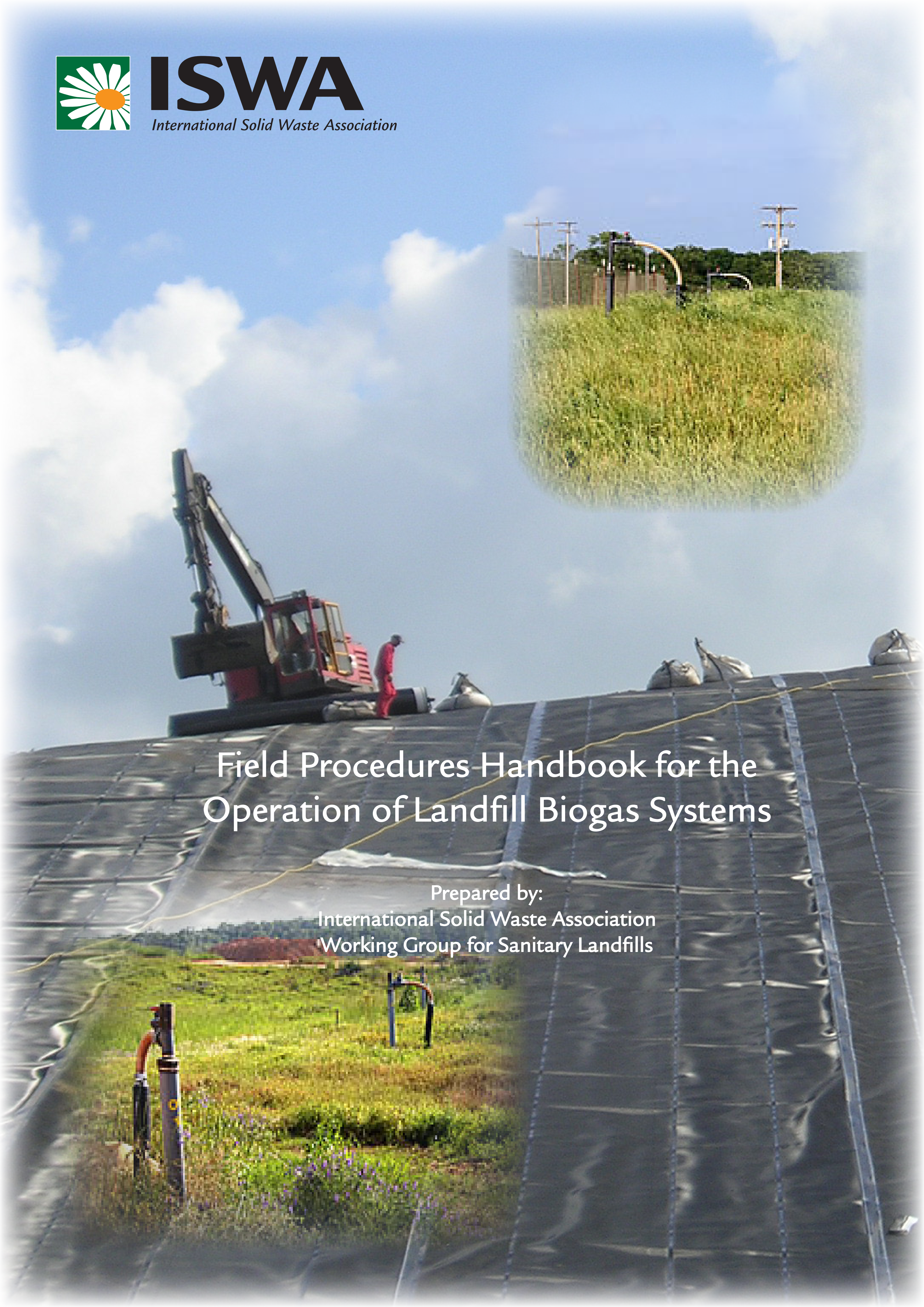

ISWA

International Solid Waste Association

Field Procedures Handbook for the Operation of Landfill Biogas Systems

Prepared by:
International Solid Waste Association
Working Group for Sanitary Landfills

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1. Landfill Biogas (LFG) System Overview

The landfill biogas industry is seeing a rise in the number of collection and treatment systems being installed worldwide. In part, these installations are due to the need to control subsurface methane migration into nearby buildings, air emissions and greenhouse gases, and odors. In addition, such systems are built to capture the energy benefits from landfill biogas. Some 1,100 such energy systems are in place in approximately 40 countries (H. Willumsen, 2003).

Coupled with this rise in landfill biogas systems comes the need for proper operations and maintenance, and the prevention of accidents. As more personnel are hired to operate active landfill biogas systems, there remains an industry concern to make sure field personnel and managers receive regular training.

In particular, such training is important where the use of sanitary landfills is on the increase. The conversion from old dump sites to lined, controlled landfills is resulting in more methane gas generation and the need for immediate collection and control. This is occurring in countries that have recently joined the European Union (EU), where the waste management programs are expected to be improved during the intermediate term.

To address this need for proper start-up and operation of landfill biogas systems, the International Solid Waste Association (ISWA), Working Group on Sanitary Landfill, was awarded a grant from the European Union (EU) to develop a practical handbook covering basic field procedures and practices. The objective is to provide EU landfill managers, site operators, and field technicians with a practical reference guide that can be used on a daily basis and contribute toward efficient, safe landfill biogas operations. This handbook is not intended to replace site-specific operation and maintenance manuals. Landfill personnel should rely on such manuals and related information sources to address issues and needs appropriate to their particular facility.

2. Landfill Basics

Simply stated, a landfill serves as a managed, engineered facility in or on the land where solid waste is deposited. These facilities are differentiated from dumps or other waste sites where waste has not been managed or the facility has no engineered structures associated with waste deposition. Modern sanitary landfills are designed to prevent the spread of pollution, fires, and disease that were prevalent in old waste dumps. Common features of sanitary landfills include security fencing, storm water/sediment control, leachate control, biogas control, and waste capping systems.

Today's sanitary landfills typically are subject to regulatory requirements, beginning with which types of wastes are acceptable for deposition, and continuing with design features for containment in an engineered cell. Most often this containment seeks to prevent the infiltration of water into the system, the leaching of liquids out of the cell (i.e., in the form of leachate), and the proper management of landfill biogas generated within the waste mass.

The amount of moisture entering the landfill and subsequent leachate leaving the system is determined, in part, by how much rainfall the landfill area receives. In arid locations where there is little rainfall, LFG likely will pose a greater risk for groundwater contamination than leachate.

Among the various landfilling methods, canyon fills, pits, mounds, or a combination thereof are the most common. Modern operations have in place a plan outlining what type of wastes will be accepted, how much will be accepted, available space, the type of daily cover material to be used (i.e., for litter control, fire prevention, water infiltration, etc.), and more. Soil is typically used as the daily landfill cover material, but alternatives exist such as waste combustion ash. The thickness and type of the selected cover material will impact how readily moisture can enter the system and also how well the LFG management system will perform.

Also, the use of geomembrane materials for landfill liners and covers has improved the operating performance of landfills from an environmental perspective, but has also generated LFG control issues as well. Operators must bear in mind and be prepared to address the following types of issues with regard to the use of geomembrane liners and covers:

- The potential for LFG build up under the geomembrane and the need to collect the LFG to reduce the possibility of membrane ballooning or other impacts;

- The possibility of LFG migration beyond the membrane; and

- The potential for air intrusion at unsealed membrane locations.

3. Landfill Biogas (LFG) Defined

LFG is formed when anaerobic bacteria consume organic material in waste that has been disposed of in a landfill. These bacteria cause a breakdown of food waste, paper, wood, etc., into simpler forms like organic acids. These are ultimately broken down in the following elements: methane, carbon dioxide, oxygen, nitrogen, and water vapor. The presence of nitrogen and oxygen are common due to the existence of air in the landfill (i.e., air is about 79 percent nitrogen and 21 percent oxygen, by volume). LFG typically also contains many other trace gases including volatile organic compounds (VOCs). It is flammable and potentially explosive, can accumulate in confined spaces and migrate within open conduits, through surrounding soils, and elsewhere.

LFG generation at any landfill is primarily driven by waste composition. More specifically, the type and quantity of organic material content found within the buried waste will largely determine the LFG generation potential. Other factors impacting the rate of LFG production include: bacterial content, moisture content, pH level, age and size of the waste volume, facility operational objectives, etc.

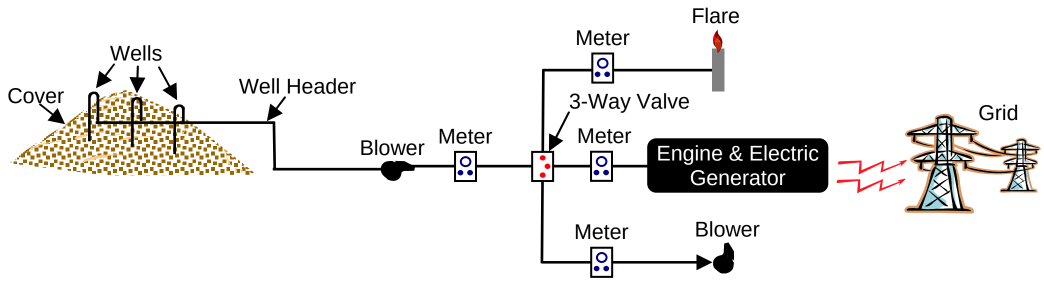
3.a Basic LFG System Operations

Successful operation of any LFG control system requires the proper running of four primary activities. These include:

1. LFG monitoring, using probes typically placed around the landfill perimeter
2. LFG extraction and collection, using wells and piping
3. The collection, pumping, storage, and treatment of LFG condensate
4. The treatment, disposal, or use of LFG using blower, flare, and/or energy recovery equipment

The system components associated with each of these activities is shown in ***Exhibit 3-1***, and is described in greater detail in Sections 5 through 9 of this Handbook.

EXHIBIT 3-1: TYPICAL LFG SYSTEM COMPONENTS



The level of effort required to properly manage a LFG system will depend upon factors such as whether there is energy recovery, the size of the operation, what problems are encountered, operational objectives, whether a proactive maintenance program is in place, etc. In general, the following activities should be performed on a regular basis (i.e., at least annually):

- Monitoring the wellfield
- Monitoring for LFG migration
- Reviewing facility regulatory compliance and permits
- Maintaining the facility
- Minimizing the facility's environmental impact
- Safety inspections
- Optimizing facility operations (LFG management, energy recovery).

