Anaerobic Digestion for On-farm Uses - Operations and Maintenance Guide

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Contents

1. Introduction

1.1 Anaerobic digestion for farm-waste management and climate-change mitigation

Ireland's extensive agricultural and food industry is a large source of greenhouse gas emissions. With a global warming potential about 25 times greater than that of carbon dioxide (CO_2), methane (CH_4) emitted by livestock and livestock manures is of particular concern. These industries also produce significant amounts of other biodegradable wastes, such as dairy, brewing and food processing wastes that require appropriate management.

Ireland has a long-term vision for a low-carbon energy system. Its goal is to reduce greenhouse gas emissions from the energy sector by 80-95% (compared to 1990 levels) by 2050.[1] To achieve this, Ireland will need to radically transform its energy system: reducing energy demand and moving away from fossil fuels to zero or low-carbon fuels and power sources.

Anaerobic digestion (AD) is the controlled use of biodegradable organic materials for the production of renewable energy in the form of biogas and organic fertiliser. The process could have numerous benefits for the agricultural sector.

AD facilities can process biodegradable organic wastes from the agricultural and food industry, other food waste, and suitable and sustainable energy crops grown specifically for energy production, such as grass silage. Energy crops with high lignin content, such as willow coppice, are not suitable for AD, being too slow to biodegrade. Usable food wastes include rejected or out-of-date products from manufacturers or retailers, and wastes from commercial and domestic kitchens. Such wastes, however, usually come with the challenge of removing items, such as packaging, bones, and cutlery, that can cause operational problems and contamination.

On-farm AD provides a means of recycling waste organic matter into organic fertiliser, thus reducing costs, diverting wastes from landfill, reducing CH_4 emissions (thereby mitigating climate change), and generating a low-carbon renewable energy source. Using the biogas in gas engines to generate electricity and heat can save on farm purchases of electricity and fossil fuels, whilst any excess electricity or heat can provide additional revenue. Biogas can also be upgraded to biomethane that is suitable for injection into the natural gas network or compressed into containers for use as a fuel in other applications, such as road transport.

Key benefits of AD to the agricultural sector:

- **Presents a clean manure- and waste-recycling route to conserve resources;**
- **Production of improved organic fertiliser, cutting the outlay on chemical fertilisers and reducing the wider environmental impacts of producing artificial fertilisers;**
- **Reduces environmental pollution through better waste management;**
- **Reduces greenhouse gas emissions, particularly from livestock, thus helping to mitigate climate change; and**
- **Produces renewable electricity and heat for on-farm use, potentially creating an additional source of income from sales of heat, electricity or biomethane as renewable energy.**

A farm-based AD system needs to be developed as an integrated system; therefore, many factors must be considered together. The key considerations include:

- The characteristics of the feedstocks to be used;
- The scale and design of the anaerobic digester;
- The use of the biogas generated, whether for energy production or upgrading to biomethane; and
- The management of the digestate to maximise the nutrient benefits available.

[1] https://www.dccae.gov.ie/en-ie/climate-action/publications/Documents/5/National%20Climate%20Policy%20Position.pdf

This document presents guidance on the implementation of farm-based AD systems.
Complementary guidance is presented in three accompanying documents:

- The **Overview Guide** introduces AD to those who are unfamiliar with the technology but may be interested in using it. For example, a farmer who produces large quantities of animal manure might consider the controlled processing of the manure in an AD facility to improve environmental performance and reduce expenditure on energy.
- The **Implementation Guide** provides guidance on the steps to implement an AD facility, from initial conception through to commissioning of an operational facility.
- The **Technology Guide** describes the main types of technologies that may form part of an AD facility.

Together these guides provide a comprehensive starting point for anyone wishing to better understand the technology, its implementation and ongoing management.

1.2 Purpose of this guide

This guide is intended primarily for those considering developing an AD facility.
Its main aims are:

- To provide information on the typical operation and maintenance requirements, good practices, and essential issues associated with running AD systems; and
- To direct the reader to sources of more detailed information on specific issues regarding the operation and maintenance of AD facilities.

1.3 Scope

The four guides concentrate primarily on farm based AD systems fed with farm-derived feedstocks such as:

- Animal manures;
- Purpose-grown crops and crop residues; and
- Other suitable biodegradable wastes and food processing residues that can be brought onto the farm as feedstock.

