployed.

3.5.5 *Discussion and Analysis*

With a single flare and four main manifolds on Ballydonagh landfill, the deployment of five systems was considered to be ideal for describing the gas field behaviour comprehensively. The remote access to near-real time data from the flare and principal manifolds represented steps towards achieving a fully instrumented landfill facility, whereby issues affecting the flare's optimal operation (e.g. insufficient gas quality, inadequate suction pressure) can be quickly identified and pinpointed to the specific area of the landfill site, thus enabling landfill gas-management problems to be readily diagnosed and remedied. The site's SCADA system for operating the flare was locally accessible only – readings were taken from the LCD display on the flare unit and field-balancing conducted fortnightly if needed. The facility had recently closed and was no longer receiving waste (capping on final cell completed in December 2012), thus ensuring minimal site disturbance to disrupt the monitoring operation.

While the extent of data was limited within the time-frame of this project due to technical and site-specific issues, the comparison of gas activity at different locations on site shown in Fig. 3.15 illustrates the value of having such data to hand. Each monitoring location revealed distinct gas characteristics, demonstrating the variation in gas generation across the site. This information would assist field-balancing by quantifying methane generation potential at the distributed locations, hence enabling control of the optimum gas mix for the flare. Furthermore, remote pressure measurements provided an insight into the effectiveness of the extraction network. The pressure data was highly fluctuant for system #1 due to its proximity to the vacuum pump at the flare inlet, whereas readings were more stabilised for the distributed systems #2 to #5.

The emergence of system faults highlights the challenge in developing robust and accurate monitoring systems capable of long-term operation. What was important in this scenario was to identify the sources of fault and subsequently rectify and future-proof against these types of failures. On the whole, GEN3 systems have demonstrated a promising potential, advancing from the GEN2 system with a lower price point and expanded functionality. This potential will be validated with this deployment to be continued beyond the current EPA STRIVE funding period.

3.6 Wastewater Treatment Plant Emissions (GEN2, São Paulo, Brazil)

3.6.1 *Aim of Deployment*

To monitor GHG emissions (CO_2 and CH_4) from an anaerobic lagoon in a wastewater treatment plant.

3.6.2 *Location and Configuration*

A GEN2 gas-monitoring system deployed next to a lagoon of a wastewater treatment plant in São Paulo. As the lagoon is exposed to atmosphere, an accumulator bag was placed on the water surface to capture the gas emissions.

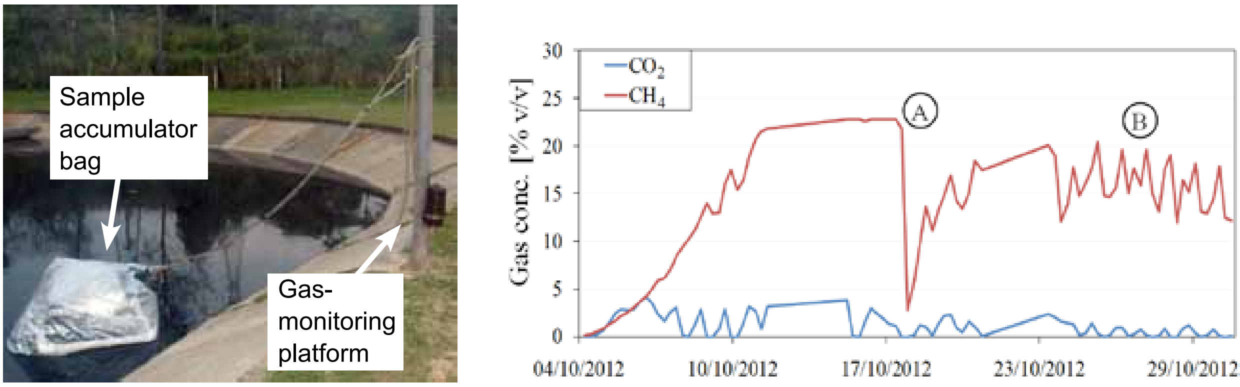


Figure 3.16. GEN2 gas-monitoring system deployed on wastewater treatment plant in São Paulo.