Each LFG operation should also have sufficient personnel to maintain accurate, timely records of facility performance. Operations and maintenance records should include the following types of documentation:

- Sheet records (read daily)
- Facility log book (daily input)
- Facility shutdown log records
- Chart recordings records
- Extraction well graphs and logs
- Monitoring probe graphs and logs

- Maintenance schedules and records
- Power sales records
- Calibration records
- Monitoring results for regulatory compliance
- Parts and other supplies inventories
- Purchase orders
- Monthly facility management reports.

Most well operated landfill facilities have developed site-specific operations and maintenance (O&M) reference manuals for their personnel covering equipment and operations at the site. Such documents typically are made readily available to facility personnel and include the following type of information:

- Plain description of facility operations
- Spare parts lists
- Start-up procedures for each piece of equipment, and on-going operating sequence descriptions for all system components
- Monitoring activities and schedules
- Data recording and reporting
- Maintenance requirements and schedules
- Safety precautions, procedures, and protocols
- Technical support contacts (e.g., equipment manufacturers)
- Alarm conditions and recommended responses (e.g., trouble-shooting, emergency shutdowns)
- Normal shutdown procedures for all LFG facility components.

3.b Potential LFG Issues of Concern

Several problematic issues arise when dealing with the management of landfill biogas. First, the most common component of LFG is methane, usually present at approximately 35 to 50 percent by volume within solid waste landfills. Methane (or biogas) is an odorless and colorless gas that is flammable and potentially explosive (i.e., at concentrations between five percent and 15 percent in air, when in the presence of oxygen and an ignition source). This gas, along with other volatile trace gases, may be emitted from the landfill into the atmosphere or elsewhere in the environment. Further, methane has been identified as a significant greenhouse gas emissions contributor.

Other landfill gases (e.g., hydrogen sulfide and mercaptans) may cause the release of nuisance odor emissions from landfills. While such emissions may not indicate an immediate physical health concern, depending upon how much is present, they can still negatively impact the quality of life in the areas near the landfill. Such odors can be controlled by making sure that the release of such chemicals does not exceed the site specific odor threshold. In other words, control of odor producing chemicals through proper LFG management must be greater than the release of such chemicals into the atmosphere.

LFG also can travel via subsurface pathways, generally up to 500 meters, and will accumulate in enclosed spaces and other structures, posing a potential explosion hazard. Movement of LFG is towards the path of least resistance and may be impacted by a number of factors such as: soil pressure changes brought on by ground water fluctuations, barometric changes, atmospheric pressure changes, etc.

The presence of oxygen in the landfill also impacts LFG formation and management. Air from the atmosphere is present in refuse being disposed in the landfill. Oxygen from the air is consumed by way of natural aerobic processes through which an anaerobic condition is created, leading to the formation of methane. As more oxygen is introduced into the landfill environment, methane-producing bacteria are inhibited and LFG generation may be reduced. This can negatively impact an energy recovery project and otherwise make proper management of LFG more challenging.

3.c Potential Benefits Associated With LFG

There are several benefits associated with the use of LFG as a source of energy. Landfill methane is considered to be a low to high grade fuel, depending upon how much it is processed, that can be put to beneficial use for electrical generation, heating, and other applications. Revenues generated through the sale of LFG power can reduce the costs associated with operating and maintaining the landfill. Renewable LFG power also can generate revenue through the sale and transfer of emission reduction credits. In addition, energy recovery can reduce the potential for unwanted LFG migration and odors.

4. Landfill Biogas Health and Safety Overview & Checklist

Summarized below are general standard safety procedures associated with LFG management and for the landfill personnel responsible for LFG management. These and other health and safety suggestions are provided in Sections 5 through 9 of this handbook.

Electrical

- Strictly complying with electrical lock-out procedures (i.e., to protect workers from injury or death) during inspection, maintenance, and repair of electrical equipment
- Using properly grounded portable tools
- De-energizing all electrical equipment before commencing work
- Eliminating or removing of all ignition sources before undertaking welding or related work.

LFG System

- Closing appropriate valves, shutting down portions of the system, plugging pipes, etc., to isolate repair areas from LFG
- No smoking or other ignition within 5 meters of any potential methane source (e.g., manholes, blower-flare, etc.)
- Using mirrors and/or flashlights instead of lighters or matches for visual inspections
- Verifying pressure relief before opening all pressurized vessels and devices
- Complying with confined space entry procedures by all people entering such a space
- Complying with trenching and excavation safety procedures (e.g., fall and other hazards)
- Never leaving open excavations or drill borings unattended, unmarked, or unsecured

Personal Protection

- Removing rings, watches, etc., before working on electrical equipment and controls
- Wearing a safety vest that is visible (i.e., florescent orange) and give heavy landfill equipment the right of way
- Wearing other safety equipment such as hard hats, safety glasses, steel-toed footwear, hearing protection, protective gloves, etc., as appropriate
- Observing good hygiene practices while in the landfill environment, do not eat, smoke, or drink, and seek prompt medical attention if injured in any fashion
- Wearing protective equipment to guard against negative impacts associated with exposure to odorous gases.

General Safety

- Notifying the appropriate local authorities (e.g., fire department, environmental protection agencies, etc.) prior to landfill drilling, trenching, LFG flaring, etc.
- Observing all posted safety signs, being familiar with where additional safety equipment is located (e.g., fire extinguishers, safety lines, chemical level indicators, etc.)
- Remaining alert to other nearby construction and maintenance activities that could potential pose a health and safety hazard

Further, at the beginning of any LFG management operation, a thorough landfill site characterization should be completed. This will help ensure the safety of personnel responsible for LFG recovery, construction, engineering, and/or monitoring. Once operational, accurate records should be maintained relating to health and safety practices (e.g., respirator use approvals, maintenance records, medical assessments, etc.). Such records can provide liability protection.

The health and safety component of the facility operations and maintenance manual, mentioned above, should address the following type of issues:

- Hazard communication (making personnel aware of exposure hazards)

- General safety accident prevention program
- Dust control
- Noise control
- Medical surveillance
- Respiratory protection program
- Personnel and work environment monitoring
- Safety training program
- Maintenance of records on all safety related issues.

5. Landfill Biogas Monitoring and Protection Systems

5.a System Description

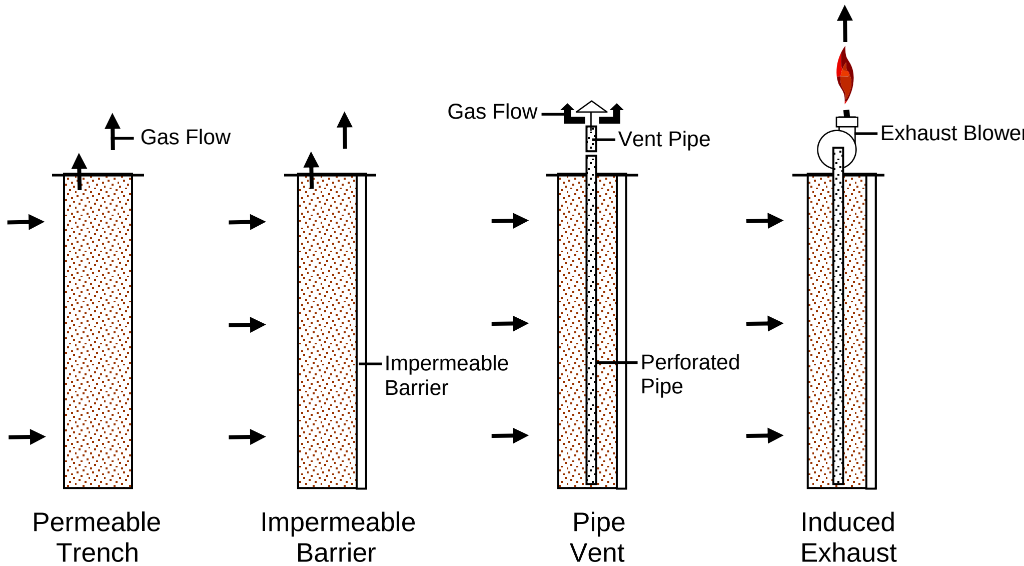
LFG operations typically involve monitoring gas composition and related gas parameters that may serve as performance indicators. These include:

- Methane
- Carbon dioxide
- Oxygen
- Liquid levels (e.g., condensate, leachate)
- Gas pressure and vacuum
- Gas flow
- Hydrogen sulfide
- Other trace gases

Landfills also are typically required to monitor for the subsurface movement of LFG, and to show that LFG migration control systems are working properly. As already noted, this is because LFG can migrate from the landfill in all directions, can accumulate, and possibly explode under certain conditions. LFG generally flows from areas of high pressure or concentration to areas of low pressure or concentration.

The lateral movement of LFG can be controlled by either ventilation or barrier systems. See ***Exhibit 5-1.*** Ventilation systems include gravel-filled vents, vertical and horizontal wells, trenches, or combinations thereof. These may be either induced exhaust systems or passive systems. Barrier systems are built outside the landfill area and extend to a bottom seal that has low permeability or to a natural barrier like bedrock.

EXHIBIT 5-1: GAS CONTROL SYSTEMS



The monitoring of LFG surface emissions also may be necessary, depending upon the air quality regulations in the area where the landfill is located. Specific reasons why LFG monitoring is necessary include:

- To determine whether LFG migration exists
- To assess the degree to which LFG migration has occurred
- To figure out whether there is any potential for a gas explosion
- To document how well the LFG system is operating
- To be in compliance with environmental regulations

LFG monitoring and sampling can be conducted within the collection system piping, in buildings and structures to maintain a safe work environment, in soils near the landfill perimeter, at the landfill surface, at the extraction wells to show that the collection system is in balance, in monitoring wells, etc. Many different types of instruments are used to monitor LFG. Monitoring and sampling can be accomplished using both portable and stationary devices and instruments. Such devices typically measure LFG in terms of the percent volume occupied in the air.

Further, operators should be prepared to trouble-shoot problems that arise from operating a LFG system. Examples include:

- Repairing broken equipment
- Re-igniting the flare
- Unclogging a blocked pipe
- Odors
- Reduced LFG flow.

Operators should keep good records of trouble-shooting activities to facilitate the correction of future problems.

5.b Typical Components

A primary monitoring system component is known as the monitoring probe or well. The purpose of such probes is to show whether LFG has migrated beyond an established boundary such as the landfill property line. Unless they are being used to collect LFG samples, monitoring probes should be placed outside the waste mass. Probes may also be located elsewhere to monitor landfill structure, specific LFG migration patterns, etc.