Figure 1.1: Farm-based AD system

However, the principles can also be applied to AD systems in other, off-farm settings.

Outside the scope of these guides are the Support Scheme for Renewable Heat (SSRH) terms and conditions.[2] The SSRH is a government-funded scheme to encourage the installation of renewable sources of heat in non-domestic applications in the Republic of Ireland. These guides will help applicants identify the appropriate standards and best practice for on-farm AD uses. These guidelines provide an applicant with guidance on good practice only. The Ministerial Terms and Conditions, the Grant Scheme Operating Rules and Guidelines and the Tariff Scheme Operating Rules and Guidelines, where relevant, set out the basis on which the support scheme for renewable heat will operate.

[2] https://www.seai.ie/business-and-public-sector/business-grants-and-supports/support-scheme-renewable-heat/

2. Environmental Considerations

2.1 Introduction

An AD plant has the potential to affect its local environment in a variety of ways. These range from simply being a nuisance to local neighbours through odour emissions or poor pest control, through to more serious environmental incidents such as release of gas or effluent to the environment. This section describes some of the environmental risks associated with operating an AD plant, and the steps that can be taken to mitigate them.

General environmental principles:

- **An AD facility can affect its local environment through emissions, vehicle movements, pests and other factors;**
- **Any operator or potential operator needs to be aware of the key risks involved and of the appropriate actions required to mitigate them;**
- **AD facility designers should always try to design-out the hazards before resorting to other methods of mitigation, such as engineering or procedural controls; and**
- **Training, standardised procedures and risk assessment are key tools to ensure a facility is run safely and effectively.**

2.2 Emissions

2.2.1 Biogas

It is vital to ensure that gas storage vessels and pipelines are gas-tight and operating correctly. A failure in the gas handling equipment can increase the explosion risk, create a health and safety risk for employees, and potentially release biogas to the atmosphere. As biogas has a high concentration of methane and carbon dioxide, the permitting authority may treat a discharge of biogas as a breach of permit conditions.

Operators should monitor gas pipework and storage closely. Devices such as pressure sensors allow operators to ensure gas pressure is stable and could alert operators to the presence of any leaks or faults in the system. Anaerobic digesters use pressure relief valves (PRV) and, sometimes, blast panels to protect equipment against pressure changes (see Section 4.5 of the accompanying Technology Guide). PRVs cause a release of biogas to the atmosphere, and should be configured to minimise unnecessary emissions, whilst ensuring that their protective function is not compromised.

2.2.2 Water

An AD facility generates wastewater with varying degrees of quality, from relatively clean surface drainage to highly contaminated leachates. Operators are governed as to how this water should be managed by their local Environmental Protection Agency officer, by Irish Water, or by both. Early communication with these bodies is critical.

It may be permissible to discharge surface water to the local surface water drainage system or a suitable watercourse, but it is likely that this will need to be monitored to ensure it meets discharge standards. Therefore, sampling arrangements form part of the drainage design.

An area where feedstock material is stored, and leachate is likely to be generated, will require its own drainage or sump, and care must be taken to ensure this cannot contaminate surface water. The best way of dealing with leachate is to use it as process water, which contributes to biogas generation and reduces the amount of fresh water required by the AD facility. Leachate that cannot be pumped into the process will need to be treated on site until it meets the standard required to be discharged locally into the sewer, or tankered away for treatment off site.

Sites that handle waste material containing animal by-products must comply with the Animal by-products Regulations. This EU legislation (No. 1069/2009) is applicable to all member states and enforced in Ireland via Statutory Instrument No. 18 7 of 2014, European Union Animal by-products Regulation.[3] This puts in place rules regarding the handling of animal by-products and animal-derived products not intended for human consumption. Further information on the regulations and the background to the applicable legislation and regulation is provided in Section 7.6.15 of the accompanying Implementation Guide. The full legislation can be found on the Department for Agriculture, Food and the Marine website.[4] Operators will need to pay particular attention to drainage to ensure 'clean' areas of the site (handling pasteurised material) cannot be cross contaminated with 'dirty' (unpasteurised) material. This may involve segregated drainage arrangements, and disinfectant to clean mobile equipment, and employees' footwear.

2.2.3 Odour

Any site that handles waste materials will need to make provision for odour management. Odour is inevitable when storing and processing biodegradable organic material and is likely to be the first thing that local residents, businesses and visitors to the site will notice when the facility is operational.