3.6.3 Duration

Installed in October 2012, proof-of-concept trial for 26 days (104 valid data readings); redeployment due imminently.

3.6.4 Discussion and Analysis

This deployment resulted from an inter-university collaboration between the University of São Paulo (USP) and DCU. Brazilian student Camila Nardi Pinto conducted a four-month internship with the DCU team, where a GEN2 gas-monitoring system was assembled and shipped to Brazil. The USP team engaged with SABESP, the Brazilian state-owned water utility organisation, who were interested in quantifying gas emissions from their wastewater treatment plants. Within days of the deployment commencing, significant gas levels were observed accumulating, particularly CH_4 levels that exceeded their flammability range. Other distinct events are clearly identifiable in Fig. 3.16; a sudden reduction in gas levels on 17 October (‘A’) when the accumulator bag was shifted and spilled by a technician on site, and daily periodic fluctuations in gas concentrations from 24 October (‘B’) onwards.

The quantification of this gas behaviour has been generating substantial interest from SABESP, who are interested in expanding the number of deployments. They are particularly interested in using the data to evaluate the processes within the wastewater treatment plant, and to reduce gas emissions by varying additive agents, water agitation and flow conditions.

3.7 Remote Gas-Monitoring (GEN2, Auchinlea Landfill, Glasgow)

3.7.1 Aim of Deployment

Remote monitoring of in-line wells on a low-calorific landfill facility in collaboration with environmental engineering consultancy Fehily Timoney & Co (FTC).

3.7.2 Location and Configuration

One GEN2 gas-monitoring system installed on a number of different wells in Auchinlea landfill facility, Scotland.

3.7.3 Duration

First installation on 23 October 2012: three days, 12 valid readings. Redeployed after servicing on 17 December 2012: 34 days, 123 valid readings.

3.7.4 Discussion and Analysis

Following a presentation given at an Environmental Science Association of Ireland (ESAI) seminar (Collins, 2012), FTC requested the use of a remote monitoring system for a trial that they were setting up on the Auchinlea landfill facility, a landfill site in Scotland. This work was conducted in collaboration with Zero Waste Scotland and Scotland Environmental Protection Agency (SEPA). The provided GEN2 system was deployed on different wells within the facility, with the purpose of evaluating the methane potential while FTC were trialling a variety of different low-calorific gas-treatment methods.

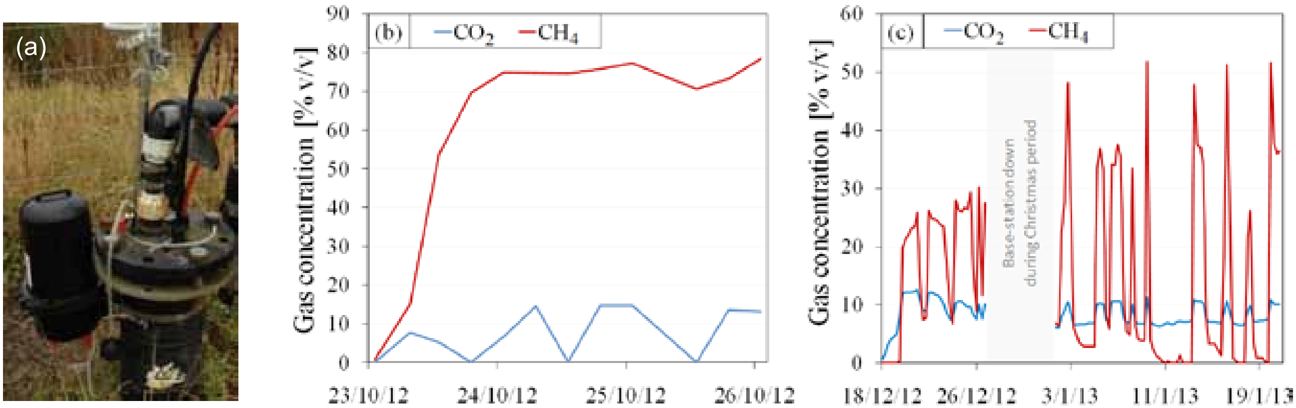


Figure 3.17. Remote monitoring from Auchinlea landfill: (a) GEN2 system deployed on well, (b) data from an in-line well under no suction, (c) data from different in-line well under intermittent extraction.