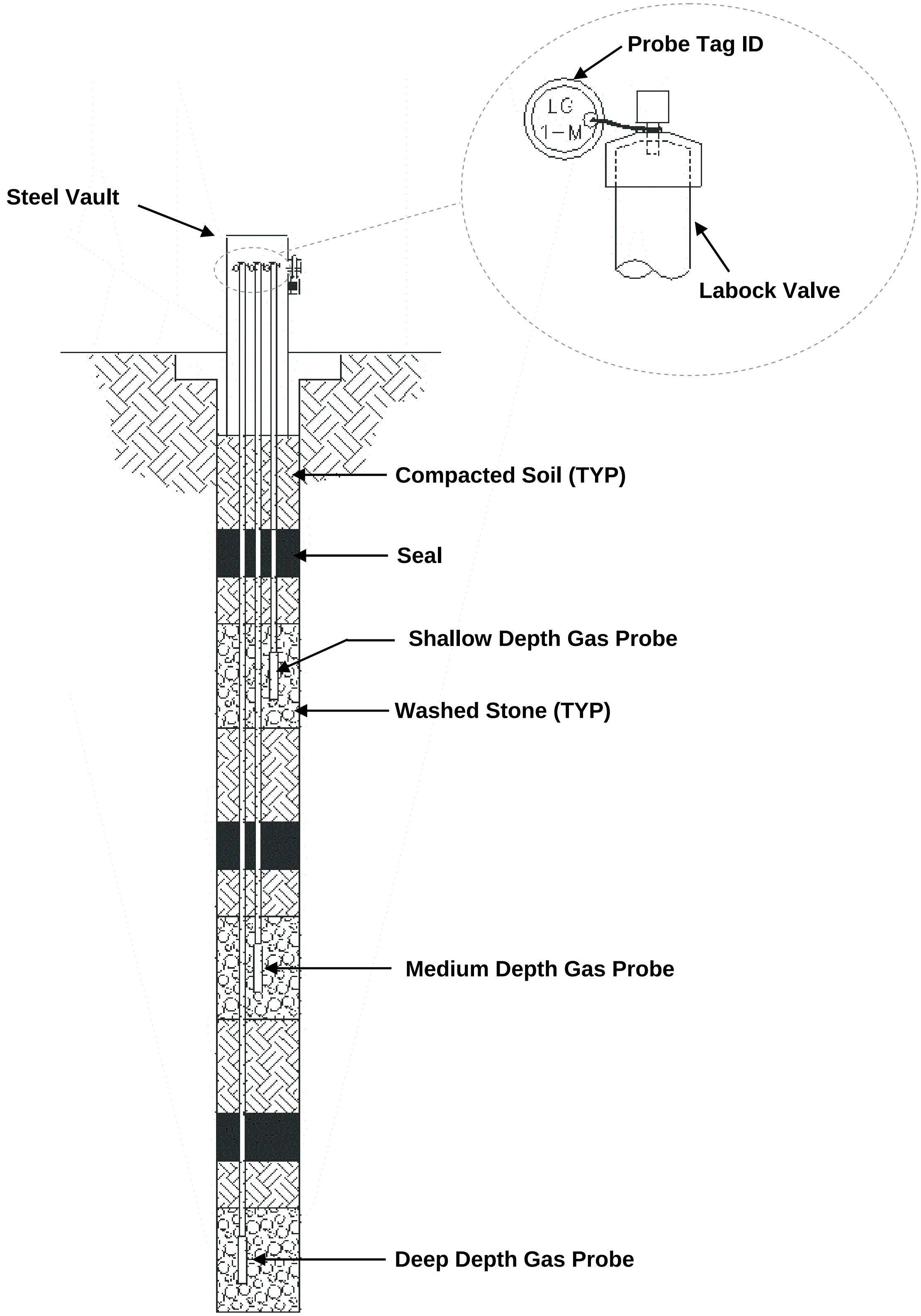
Monitoring probes can be driven into the soil, instead of using a borehole, if the probe depth is less than about 5 meters. Probes can also be single- or multi-depth, with multi-depth probes consisting of varying depth pipes within the same borehole. See ***Exhibit 5-2.*** Depths should typically be determined by how deep the landfill is in the area of the probe.

The LFG probes typically monitor for the following types of indicators: methane, carbon dioxide, pressure, and balance gas (indicating nitrogen).

To specifically determine methane levels, the following kinds of instruments are used:

- An organic vapor analyzer/flame ionization detector (OVA/FID)
- A combustible gas analyzer
- An infrared analyzer.

EXHIBIT 5-2: MULTI-DEPTH LFG MONITORY PROBE



Other key LFG monitoring equipment includes:

- Pressure measurement devices
- Oxygen detectors
- Flow measurement devices.

Specific knowledge about each instruments capabilities, limitations, and requirements is important. For example, an OVA/FID can also be used to measure the following:

- Low levels of VOCs or combustible gases
- Surface emissions
- Human exposure in specialized applications
- Fugitive leaks from pipes and equipment.

In addition, landfill surface emissions monitoring may be accomplished using various monitoring devices, and applying different collection methods such as:

- Immediate random landfill surface sweeps using an OVA/FID and a site map
- Immediate direct landfill surface sweeps covering a defined area using an OVA (plus optional strip chart recorder or data logger)
- Collection of an emission sample over time covering a defined landfill area using a bag sampler (OVA used to derive and average grid reading)
- Ambient air sampling using up-wind and down-wind integrated bag samplers to measure total non-methane hydrocarbons (TNMHC) and track priority pollutants from the landfill

Portable measurement instruments are typically comprised of a detector element, an electronic circuit that responds to the detector, and a user interface such as a digital meter or analog current meter. The instrument must be calibrated to ensure accurate measurements. Also, the term indicator is sometimes used instead of the term analyzer to reflect the fact that the instrument in not that precise. For example, the presence of a combustible gas may be measured but not the actual quantity. One example is provided by the simple combustible gas analyzer or indicator (i.e., CGA or CGI). Such instruments can determine the presence of most combustible gases and, therefore, if the CGI is calibrated for methane, other gases that are present may impact the accuracy of the reading.

Typical instrument types and associated LFG application include:

- Flame ionization detector (for methane detection)
- Thermal conductivity detector (methane)
- Catalytic combustion sensor (methane)
- Infrared bench detector (methane, CO2)
- Chemical reaction (oxygen, H2S, CO)

5.c Data Measurements

Generally speaking, technicians should track and operate the following type of monitoring data and equipment:

- Geologic/hydrologic reports
- Gas well and probe location map
- Landfill depth information
- Barometric data from a nearby airport
- Gas monitoring instruments for oxygen, methane, CO2, plus pressure gages

For each monitoring well tracked, the following type of specific data should be recorded:

- Date and time of readings
- Name of technician
- Weather conditions
- Atmospheric pressure
- Methane, CO2, and oxygen gas composition
- Probe location, pressure/vacuum

A partial list of other areas where monitoring data should be collected from, as applicable, includes:

- Elevator shafts, pits and seals
- Wall space hollows and behind switch plates
- Basements and substructures
- Pilot light and fired equipment locations
- Water wells
- Foundation expansion joints and seams
- Electrical conduit
- Non-ventilated areas and small rooms
- Cracked flooring

In any event, data measurements should be conducted during the time of the day when LFG migration is identified to be at its highest. This is typically during the mid-afternoon to late-afternoon period when barometric pressure is on the decline and LFG tends to migrate and vent from the landfill.

In terms of landfill surface emission data measurements, the following is a summary of each alternative defined in Section 5.b:

- **Immediate random landfill surface sweeps** involves observing and recording instrument readings using an OVA/FID and a site map, and following a random or predetermined pattern over the landfill. Particular attention should be given to high readings that result from damage to the landfill cap (i.e., as a result of drying, cracking, and settlement) or thin landfill cover.

- **Immediate direct landfill surface sweeps** covering a defined area involves taking data measurements similar to the random sweeps but the technician walks at a defined speed, recording readings with an OVA at a set time interval, within an established grid segment, and following a predefined pattern. A data logger or strip chart recorder may also be used with the OVA.

- **Collection of an emission sample over time** covering a defined landfill area involves taking a continuous data measurement at a set sampling rate and speed. A bag sampler is used to collect the sample and methane concentration can be measured using an OVA.

- **Ambient air sampling** involves the measuring of TNMHC and individual species of trace priority pollutants up-wind and down-wind from the landfill property using integrated ambient air samplers.

By taking data measurements from the landfill surface on a regular basis, surface emissions can be documented and corrective actions taken. Generally, readings above 100 parts per million (ppm) may be a trigger for corrective action, but this depends on local or prescribed compliance requirements. To reduce detected surface emissions, improvements to landfill cover or an increased extraction well flow rate can be undertaken.

5.d Operations and Maintenance

In order to perform proper LFG system monitoring, the technician must possess a thorough understanding of operational principles, instrument procedures and maintenance, and the instrument operating limitations. Also, data collection personnel should ensure that the monitoring equipment is calibrated to collect the most accurate data possible. For example, readings from portable field instrumentation can be affected where there is low oxygen, or when working with explosive gases.

Using LFG monitoring probes as a specific example, accurate records should be maintained including, at a minimum, specific pipe identification (i.e., especially within a multi-depth probe scenario), probe depth, and construction information.

In addition, operational steps associated with LFG migration probe monitoring should include the following:

1. Measuring and recording probe pressure/vacuum
2. Checking the entire sample train for leaks
3. Purging the probe piping
4. Reading and recording gas composition
5. Resealing the probe once monitoring complete.

The monitoring schedules for various components of the LFG system generally fall into two categories: routine and accelerated. A summary of typical monitoring schedules is provided in ***Exhibit 5-3***. Bear in mind that monitoring during the initial LFG system startup is part of the construction acceptance tests. Also, accelerated monitoring occurs when a there is a change of condition at the monitoring location. It is recommended that an additional round of perimeter and extraction system monitoring take place should the LFG system be shut down for a period of three days or more.

EXHIBIT 5-3: TYPICAL LFG SYSTEM MONITORING SCHEDULE

LOCATION	ROUTINE	ACCELERATED	ACCELERATED SCHEDULE CRITERIA
LFG Monitoring Wells	Quarterly	Weekly	Monitoring well with methane reading > 5.0% GAS
On-site Structures	Quarterly	Daily	Interior methane concentration reading of >25% LEL
Blower/Flare Station	Weekly	Daily	Adjustments made to any extraction system components (i.e., blower, extraction well)
Extraction System (first Year)	Monthly	Weekly	Adjustments necessary at extraction wells

Notes: Accelerated monitoring schedules at the various locations are independent of each other (i.e., on-site structures can be under an accelerated monitoring schedule while the other locations remain under their respective routine monitoring schedules).

If the extraction system is inoperable for three or more consecutive days, a non-scheduled routine monitoring round should be conducted at all locations.