The level of odour control required varies from site to site and depends on factors such as proximity to sensitive receptors (for example, dwellings and schools), type of material being handled and the installed facility infrastructure. If odour-control equipment is required, this typically includes an air extraction system made up of ductwork and fans, odour abatement equipment (for example, a biofilter or activated carbon filter or scrubber) and an exhaust stack.

The type of odour abatement equipment required will depend on the composition of the odorous air stream. Operators should seek specialist advice on the appropriate odour control system for their feedstock and process. More information is provided in Section 7.3 of the accompanying Technology Guide.

The planning and permitting authority are likely to require an odour management plan. Part of this will include regular on-site and off-site monitoring to check that odour levels are acceptable to neighbouring residents and businesses.

2.2.4 Combustion emissions

Figure 2.1: Typical containerised gas engine

Where biogas is used as a fuel on site (for example, in a boiler, gas engine or turbine, and flare) combustion emissions are generated. As part of the permitting process, emission limits will be imposed. The permit will also stipulate a testing schedule whereby results are reported to the permitting authority. Common combustion emissions that require monitoring include:

- Sulphur dioxide
- Nitrogen dioxide
- Volatile organic compounds
- Carbon monoxide

The emission limits imposed should be made available to the combustion equipment supplier so that the equipment can be specified and commissioned accordingly.

[3] http://www.irishstatutebook.ie/eli/2014/si/187/made/en/print
[4] https://www.agriculture.gov.ie/agri-foodindustry/animalbyproducts/

2.2.5 Dust and bioaerosols

Dust can be an issue when storing and processing dry feedstocks, or in summer months when site roads can become dusty. In extreme cases, dust poses an explosion risk. In less concentrated amounts, it can be an irritant for staff members, local residents and businesses. It can also present a fire risk if allowed to accumulate on buildings and equipment. Operators should take measures to control dust, such as damping down roads and dry stockpiles with water and put in place a thorough cleaning regime to clear accumulated dust regularly.

When organic wastes are processed, small amounts of material are often released as microscopic particles that can disperse through the air as bioaerosols. Measures should be put in place to control bioaerosol emissions (refer to Section 5.1 of the Overview Guide for information on microbial pathogen risks).

2.2.6 Litter

For facilities processing waste materials, particularly packaged waste (which will need to be de-packaged prior to digestion), consideration should be given to managing litter around site. Waste packaging material should be stored and loaded into vehicles within a building where possible, and the vehicle container sheeted or sealed before leaving the building. Where this is not possible, operators should install litter fencing at the site perimeter, and conduct regular litter picking.

2.2.7 Vehicles

For a facility processing waste or importing energy crops from other locations, most of the feedstocks is carried in road vehicles. The site planning permission is likely to specify the maximum permissible number of vehicles that can enter and leave the site in a day, and the hours during which vehicle movements are allowed. When planning a facility, operators should consider the type of vehicle, the capacity, and the amount of waste to be imported so they can accurately forecast vehicle movements.

During the design stage, operators should consider how vehicles will be received on site, and how they will circulate around it. A good design will minimise congestion and prevent vehicles from queuing off site; something that could prove a nuisance for nearby residents and businesses and cause localised pollution.

Vehicles should be suitable for the type of material they are carrying. In addition, waste materials should be enclosed or sheeted, to prevent items falling out in transit.

2.3 Pest management

2.3.1 Birds

Depending on the type of facility, birds may or may not be considered pests. For a simple facility that processes energy crops and stores material in the open, birds are hard to control but are unlikely to cause too many issues.

For a facility processing waste material with enclosed storage areas, however, scavenging birds may be attracted to the site and become a nuisance as they will roost inside buildings. They may also build nests, which is a fire risk. On a site that must comply with the Animal by-products Regulation, the presence of birds must to be controlled so that they do not risk contaminating pasteurised material.

2.3.2 Flies

Flies will only present an issue at certain facilities. Operators of facilities processing energy crops with open storage areas may not experience any problems with flies or may consider the number of flies present to be acceptable, depending on how close the facility is to neighbours.