The first deployment showed a substantial accumulation of gas levels, particularly CH_4, in a well that was not under regular suction (see Fig. 3.17(b)). These gas concentrations were found to dispel rapidly when extraction was activated. This indicated a low rate of gas generation, a characteristic feature of low calorific landfill sites. Unfortunately, a technical fault in the monitoring system (later diagnosed as a faulty cable connection of the CH_4 sensor) cut this deployment short. After servicing the system, it was redeployed on a different well on site. As displayed in Fig. 3.17(c), abrupt fluctuations in gas levels corresponded to changes in the operation of the flare's extraction.

Though these deployments were of short duration, this trial was promising in terms of demonstrating the use of the technology to industry. Feedback from FTC was very positive, particularly with regard to the ease of installation and quick access to data acquired from the remote locations. With the capability of quantifying gas levels at distributed locations in response to adjustments in the flare operation, the methane generation potential of the site could be more readily determined. The greater extent of information provided by the autonomous systems therefore leads to more informed decision-making, thus optimising the treatment of gas in low-calorific sites.

4 Conclusions and Future Outlook

With 2013 being described as the ‘Year of Air’ by European leaders, it has never been more important to attain extensive, accurate and relevant environmental measurements. This project has progressed towards this goal by developing a remote monitoring service using low-cost yet reliable autonomous sensor platforms. This delivers the increased frequency of monitoring required by the regulators, the enhanced operational and performance monitoring that is beneficial to the operators and the low-cost operation that enables an increased scale of deployments.

In this project, autonomous monitoring platforms with web-based data accessibility were developed for the application of monitoring GHGs. These platforms were applied principally on landfill sites, with applicability demonstrated for alternative gas emission sources such as peatlands and wastewater treatment plants. Numerous long-term field deployments have demonstrated the beneficial value of remote gas monitoring. During these deployments, the monitoring platforms withstood severe environments and adverse weather conditions, necessitating only relatively minor on-site modifications.

The web-based monitoring enabled the site operators and the EPA to characterise, for the first time, the dynamics of landfill gas behaviour in a near real-time and fully autonomous process. When monitoring perimeter borehole wells, gas levels were observed to frequently surpass regulatory threshold limits. The full extent of these breaches would not have been ascertained using the existing monthly manual sampling regime. Indeed, the magnitude of these regulatory threshold limits was questioned in this project, with their limits slightly exceeded in unharvested peatlands without the contribution of landfill waste decomposition. Regarding in-line monitoring with the site’s gas-extraction network, feedback from landfill operators has been positive, confirming that the availability of near real-time methane concentration variation data across the site can assist in field-balancing to attain the optimum gas composition for combustion in the flare/engine. Furthermore, the monitoring of in-line gas concentrations and extraction pressure at distributed points throughout the extraction system has shown potential as a useful diagnostic tool for evaluating the effectiveness of the landfill gas-extraction network.