Extraction system monitoring should be conducted at least monthly for the first year, depending on the stability of the extraction system flow rates, methane content, etc. With time, this monitoring frequency may be reduced.

5.e Health and Safety

When monitoring for methane gas concentrations, it is important to mind the following health and safety issues:

- Methane concentrations less than the lower explosive limit (LEL), equivalent to five percent by volume in air, may be indicative of a potential problem if corrective action is not taken;
- Methane concentrations greater than 15 percent (the upper explosive limit, or UEL) may be diluted at a later point and thus, offer the potential for a methane-air explosion;
- Good safety practices dictate that explosive concentrations of methane should not exceed 25% of the LEL, or 1.25 percent methane by volume in air, in structures (e.g., buildings, manholes, vaults, drainage culverts, structures housing an electric sparking device) on or near the landfill; and
- LFG displaces air as it builds up and may result in oxygen deficiency and death by asphyxiation in confined spaces and elsewhere.

In addition, a qualified worker should be responsible for the operation of the following types of field sampling instruments:

- A methane analyzer (e.g., a CGA)
- An instrument to measure hydrogen sulfide (potentially lethal gas)
- An oxygen analyzer

Such instruments and other portable electronic monitoring equipment should be rated explosion-proof and safe. Also, other gas compounds may need to be monitored (e.g., benzene, vinyl chloride) during drilling operations, and a daily record of monitoring activities should be maintained.

6. Landfill Biogas Wellfield, Conveyance, and Condensate Systems

6.a System Description

6.a.1 Wellfield and Conveyance Systems

The LFG wellfield system is comprised of a network of wells or collectors in the landfill, coupled with conveyance piping for the transport of LFG to a blower-flare facility, other treatment and disposal, and/or energy recovery equipment.

Vertical extraction wells are commonly installed into the interior landfill waste mass for LFG emission control and energy recovery, once the filling operations have been completed. They are also installed along the landfill perimeter for LFG migration control. See ***Exhibits 6-1a*** and ***6-1b***.

EXHIBIT 6-1a: VERTICAL LFG EXTRACTION WELLS

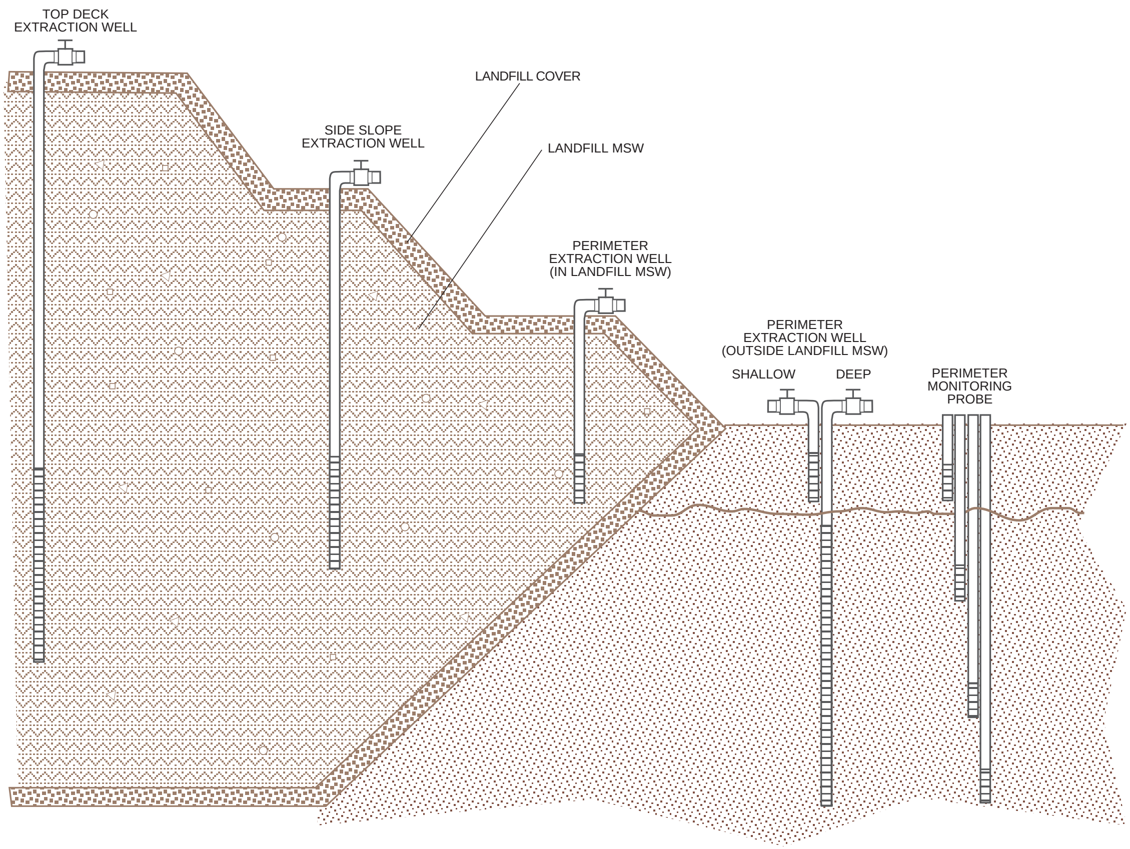
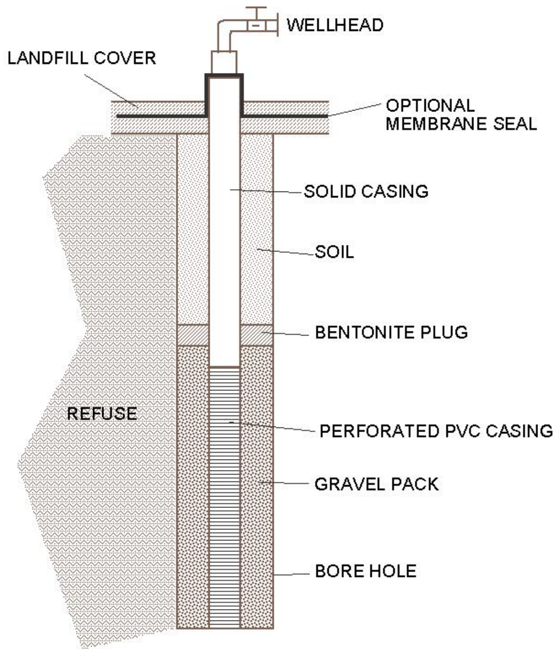


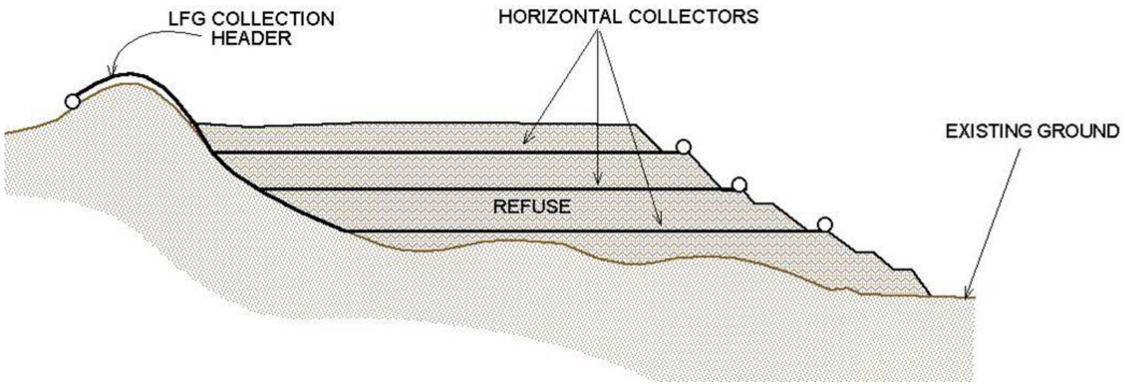
EXHIBIT 6-1b: VERTICAL LFG EXTRACTION WELL DETAIL



The installation of horizontal wells (e.g., trench collectors) serves as another efficient LFG collection method, particularly in landfills that are still being actively filled. See ***Exhibits 6-2a*** and ***62b***. Once a lift of waste has been placed and compacted in the landfill, perforated collection pipes are installed and another layer of waste is placed on top. This allows for LFG collection directly below an active fill area.

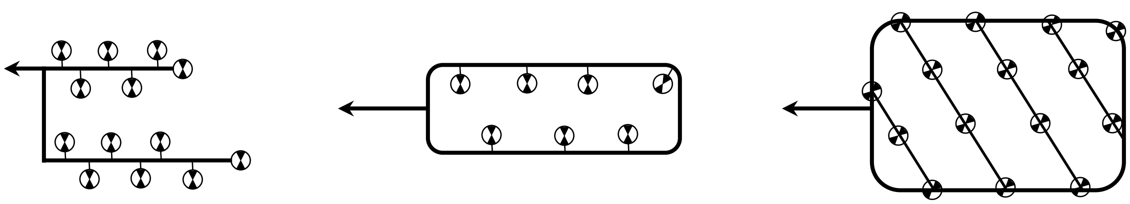
EXHIBIT 6-2a: HORIZONTAL LFG EXTRACTION WELL

EXHIBIT 6-2B: HORIZONTAL COLLECTORS DIAGRAM



A piping network is constructed to connect the LFG collection wellfield to the blower and flare facilities. The main pipe used to transport LFG from the wellfield to the processing facilities is known as a header. Lateral pipes connect landfill wells and trenches to the header(s). Subheader pipes connect the lateral pipes. There are different header piping configurations including: matrix, branch, and looped arrangements. See ***Exhibit 6-3***. A primary objective when designing the collection header piping configuration is to achieve effective LFG drainage.