Flies are more likely to present a problem at facilities processing waste feedstocks, particularly where these are close to neighbouring residences or businesses. Fly numbers can be reduced by maintaining a regular stock rotation and processing delivered materials promptly to ensure fly eggs in the waste do not hatch. A good cleaning regime will also help to keep areas clear of organic material and to remove fly eggs before they hatch. Finally, there are numerous commercial pest control companies available to carry out fly knockdowns using chemicals.

2.3.3 Rodents and other vermin

Rodents and vermin are commonly found anywhere that a food source is stored. These can include mice and rats, but also other animals such as foxes and cats. These pests are problematic as they consume the feedstock, create an unhygienic environment, and can spread diseases such as Weil's disease.

It is difficult to control of vermin once they become numerous. Simple precautions such as maintaining good standards of cleanliness and hygiene help, as does storing feedstocks in bunkers or storage vessels that the animals will find hard to get into. There are also commercial pest control companies that can put together a pest management strategy using bait boxes, traps and poisons.

2.4 Site security

2.4.1 Perimeter security

An AD facility is a dangerous environment and it is the operator's responsibility to ensure that, as far as practicable, the site cannot be accessed by intruders who could put themselves at risk or compromise site safety. The site perimeter should be secured using appropriate fencing, and all access routes should have secure gates and locks or a form of access control.

2.4.2 Closed-circuit television

Closed-circuit television (CCTV) is useful for security, as it enables constant monitoring of the site and identification of suspicious activity; and for monitoring process safety and process control. Cameras can be used to check for material blockages in equipment, and view stock levels and vehicle tipping operations. Combined with recorders, CCTV allows incidents to be reviewed as part of any investigation process. Two types of camera are commonly used:

- Fixed
- Pan, tilt and zoom.

A fixed camera is useful for surveilling an area that needs constant attention, such as an entrance gate. A pan, tilt and zoom camera is well suited for process monitoring as it allows a single camera to monitor several pieces of equipment spread around an area.

Operators should note that CCTV footage is covered under EU Regulation 679 of 2016, General Data Protection Regulation[5], on the protection of natural persons with regard to the processing of personal data and on the free movement of such data. Operators should familiarise themselves with the requirements for operating a CCTV system.

Figure 2.2: Typical pan/tilt/zoom closed-circuit television camera

[5] https://eur-lex.europa.eu/eli/reg/2016/679/oj

3. Health and safety

3.1 Introduction

An anaerobic digestion (AD) facility is a potentially dangerous environment. Therefore, the health and safety of staff, visitors and members of the public needs to be prioritised in all aspects of the design, construction and operation of the facility. The purpose of this section is to highlight some of the key risks that may be present at the facility, and to propose means to mitigate them.

General health and safety principles:

- **An AD facility is a hazardous environment;**
- **Moving machinery, explosive atmospheres, risk of suffocation and risks associated with handling waste are among the hazards present;**
- **Any operator or potential operator needs to be aware of the key risks involved and appropriate action to mitigate them;**
- **AD facility designers should always try to design-out hazards before resorting to other methods of mitigation, such as engineering or procedural controls; and**
- **Training, standardised procedures and risk assessment are other key tools to ensure the facility is run safely and effectively.**

3.2 Hazards

3.2.1 Moving machinery

At an AD facility, moving machinery can be classed as fixed plant and equipment; or mobile plant and equipment. They both present different risks.

Fixed plant and equipment typically include:

- Crushers and shredders
- Pulpers
- Screw and belt conveyors
- Mechanical agitators and stirrers
- Pumps and valves.

These present numerous potential dangers during operation and maintenance such as trapped limbs, clothes being snagged, operators being drawn into the machine, and material being forcibly ejected, all with the potential to cause serious injury or even fatalities.

In addition to injuries resulting from mechanical hazards, workers can suffer exposure to high temperatures from drive motors or gearboxes, contact with liquids at high pressures and high temperatures, and contact with corrosive or harmful substances.

These risks should all be minimised through appropriate design, including guarding and shielding equipment, good maintenance and safe operating procedures.

Mobile plant and equipment typically include:

- Delivery vehicles
- Shovel loaders
- Grab loaders
- Forklift trucks
- Mobile elevating work platforms such as a cherry pickers or scissor lifts.

Figure 3.1: Shovel loader

These vehicles are heavy, and drivers often have limited visibility and significant blind spots. Their working environment can be slippery and is often confined, which requires careful manoeuvring.