The greater temporal and spatial resolution afforded by autonomous monitoring systems has enabled a more detailed investigation into the factors that contribute to landfill gas behaviour. That said, the identification of such factors is no trivial task. Given the unpredictable environment, it is practically impossible to arrive at clear-cut correlations between landfill gas behaviour and individual factors in a functioning high-capacity landfill facility. Instead, one must identify and investigate events occurring in landfill gas behaviour with a view to attributing them to on-site conditions. In this way, a greater understanding of the dynamics of landfill gas generation and migration is attained; this leads to better informed decision-making and operational practices in managing landfill gas. The availability of high-quality, long-term data such as provided by the sensor platforms developed in this project plays a key role in unravelling the complex interactions between site operations, weather and local environment that together influence gas behaviour on landfill sites. In the course of this project, key events in gas activity were ascribed to on-site extraction conditions and weather conditions such as atmospheric conditions and rainfall. This new information can assist in the development of more effective management procedures and control of the underlying processes that govern GHG emissions from such sites, thus presenting landfill operators with the opportunity to rapidly and cost-effectively attain compliant parameters in accordance with the waste permit licence.

Over the course of this project, there has been increasing commercial interest as a result of our publications. Feedback from market research and interactions with relevant personnel (including OEE officers, landfill operators and local authorities) indicates that there is a viable commercial prospect because of the increased wealth of data provided by distributed monitoring platforms complemented with value-added analysis and the interpretation of landfill gas activity. Therefore, it was important to consider how the research could be continued in a strategic manner in order to grow the expertise and develop customised services that could assist the EPA and other interested parties in their efforts to improve the quality of our environment. To this end, the project team have successfully negotiated a grant under the Enterprise Ireland Commercialisation Fund for continuing this work beyond the current EPA STRIVE funding. Begun in mid-March 2013, this new funding award will enable a further 18 months of work. With the GEN3 platform serving as the basis for the next project, further technical developments will include exploring different communications protocols (lower-cost intra-network radio frequencies) and implementing alternative sensor types (different gas targets pertaining to ambient air quality).

In continuing to target the waste sector, the use of the devices on landfills and wastewater treatment plants will be expanded upon, with a greater focus on the market viability of the platform. The authors aim to continue working closely with the EPA and landfill operators, demonstrating that the integration of data arising from distributed sensor networks into landfill operational practice would assist in field-balancing, gas management and environmental preservation. With clever implementation of this technology on site, the potential exists to configure an early warning system in pathways to receptors at risk, thus facilitating a more comprehensive environmental assessment. Overseas, substantial interest has arisen from Brazil, where the water-utility agency SABESP has indicated its intention to greatly expand upon the number of deployments in their wastewater treatment plants. Additional GHG emission sources to be investigated include the agricultural sector (a dominant source of GHG emissions in Ireland, accounting for 30.5% of the national total). Furthermore, this technology has potential in efforts being undertaken in designing GHG sinks and carbon storage initiatives (e.g. re-wetting and restoration of managed peatlands). Beyond GHGs, the implementation of alternative sensor types could see the platform technology adapted for ambient air-quality monitoring, for which a considerable market demand has been identified. In this way, autonomous air and gas-monitoring solutions will be delivered, as accomplished in this project with respect to GHGs.

5 Research Implications and Policy Delivery

Numerous international policy-driven initiatives stipulate the acquisition of high-quality environmental data. In recent years, continuous monitoring has become prominent in the policies of regulatory agencies – in particular for landfills. The effective implementation of continuous monitoring depends on validated autonomous sensor platforms and meaningful analysis of the resulting data. This will allow a deeper insight into gas dynamics and landfill operation that has up to now been either not fully understood or indeed unknown. The implications of this research are:

1. The control and mitigation of GHG emissions is dependent on the ability to measure such emissions quantitatively, using technology that can withstand adverse environmental conditions, remote locations and the durability inherent to typical GHG emission sources associated with industrial and municipal activities. This research has delivered this technology to an advanced prototype stage with extensive validated field trials.
2. Beyond mere data acquisition, the value-added benefit of such monitoring needs to be delivered by characterising the factors contributing to the emissions' behaviour. This includes identifying 'events' within datasets and annotating them with respect to their environmental conditions, such as the emission source properties or local weather patterns. In this way, a deeper insight into the behaviour of gas emissions is achieved, thus allowing appropriate mitigation efforts to be undertaken. The more informed decision-making process is therefore more conducive to reducing these types of emissions.
3. Two aspects of this research can be applied in terms of landfills:
   a. For compliance with environmental legislation, autonomous sensing platforms can be employed at perimeter locations to measure fugitive gas migration. This is crucial to protect the local environment and adjacent residential areas. This has become increasingly relevant with the reduction in landfill personnel and tightening budget constraints due to the closure of numerous facilities, though the gas generation will continue for a further 30–50 years. Furthermore, there are numerous historical landfill sites, many of them unlined and so non-compliant with modern landfill engineered construction. The longevity of gas generation implies a risk to the local environment (e.g. fire hazard, asphyxiation, ground-water contamination); such risks could be evaluated and addressed by use of cost-effective autonomous sensor platforms as developed in this project.
   b. For optimised landfill gas management, multiple autonomous sensing platforms can be deployed at key distributed locations such that the gas field is fully characterised. Gas-concentration measurements will define the methane generation potential at a particular section of the site, thus aiding in field-balancing. Furthermore, pressure measurements at these locations will provide an indication of the gas-extraction effectiveness, thus diagnosing if any fault such as a blockage or leakage arises. In this way, the landfill gas is managed more effectively and the operation of the flare/engine onsite is optimised.
4. The deployment on the pristine bog demonstrated the applicability of this technology in areas outside of landfill for which it was originally developed. This was particularly of interest in the light of recent developments towards agreement on the reporting of emissions from managed peatlands which are subject to restoration and re-wetting activities. Monitoring of *in situ* GHG emissions and sinks may be facilitated by this technology, although with further development tailored towards the underlying processes governing gas generation and dissipation in peatlands. This has potential market/research funding opportunity in the area of carbon sinks, carbon storage and so on.

5 Web-based accessibility to data is ideal for informing public awareness on local environmental quality. People appear to have a growing appetite for information, particularly information that can be accessed through the Internet with the expanding market of smart media (smartphones, tablets etc.). In addition to the waste-sector applications used in this project, web-based accessibility to gas data will be appropriate to applications with controversial social implications such as odour monitoring (e.g. H_2S from landfills), air quality (e.g. NOx from urban traffic) and heavy industry (e.g. methane emissions). Publically accessible knowledge would place a greater pressure on relevant parties to comply with environmental standards. Moreover, if there is a better informed public, this could mean less misinformed controversy and in turn less disruption to necessary industrial processes. The technology described within this project, with some technical modifications, would be viable for such applications.

Recommendations for the implementation of this research are summarised in Table 5.1.

Table 5.1. Recommendations for implementation and uptake of research findings.

Issue	Recommendation	Target users	Time frame
GHG reduction from emission sources	In order to evaluate remedial actions, it is necessary to employ accurate and reliable technology that enables quantitative measurement of GHG generation and migration. The technology developed within this project has demonstrated the potential to fulfil such requirements.	EPA DECLG Local authorities	Long term (GHG targets for 2050)
Characterisation of GHG emission activity	More robust data analytics is enabled by the greater wealth of data acquired by these autonomous remote sensing platforms, hence allowing the attribution of landfill gas generation/migration patterns to site factors and weather conditions.	Local authorities Public service industry Private operators	Medium term
Landfill gas fugitive emissions	To protect the local ecosystem and nearby human residential areas, remotely deployable platforms can be employed to monitor fugitive emissions, whereby alerts can be triggered if specified levels are breached.	Landfill operators (local authorities and private operators)	Long term
Landfill gas utilisation	Distributed sensing platforms can evaluate the methane generation potential at key locations on site, hence aiding field-balancing to maintain optimal operation of the flare/engine. Additionally, remote pressure sensing serves as a diagnostic tool to monitor the effectiveness of the extraction network.	Landfill operators (local authorities and private operators)	Medium term
Public awareness of gas emissions	Web-based accessibility of sensor data would be beneficial for such public dissemination to more compliant industrial processes and an improved standard of our environment	EPA DECLG Local authorities	Long-term

DECLG = Department of the Environment, Community and Local Government, EPA = Environmental Protection Agency, GHG = greenhouse gas.