EXHIBIT 6-3: LFG HEADER ROUTING CONFIGURATIONS

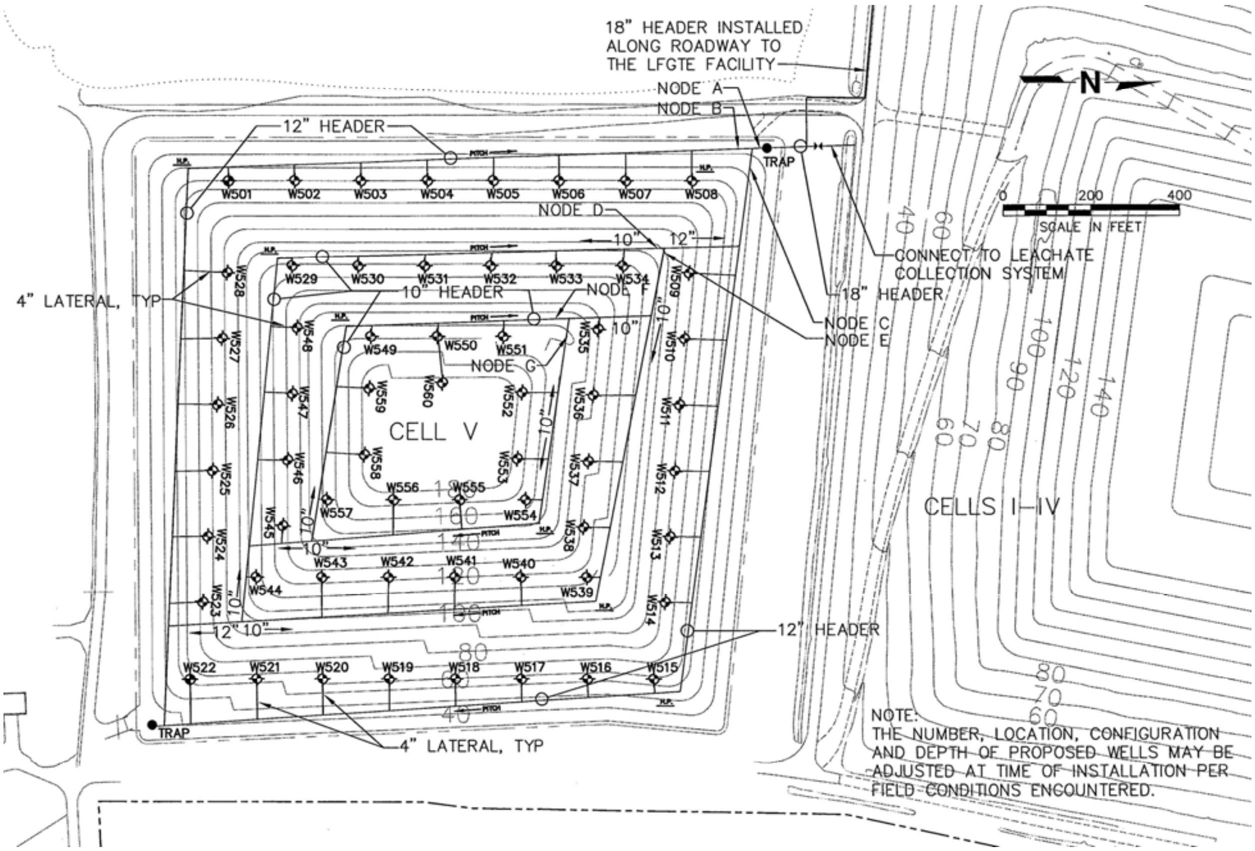


Branch **Loop** **Matrix**

Before LFG from the wellfield reaches the blower and flare systems, it typically passes by an inlet block valve which serves as the primary wellfield LFG flow throttle. During maintenance activities, the throttle may also be used to isolate the blower and flare facilities from the wellfield.

Next, the LFG typically passes through a liquid knockout vessel (i.e., mist eliminator) installed in a piping segment which removes the flowing liquid and particulate from the gas. The liquid may be collected in sumps or drained back into the landfill. A big advantage associated with inline knockouts is that they can be used in LFG piping where there is little or no slope. ***Exhibit 6-4*** shows a typical LFG wellfield and conveyance systems layout.

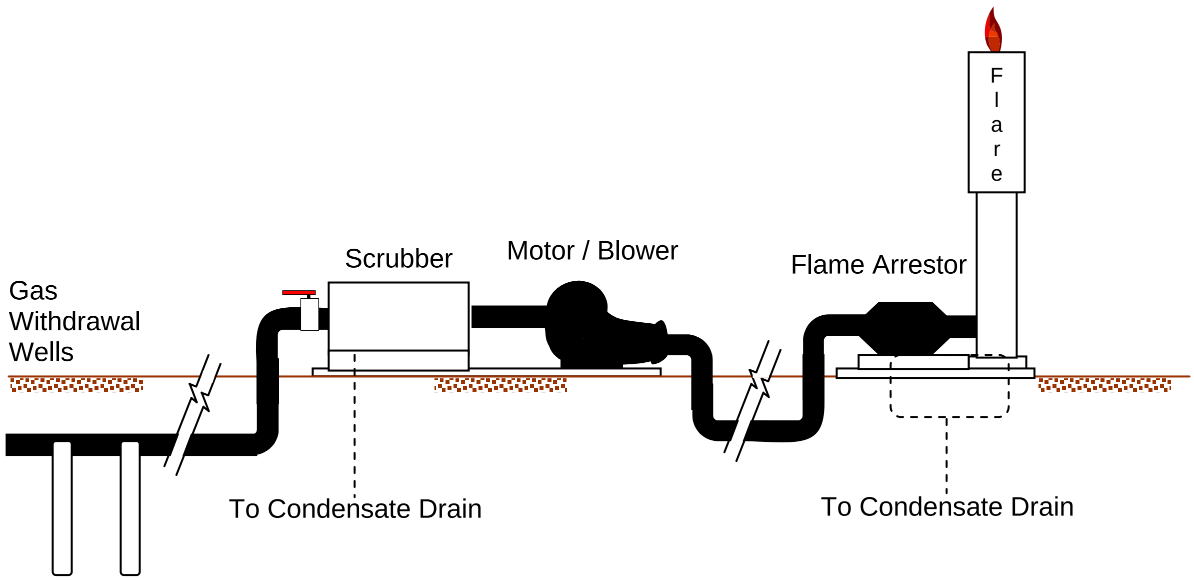
EXHIBIT 6.4: TYPICAL LFG WELLFIELD AND CONVEYANCE SYSTEMS



6.a.2 Condensate System

The LFG condensate system is responsible for removing water that condenses in the system as a result of gas cooling as it passes through the header piping and processing equipment. The condensate system uses traps, sumps, and knockouts, specifically located in the collection system, blower, and flare facilities, to collect and remove water. Such liquid gets in the way of LFG flow and must be properly managed, either through treatment and disposal back in the landfill or elsewhere. Typical LFG condensate system locations are shown in ***Exhibit 6-5***.

EXHIBIT 6.5: TYPICAL LFG CONDENSATE SYSTEM LOCATIONS



6.b Typical Components

6.b.1 Wellfield and Conveyance Systems

The primary components of the wellfield and conveyance systems include:

- Horizontal and/or vertical extraction wells (collectors)
- Well monitoring ports and flow control assembly for the extracted gas
- Piping for the LFG collection and conveyance
- Block valve
- Liquid knockout vessel
- Surface collectors
- Cover cap for the landfill.

LFG conveyance systems are typically made up of one or more of the following plastic materials: polyvinyl chloride (PVC), high density polyethylene (HDPE), and/or fiberglass-reinforced plastic (FRP) pipe. Such pipe may be placed either under ground or above ground.

6.b.2 Condensate System

The primary components of the condensate system include:

- Condensate water traps
- Sumps
- Drain lines
- Oil and water separator
- Pumps
- Treatment equipment
- Air compressor
- Storage tank

6.c Data measurements

6.c.1 Wellfield and Conveyance Systems

Collecting data from the LFG wellfield on a consistent basis is important. This will enable operators to best achieve the goal of a balanced system. Monitoring frequency for the gas wellfield depends upon field conditions and requirements, but should at least be performed monthly. Landfills with energy recovery, ground water protection concerns, etc., should be monitored more frequently.

Further, it may be necessary to adjust the wellfield to ensure that the gas collection system is in an approximate ‘steady state’ of operation. This will help to minimize the amount of air that enters the landfill through the landfill cover and other means. Balancing the wellfield is accomplished by stabilizing the quality and rate of the LFG extracted.

It is important to note that the adjustment of one well can impact the performance of other wells at the landfill site. It is suggested that adjustment readings be started at the furthest location from the blower and flare facilities and then worked toward these facilities. In this situation, it makes sense to record all of the data before making any adjustments.

The typical data measurement categories associated with wellfields include:

- Measurement person's name
- Time and date measurements taken
- Carbon dioxide concentration (as a basis for well adjustment)
- Oxygen concentration (as a basis for well adjustment)
- Methane concentration (as a basis for well adjustment)
- Balance gas (nitrogen) concentration (as a basis for well adjustment)
- Ambient temperature
- Wellhead gas temperature (an indicator of anaerobic conditions)
- Gas velocity
- Wellhead gas flow rate before and after adjustment (key parameter)
- Wellhead vacuum before and after adjustment (to calculate and determine flow)
- Wellhead adjustment valve position (to note degree it is open or closed)
- Carbon monoxide concentration (if problem suspected)
- Hydrogen sulfide reading (if problem suspected - potentially lethal)
- Maintenance observations.

While there are many wellfield adjustment criteria, methane quality and flow rate are the primary ones. These are indicators of the landfill's general anaerobic state and the impact of air intrusion on this condition. Still, a combination of criteria should be used to determine the appropriate wellfield adjustment. Key criteria, not previously emphasized, include:

- LFG control and collection system objectives

- Whether landfill conditions favor the generation of methane
- Landfill cover and construction factors (e.g., porosity, depth, leachate control, etc.)
- LFG gas well construction factors
- Proximity of side slopes to well
- Climatic, geographical, seasonal, geological, atmospheric (barometric) and other conditions

Of special note is the impact atmospheric pressure has on the behavior of LFG and system operation. Atmospheric air is driven into the landfill when this pressure exceeds the landfill pressure (i.e., indicated by negative landfill probe gage pressures). LFG is forced out of the landfill when the landfill pressure exceeds the atmospheric pressure. It therefore makes sense to monitor for LFG migration during periods when there is falling atmospheric pressure (i.e., early to mid-afternoon).

6.c.2 Condensate System

When conducting condensate data measurements, personnel should bear in mind that is very odorous and must be managed to avoid spillage.

A primary data measurement associated with condensate relates to blockage. Blockages typically result from differential settlement in the horizontal collectors, at buried road crossings, and along the LFG collection headers. By monitoring system vacuum pressure at various access ports in the system blockages can be isolated (i.e., pressure drop between access ports is a good indication of blockage).

6.d Operations and Maintenance

6.d.1 Wellfield and Conveyance Systems

From an operations standpoint, LFG extraction wells usually consist of perforated or overlapping pipe casing placed in the solid waste. A permeable material, such as gravel, is then typically backfilled over the solid waste, and an impermeable material is placed over the gravel to prevent air infiltration. Suction is then applied to each well and trench using a blower and the LFG is extracted and transported to the processing facility.

Landfill managers should always strive to achieve a smooth, consistent wellfield operation that promotes effective LFG recovery and control. Readings may be taken, relating to line vacuum, gas flow and quality, at key points along the main gas collection header and lateral branches. By doing so, leaking sections, poor performance, and pressure drops can be identified.

Normal operating activities associated with the wellfield and conveyance piping includes:

- Monitoring and adjusting LFG extraction wells;
- Inspecting landfill surface for indications that gas venting or air intrusion is taking place (e.g., settlement, openings, etc.);
- Looking at wellfields and conveyance piping for any needed adjustments and maintenance;
- Making sure monitoring instrumentation is operating properly; and
- Keeping thorough and accurate records and logs and scheduling appropriate maintenance services.

In terms of system maintenance, air leaks are a main concern. These may occur in the system as a result of settlement damage, conveyance piping expansion and contraction, system aging, and other factors. By comparing oxygen readings from the wellhead to access point readings, and looking for increasing concentrations, leaks can be detected and isolated. Major vacuum loss is another indicator of leaking air within the system. Such leaks are best repaired by replacing the damaged equipment. It is recommended that oxygen not be greater than 3 to 4 percent by volume of LFG in the collection piping.

Other maintenance activities associated with the wellfield and conveyance systems include:

- Repairing or replacing system components (e.g., wellheads, condensate traps, valves, etc.)
- Reinstalling probes (due to loss, damage, etc.)
- Repairing and adjusting piping supports and anchors
- Re-sloping and re-leveling piping support earth berms

- Removing sludge or particulate from the liquid knockout vessel (visually inspect annually)
- Making adjustments to the landfill surface (e.g., cover and cap maintenance).

Proper selection of the type of conveyance system pipe material is also important from an operations and maintenance standpoint. In choosing which pipe material(s) is most appropriate for a given LFG system, the following factors should be considered:

- Strength (a function of pipe thickness, type, and how installed)
- Chemical resistance (to varying mixtures found in the landfill)
- Weather resistance (minimized through proper storage and installation)
- Stress cracking (due to solvent, environmental, oxidative, and thermal conditions)

Ultimately, how long a pipe material lasts will depend upon the service conditions and the durability of the material.

It is also advisable to check the wellfield and collection systems for unusual conditions and maintenance needs. Unusual conditions would include: cracks and fissures, subsurface fires, liquid ponding, major settlement, etc. It should also be noted that the operation of extraction wells at temperatures greater than 145 degrees F or 63 degrees C may result in the weakening and possible collapse of thermoplastic well casings.

When repairs are being made to the LFG collection system it is often necessary to shutdown the blower and flare facilities as well. Such repairs should be coordinated with other shutdown procedures to minimize the down time of the overall LFG system.

6.d.2 Condensate System

It is typical to collect condensate from drain points in the main LFG collection header, the blower facility, and the flair facility. The condensate is actually captured and drained from the collection system using traps. These traps vary in design but all rely on a loop seal to maintain a liquid head pressure and overcome any countervailing force. ***Exhibit 6-6*** illustrates typical condensate trap.

EXHIBIT 6-6: LFG CONDENSATE TRAP

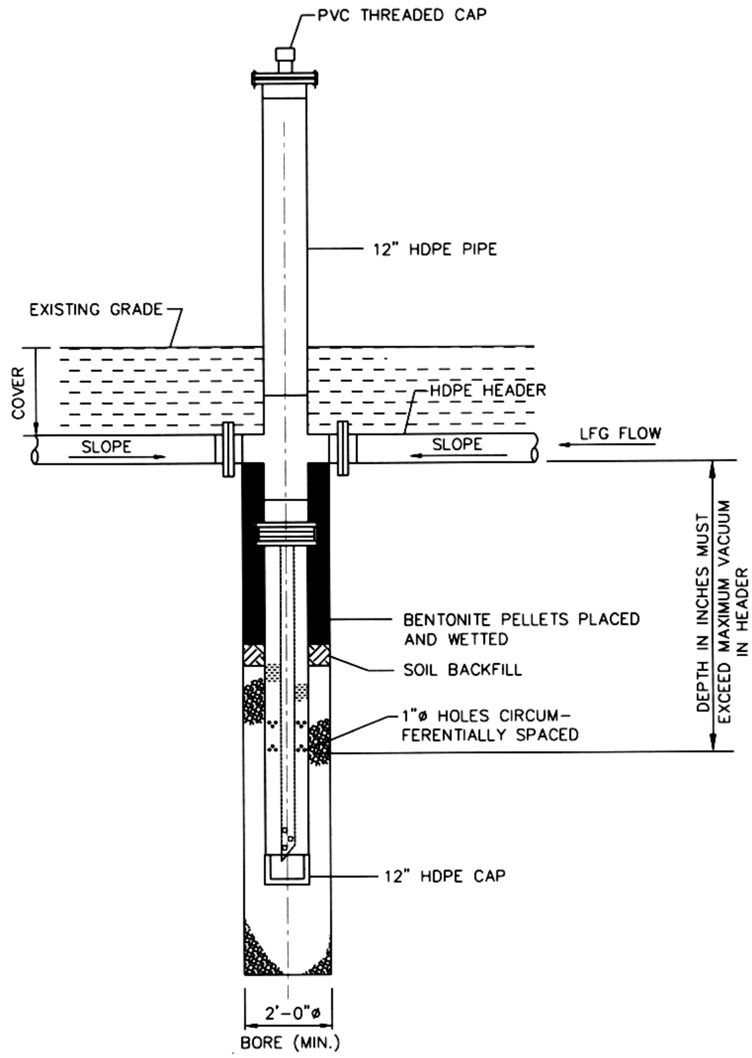


EXHIBIT 6-7: LFG CONDENSATE TRAP CONFIGURATIONS

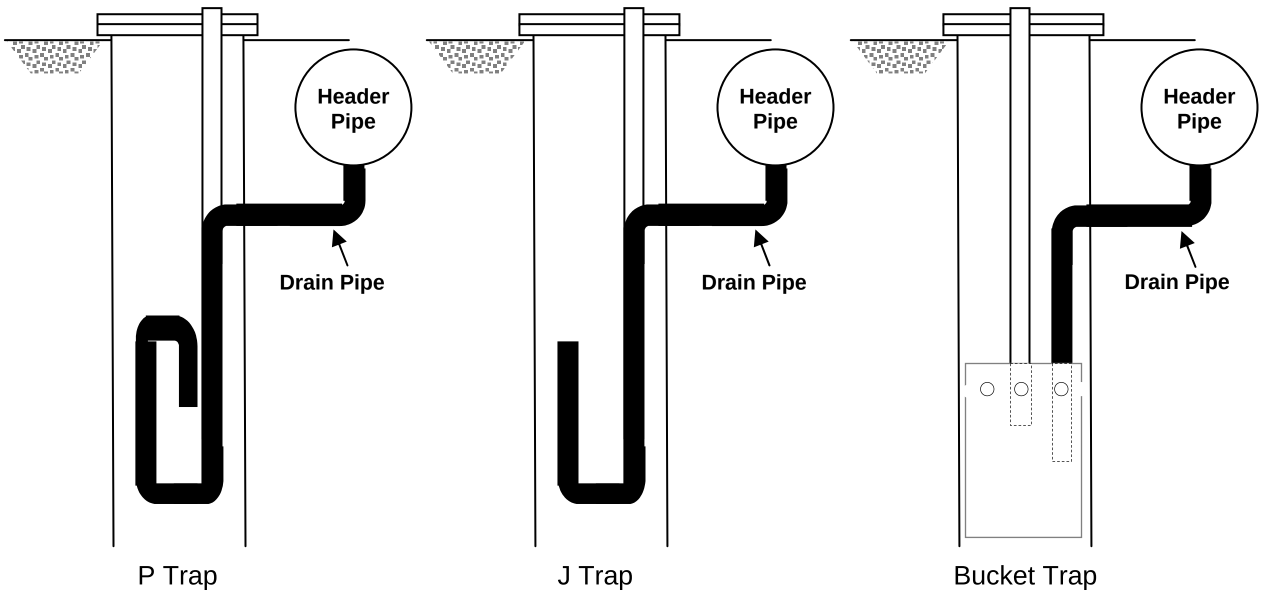


Exhibit 6-7 specifically shows “J,” “P,” and “bucket” style traps. J and P traps protect against liquid loss by being fitted with a sealing check valve to maintain a vacuum and seal the system. Bucket traps overflow either into a gravel pack and are directed into the landfill, or into a sump or container for transport off-site. Sumps can be automatically or manually pumped or drained.

Once collected, condensate is often stored in a single tank for later treatment and disposal. Such treatment and disposal can be done in a number of ways. Depending upon the level of contaminants in the condensate, treatment may simply involve the separation of oil from water or the adjustment of liquid pH, or it may involve a more complex process. Condensate often consists of a water based phase (i.e., aqueous), and an organic solvent and oil based phase (i.e., hydrocarbon).

Treatment and disposal options for LFG condensate include:

- Biological treatment
- Physical and chemical treatment
- Ultra-violet (advanced oxidation potential) and ozone treatment
- Combustion destruction (incinerator or flare)
- Waster reclamation discharge (for irrigation)

- Leachate management system discharge
- Hydrocarbon phase recycling
- Treatment, storage, and disposal as hazardous
- Sanitary sewer disposal
- Publically-owned treatment works disposal

Treatment and disposal techniques for condensate vary, depending upon the contaminants present, compliance requirements, and available treatment options.

The primary maintenance activities associated with the condensate handling includes:

- System components replacement or repair (e.g. condensate traps, sumps, pipe fittings, etc.)
- Correcting condensate blockages

6.e Health and safety

6.e.1 Wellfield and Conveyance Systems

When drilling and constructing a gas extraction well, the following types of safety procedures should be followed:

- One person who is fully trained in safety procedures and the use of safety equipment should be present at all times
- Fire extinguishers should be on location and there should be no smoking within 15 meters of a boring
- Personnel working near the well edge should be tethered to a parachute-type harness and safety line tied to an immobilized structure
- Workers near the drilling operation must bear in mind the less stable nature of solid waste buried in a landfill and the potential for side wall failure

- Drill operators should bear in mind potential contact with hazardous materials (e.g., chemical drums, asbestos, biomedical waste, radioactive waste, military munitions, etc.), especially if drilling in older landfills
- The well hole should be covered and all pipes should be capped at the end of the work day
- An exhaust hood should be used, if possible, to reduce exposures to LFG vapors

In addition, landfill personnel should be prepared for potentially lethal concentrations of hydrogen sulfide that could be present. Should high levels be detected, the use of supplied air or self-contained breathing apparatus may be required. In addition, operators should also periodically monitor for the presence of high levels of residual nitrogen since this could indicate conditions that could spark a landfill fire. Carbon dioxide concentrations can be used to determine residual nitrogen.