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Acronyms

% v/v	Percentage volume in air
CH_4	Methane
CO_2	Carbon dioxide
DCU	Dublin City University
DECLG	Department of the Environment, Community and Local Government
EA	Environmental Agency
EPA	Environmental Protection Agency
FTC	Fehily Timoney & Co
GEN2	Generation 2 (second generation system)
GEN3	Generation 3 (third generation system)
GHG	Greenhouse gas
GSM	Global System for Mobile Communications
H2S	Hydrogen sulfide
IC	Integrated chip (electronic component)
IR	Infrared
OEE	Office of Environmental Enforcement
ppm	Parts per million
SCADA	System Control And Data Analysis
USP	University of São Paulo
WSN	Wireless sensor network

Appendix

Published Papers, Posters, Conference Presentations and Awards

Collins, F., McNamara, E., Orpen, D., Fay, C., Nardi, C., Costa, E., Diamond, D., *Autonomous remote gas sensing: Web-based monitoring of greenhouse gases*. Presented at CEST2013 (13th International Conference on Environmental Science and Technology), Athens, Greece, September 2013.

McNamara, E., Nardi, C., Collins, F., Fay, C., Costa, E., Piza, L., Céspedes, A., Cogan, D., Cleary, J., Morgada, M., Diamond, D., *Distributed sensing of key environmental parameters using autonomous chemical sensor platforms*. Presented at Analitica Latin America, São Paulo, Brazil, September 2013.

Collins, F., Orpen, D., McNamara, E., Fay, C., Diamond, D., *Landfill gas-monitoring network – development of wireless sensor network platforms*. Proceedings of SensorNets 2013, Barcelona, Spain. February 2013. **Awarded Best Paper at conference**.

Diamond, D., Collins, F., Cleary, J., Zuliani, C., Fay, C., Distributed environmental monitoring, *Autonomous Sensor Networks: Collective Sensing Strategies for Analytical Purposes*. Springer Series on Chemical Sensors and Biosensors, pp. 321–64, February 2013.

Collins, F., Orpen, D., Fay, C., Diamond, D., *Recent advances in web-based sensor technology for remote monitoring of landfill gas*. Invited talk at ESAI seminar *Treatment and Monitoring of Landfill Gas*, Lifetime Lab, Cork, September 2012.

Collins, F., Orpen, D., Fay, C., Diamond, D., *Web-based monitoring of gas emissions from landfill sites using autonomous sensing platforms*. Poster presented at EPA STRIVE research conference, Trinity College, 28 June 2012.

Collins, F., Orpen, D., Fay, C., Diamond, D., *Analysis of landfill gas migration using autonomous gas-monitoring platforms*. Presented at 27th International Conference on Solid Waste Technology and Management, Philadelphia, USA, 12 March 2012.

Collins, F., Orpen, D., Fay, C., Foley, C., Smeaton, A.F., Diamond, D., *Web-based monitoring of year-length deployments of autonomous gas sensing platforms on landfill sites*. Proceedings of Institute of Electrical and Electronics Engineers (IEEE) Sensors, Limerick, Ireland, October 2011.

Collins, F., Orpen, D., Fay, C., Diamond, D., *Autonomous gas sensing platforms for remote monitoring of greenhouse gas emissions*. Poster presented at Enterprise Ireland Big Ideas event, Dublin, 10 October 2011.

Collins, F., Orpen, D., Maher, D., Cleary, J., Fay, C., Diamond, D. *Distributed chemical sensor networks for environmental sensing*. Presented at SensorDevices 2011 (2nd International Conference on Sensor Device Technologies and Applications), Nice, France. August 2011. **Awarded Best Paper at conference.**

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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, Pobal agus Rialtais Áitiúil.

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;
- dumpáil mara.

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.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government