When performing landfill excavations, trenching and pipe installation, the following additional types of safety procedures should be followed:

- The atmosphere should be tested in excavations deeper than three feet before personnel are allowed to enter the space. Depending upon the test results, the appropriate respirator device should be used
- Workers should wear protective gloves and clothing to protect against direct exposure to the excavated waste
- Electrical motors should be non-sparking or explosion proof and construction equipment should have a vertical exhaust at least five feet above landfill grade
- Soil should be stockpiled near the excavation to smother any combustion that might occur
- Welding should not be permitted in or near the work area, unless it is verified on a continuous basis that methane and other combustible gases are not present
- As pipes are assembled, valves should be closed to prevent LFG migration through the system
- Gluing, bonding, or solvent pipe cleaning should be performed outside the trench to the fullest extent possible

- Common trench precautions should be taken. For example, no one should enter a trench deeper than about one meter unless precautions have been made to prevent cave-in (e.g., bracing, shoring).

6.e.2 Condensate System

Personnel should always avoid skin contact with condensate water because it may be biologically active and contain trace chemicals. When handling condensate, protective gloves and the appropriate splash protection should always be used. Also, VOCs may be released from LFG condensate and vapors emitted from storage tanks may be flammable. Such vapors need to be properly managed.

7. Landfill Biogas Blower Systems

7.a System Description

As noted in previous sections, landfill biogas is transported from the landfill wellfield to the blower facility by way of the main gas collection header. LFG then typically passes through a liquid knockout vessel for the removal of gas particles and liquid, before being routed to the blower. Block valve and bypass valves may be actively used at some landfills if there is a desire to route gas around the liquid knockout vessel. This is generally not recommended because condensate removal helps to protect processing instrumentation and equipment.

The blower facility and associated control equipment can either be housed inside a building or be exposed to the elements outside. See ***Exhibit 7-1***. It should be centrally located with room for expansion and supplied power. It should also have the capacity to handle 100 percent of the LFG peak production estimate, plus additional size for LFG migration control. Butterfly valves are often installed on the inlet and outlet piping for each blower being used to allow for continuous blower operation during scheduled maintenance and shutdowns.

EXHIBIT 7-1: TYPICAL BLOWER FACILITY

The purpose of the LFG blower (also known as a compressor) is to create a vacuum for the extraction of gas from collection wells and trenches under pressure, the pulling of the LFG to the blower, and the pushing of the LFG to the flare or other treatment equipment. This process is known as actively controlling LFG, which contrasts with passive LFG control (i.e., LFG is allowed to move without any mechanical assistance). Passive systems, where LFG is typically allowed to vent into the atmosphere with little or no treatment (i.e., treatment options might include removal of VOCs using granular activated carbon and flaring at vent wells), most often are not advocated for modern landfill operations.

The start-up procedure associated with the blower system will vary depending upon the design of individual facility. Landfill operators should follow the recommended procedure of the blower system manufacturer.

7.b Typical Components

The primary mechanical component of the blower system is the gas compressor or blower itself. Other associated equipment may include:

- Valves (automatic block, check)
- Flow metering and recording
- Gages to measure pressure, temperature, etc.
- Condensate treatment and handling equipment
- Electrical equipment
- Instrumentation
- Utilities.

Selection of the appropriate blower is determined by such factors as the quantity and end use of the LFG, the vacuum required to extract the gas, the pressure required for processing, etc. The main types of blowers used for LFG applications include:

- Single- and multi-stage centrifugal blowers (i.e., constant vacuum/pressure, variable gas volume machines, incorporating a butterfly valve at the unit inlet)
- Positive displacement lobe blowers (i.e., constant volume, variable pressure machines, where volume is varied only by a speed change of the rotating lobe)

7.c Data Measurements

Operators should bear in mind that blowers compress LFG, typically in the 10 to 100 inches water column of total pressure or head. The vacuum created by the blower is impacted by the number of wells and will typically range between 15 and 85 inches w.c. of vacuum. Depending upon the operating gas flow and flare burner design, the discharge pressure from the blower typically ranges between 5 and 15 inches w.c. As the LFG is pushed from the blower toward the flare system, it is often routed through a metering device so flow rate can be measured and recorded.

Key process parameters are also measured in the blower facility through the use of pressure gages. The typical type and location of these gages include:

- Inlet temperature
- Inlet vacuum
- Inlet separator differential pressure
- Ambient temperature
- Blower suction pressure
- Blower discharge pressure
- Blower discharge temperature

7.d Operations and Maintenance

The typical blower is a single-stage or multi-stage centrifugal gas compressor that is belt-driven or directly-driven by an electric motor. Proper operations and maintenance of a blower facility requires the following types of activities, on an as needed basis (i.e., daily to monthly, depending upon the facility design, system components, etc.):

- Checking the pressures and temperatures associated with blower suction and discharge to make sure there is adequate flare fuel pressure
- Checking for out of the ordinary blower vibration or temperature (weekly)
- Periodically draining condensate from the blower housing
- Running standby blowers (weekly)
- Checking drive belt wear and tension (monthly)
- Observing the levels of lubricants
- Greasing appropriate equipment parts (electric drive motor)

- Looking at the position and condition of valves (check valve, block valve)
- Determining the quality and temperature of LFG gas
- Monitoring instrument air operation
- Figuring out the status of condensate, LPG, propane, lube oil tank levels
- Monitoring overall system operations.

If maintenance is required, it is important to note all activities in a log book and on recorder strip charts, and take all appropriate corrective action as soon as possible.

7.e Health and Safety

When working in the vicinity of the blower facility, the appropriate health and safety precautions associated with electrical equipment, noise, heat, etc., should be taken.

Loose items, such as identification badges hanging around the neck, should never be worn around belt-driven or rotating equipment. When performing any type of troubleshooting or testing, personnel should not wear rings, watches, id bracelets, or any other accessory that could be caught in the equipment.

8. Landfill Biogas Flare Systems

8.a System Description

Once LFG gas has been routed through the blower system, it typically passes through check valves and an automatic block valve enroute to the flare facility. The automatic block valve is usually fitted with a valve position indicator. LFG then travels to a flame arrester and into the flare facility where it is burned (i.e., in systems without energy recovery). The high temperature flaring of LFG converts methane to carbon dioxide and water, eliminates odorous gas compounds, and ensures that trace chemicals are largely destroyed.

LFG is burned by one of two types of flares. The first is an enclosed ground flare which burns at a controlled and predetermined temperature range. See ***Exhibit 8-1***. These flares are commonly equipped with air dampers to control combustion temperature. Such dampers can be manual, automatic, or a combination of both. The second type is a candlestick or open flame flare which is less sophisticated and not temperature controlled. See ***Exhibit 8-2***. Either flare system provides for a LFG disposal alternative.

Flares are also typically equipped with a pilot ignition system (i.e., natural gas or propane) and a safeguard system for flames. The flame safeguard controller has the following two functions:

1. Makes sure that the pilot and main flame are lit and the on-going operation of the main flame
2. Shuts down the flair unit if the flame goes out

EXHIBIT 8-1: TYPICAL ENCLOSED GROUND FLARE

EXHIBIT 8-2: TYPICAL CANDLESTICK FLARE

The primary goal of proper flare design is to burn all of the LFG collected from the landfill. Optimizing this objective usually requires making sure a balance is achieved between the flare having enough capacity to handle the LFG flow, and making sure the LFG flow is sufficient to optimize the flare handling capacity. Flares may also be used as a backup for energy recovery systems during scheduled and unscheduled down times.

While the most common LFG treatment and disposal method is destruction by combustion in a flare, venting LFG through granular activated carbon (i.e., for the removal of VOCs and non-methane organic compounds (NMOCs) emissions) is also practiced.

8.b Typical Components

The primary components of the flare system may include:

- Valves
- Flow metering
- Pilot ignition system
- Flame safeguard system

- Flame arrester (prevents flare flame from moving backwards into piping)
- Flare
- Electrical controls and service
- Gages to measure temperature, pressure etc.
- Instrumentation
- Condensate equipment (traps, drains, sumps, pumps)
- Utilities

8.c Data measurements

It is typical for data measurement test ports to be installed in the flame arrester. These are used to test LFG pressure as an indicator for blockage. Installation of a differential gage across the flame arrester ports is also worth considering.

In terms of the flare itself, testing access ports are typically located half way down from the top. These are equally spaced in four locations and allow for source testing. For enclosed ground flares, the temperature of the combusted LFG in the flare is measured using a thermocouple device. Also, air flow into the flare is controlled to maintain the desired temperature. The flare operating temperature is the primary process control variable used to ensure that LFG VOCs and methane are sufficiently destroyed.

Key process parameters are also measured in the flare facility through the use of pressure gages. These are typically located in the following areas:

- Flame arrester (differential pressure)
- Flare inlet (pressure)
- Air receiver instrument (air pressure)

8.d Operations and Maintenance

The equipment leading up to and including the flare system are operated by a nearby electrical control panel. This includes start, stop, and reset buttons, and other switches for system operations. An electrical service panel is also typically located in close proximity.

To start the flare ignition sequence, most systems rely on a switch or button operation. Pilot fuel is lit with a spark igniter after the pilot solenoid valve is opened. The flame safeguard system verifies the existence of the pilot flame, the automatic block valve opens and the blower starts. This is followed by the ignition and operation of the main LFG flame which will establish a minimum operating temperature of 760^{o}C. If the flare does not reach this minimum operating temperature within an established period of time, it will shut down. The normal operating temperature range is 750^{o}C to 850^{o}C.

Proper operations and maintenance of a flare facility requires a variety of activities, on an as needed basis (i.e., daily to monthly, depending upon the facility design, system components, etc.). A majority of the maintenance activities associated with the candlestick flare (i.e., proper fuel mixing, velocity, quality, flame condition, wear due to thermal stress) are also required for the enclosed ground flare system. The operational life of flare equipment can be maximized by operating the flare at the minimum recommended temperatures for emission control. Other specific operation and maintenance activities include:

- Checking the alarm or annunciator panel for any system malfunctions
- Observing that the flare temperature is in the proper operating range (daily)
- Inspecting the firing condition of the flare (secondary air dampers and flame)
- Checking the valve position at the flare inlet (for proper flare adjustment)
- Making sure the flame arrester is properly functioning (differential pressure)
- Observing facility flow
- Maintaining the igniter and pilot fuel systems
- Removing any condensate from the flare
- Checking the internal refractory for heat and other damage (enclosed ground flare)

- Inspecting high temperature shutdown/switch annually
- Cleaning electrical equipment controls and instrumentation annually
- Inspecting condensate equipment corrosion and other maintenance needs
- Completing a visual and audible check of overall system operations.

If maintenance is required (e.g., replacing corroded pipes, valves, etc.), it is important to note all activities in a logbook and on recorder strip charts, and take all appropriate corrective action as soon as possible. Further, it is desirable to maintain a minimum methane concentration for good combustion at the flare. About 25 percent methane is a practical minimum.

8.e Health and Safety

In terms of health and safety issues associated with flare operations, it is advisable to stay away from any flare openings during system ignition. This is because some flares can start with a “poof” and flames can shoot through flare dampers. Toward this end, personnel should avoid wearing synthetic clothing (e.g., polyester) since it is extremely flammable and potentially fatal if it catches on fire. All cotton clothing is recommended.

It is also advisable to install a safety shutoff device or high temperature sensor between the flame arrester and the flare. This will provide the operator with a safety switch should there be a flare flame in the pipe or a flash back.

When conducting maintenance inspections on a flare, health and safety precautions must be applied. Activities requiring entering the flare and should be treated as accessing a confined space. Before entering a flare, all appropriate testing for an explosive and oxygen deficient environment, confine space entry requirements, and safety precautions should be performed.

Likewise, loose items, such as identification badges hanging around the neck, should never be worn around belt-driven or rotating equipment. When performing electrical troubleshooting or testing, personnel should not wear rings, watches, id bracelets, or any other accessory that could be caught in the equipment.

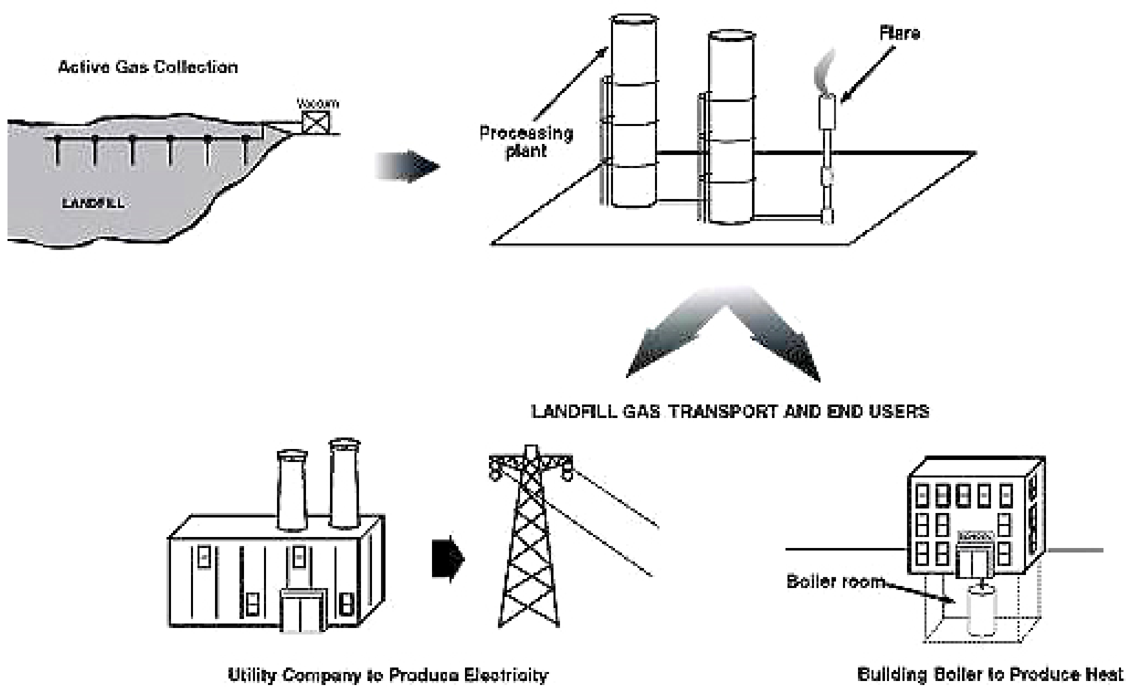
Further, it is advisable to have an emergency shutdown procedure for the flare facility. Such a procedure typically involves having an emergency stop button, a method for ensuring that gas from the wellfield can be stopped via a redundant block valve system, having a procedure in place to respond to a fire, cutting off the main power at the electrical service cabinet, etc.

9. Landfill Biogas Energy Recovery Systems

9.a System Description

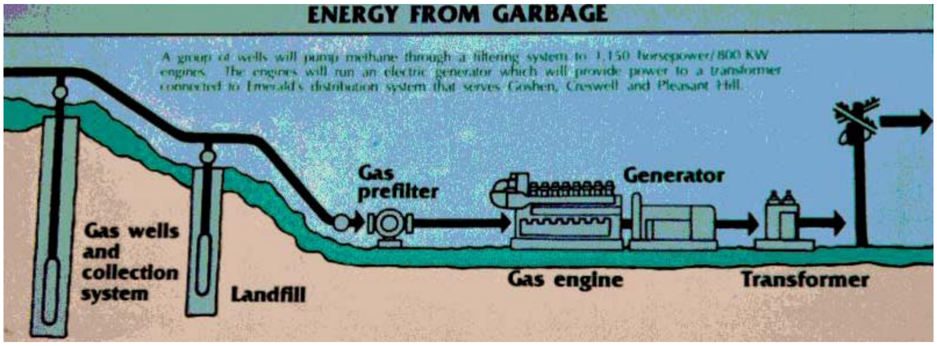
Methane from LFG can be recovered and put to beneficial use as a renewable energy resource. There are many applications for methane use including in furnaces, vehicles, fuel boilers, as a feedstock for chemical processes, engines, etc. See ***Exhibit 9-1*** for a summary of alternative LFG energy uses.

EXHIBIT 9-1: LFG ENERGY USES



In LFG systems designed with energy recovery as the end objective, the goal is to maximize the BTU flow rate and meet established emission limits. See ***Exhibit 9-2*** for an example of a typical LFG energy recovery facility. With this type of operation, combustion is typically used to destroy LFG volatile organic compounds (VOCs). This is one of the side benefits associated with generating energy from LFG.

EXHIBIT 9-2: TYPICAL LFG ENERGY RECOVERY FACILITY



The energy generated from LFG can range from low-grade to high-grade, depending upon the level of processing the gas is subjected to. A brief description of the processing associated with each fuel type follows:

- **Low-grade fuel** production requires little processing, primarily involving condensate removal as part of the LFG collection system, and the use of liquid knockout vessels to reduce LFG moisture quantities

- **Medium-grade fuel** requires additional LFG treatment (e.g., compression, refrigeration, scrubbing, and/or chemical treatment) to extract more contaminated moisture and finer particles

- **High-grade fuel** requires extensive gas pretreatment to remove carbon dioxide and other gases (i.e., with no heat value) from the methane, to remove impurities such as VOCs, and also requires gas compression for gas dehydration

9.b Typical Components

Typical LFG energy recovery operations include the following types of system components:

- Heat Exchangers
- Process Chillers
- Engines
- Gas Compressors

- Gas Turbines
- Electrical Generators
- Boilers

A brief description of each component follows:

- **Heat Exchangers** are used to cool and heat LFG; examples include: a gas/chilled water exchanger used to cool LFG and capture water condensate to meet dew point specification of the gas; a gas/gas exchanger to reheat LFG back to above its dew point; air exchanges to cool LFG or water from compressors; jacket water radiators for the compressor, engine, or turbine to maintain cooling jacket oil or water within a set temperature range; cooling tower to cool compressor and engine water jacket water.

- **Process Chillers** are used for LFG dew point suppression in order for the LFG product to meet use specification and not condense out liquids that might interfere with LFG use.

- **Engines** are responsible for driving generators and compressors in medium BTU LFG operations, and usually require a minimum gas quality of 50 percent to function properly.

- **Gas Compressors** are responsible for pressurizing LFG for use in engines, turbines, boilers, and gas pipelines.

- **Gas Turbines** are responsible for driving generators to create electric power, and may be adversely impacted by corrosion and poor gas quality.

- **Electrical Generators** are typically linked to a gas turbine or engine and are responsible for generating electricity.

- **Boilers** are used to generate steam through the heating of water, under high or low pressure. Like turbines, boiler performance may be adversely impacted by corrosion and poor LFG quality. Delivery of consistent LFG pressure also facilitates good combustion and operation.

9.c Data Measurements

To ensure proper operation of the energy recovery system, data measurements linked to the components described in Sect 9.b. should be taken on an as needed basis. As with other LFG system equipment components, it is advisable to follow the equipment manufacturer's recommendations concerning the frequency of practices relating to data measurement and equipment maintenance.

9.d Operations and Maintenance

When operating the LFG system with energy recovery in mind, it is important to keep the concentration of methane at a high level (e.g., 50 percent or more), to manage the flow of LFG from the wellfields conservatively, and to keep air intrusion into the system to an absolute minimum. Too much air will inhibit the production of LFG and too much LFG extraction will reduce the heat value and quantity of available methane.

When maintaining an energy recovery system it is common to have to shut the equipment down. This should be kept to a minimum since LFG will escape from the landfill and that energy value will be forever lost. There is the potential for considerable odor releases during shut down as well. During such maintenance procedures, LFG should be redirected to a control device (e.g., flare) to minimize emissions and migration.

It is typical with energy recovery efforts for operators to have a dual objective of energy recovery and management of emissions and migration. In such cases, it is common for operators to pull the LFG easier from the interior of the landfill for energy recovery purposes, and to pull harder along the landfill perimeter for migration control. Ultimately, good planning and a proactive maintenance program are keys to successful energy recovery operations.

Further, it is desirable to maintain a minimum methane concentration for the successful operation of energy recovery equipment. About 25 percent methane is a practical minimum for boilers. Engines typically require at least 40 percent methane.

Another key to successful facility operation is the proper operation and maintenance of the process chillers. This is best accomplished by observing operating pressures and temperatures and watching for signs of off specification performance such as refrigerant leaks, a dirty process chiller condenser, an overloaded process chiller, etc.

Likewise, LFG operations are often hindered by excessive engine wear resulting from acid formation in the engine crankcase. This is best remedied by maintaining oil temperatures in the 90o C range (i.e., well above the water dew point). Routine maintenance of gas compressor components, and annual inspection of generator windings are other keys to consistent facility performance.

9.e Health and Safety

When working in the vicinity of the energy recovery facility, the appropriate health and safety precautions associated with electrical equipment, noise, heat, etc., should be taken.

Loose items, such as identification badges hanging around the neck, should never be worn around belt-driven or rotating equipment. When performing electrical troubleshooting or testing, personnel should not wear rings, watches, id bracelets, or any other accessory that could be caught in the equipment.

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