A mobile plant presents a significant risk to any pedestrians in the area. Therefore, the managed segregation of vehicles and pedestrians in working areas must be carefully considered. Methods for managing this risk could include site layout, traffic control measures, and barriers and guarding. Vehicles should be fitted with warning lights and reversing alarms.

3.2.2 Explosive atmospheres

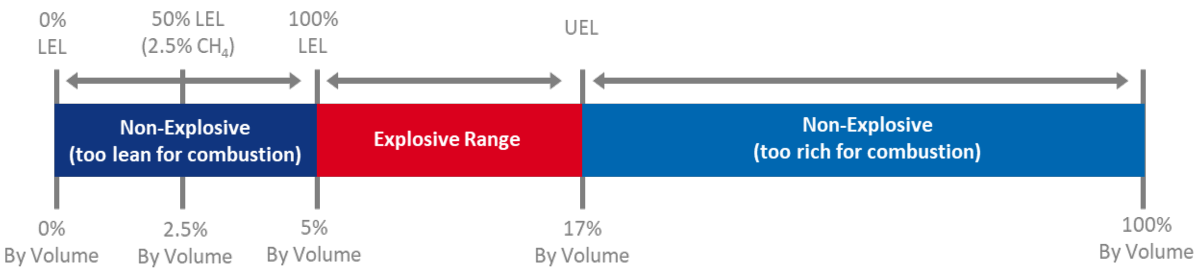
An AD facility produces biogas, which primarily consists of highly flammable methane (CH_4). This is stored in sealed tanks at a site and poses a significant fire and explosion risk, which needs to be carefully managed. For a fire or explosion to occur, three elements need to be present simultaneously – fuel (biogas), oxygen (air) and an ignition source (a spark or flame).

The minimum concentration of gas in air at which combustion could occur is known as the Lower Explosive Limit (LEL). Combustion in confined spaces is typically more violent and destructive. For pure CH_4, the LEL is 5%. For biogas, the LEL varies depending on the CH_4 concentration in the gas.

In order to quantify the risk of explosion in an environment, the quantity of a combustible gas in the air is often referred to on a sliding scale from 0% LEL to 100% LEL. Environments with no trace of combustible gas are known as "0% LEL", and environments where the volume of combustible gas is at the LEL is known as "100% LEL", for example, there is enough combustible gas at this concentration to cause an explosion. It is common safety practice for personnel not to enter an area unless the atmosphere is below 50% lower explosive limit, equating to 2.5% CH_4.

The maximum concentration of gas in air at which combustion could occur (for example from an air leak into a gas line) is known as the upper explosive limit (UEL). For pure CH_4 this is variously described as from about 15% to 17%. Above this value, the gas air mixture is too rich in CH_4 and will not burn. The lower and upper explosive limit for CH_4 are illustrated in *Figure 3.2*.

Figure 3.2: Methane lower and upper explosive limit states



Inside a pipeline or storage container, an instrument, sensor or piece of equipment such as a mixer, could all act as ignition sources. The designer of an AD facility must ensure that potential ignition sources are minimised. Any item present must meet the required standards for use in an explosive atmosphere (comply with the requirements of EU Directive 34 or 2014[6] on equipment and protective systems intended for use in potentially explosive atmosphere, known as the ATEX Directive).

[6] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0034

Figure 3.3: Example of pipework labelling

Operators should monitor gas pipework and storage facilities closely to ensure conditions are safe. This can be done through regular facility inspections, and by observing changes in key facility parameters monitored by sensors, such as gas pressures and gas composition, to identify any potential issues. All pipework on site should be clearly labelled to allow staff members to easily identify the contents (see *Figure 3.3*).

A dusty environment can also result in potentially explosive conditions. As AD is predominantly a wet process, most feed materials and processed waste are moist and unlikely to cause dust. However, where dry feedstock is processed or a dry digestate is produced (for example, from a drying process), precautions must be taken to reduce dust generation and minimise ignition sources in areas where dust may be generated.

In Ireland, the Safety, Health and Welfare at Work (General Application) Regulations 2007, Part 8: Explosive Atmospheres at Places of Work, puts duties on operators to protect people from risks arising from explosive atmospheres from any source, including flammable gases or dusts. The associated Health and Safety Authority guide to Part 8 of the Regulations[7] should be the first point of reference for an operator responsible for managing explosive atmospheres.

3.2.3 Suffocation and poisoning

There are several potential suffocation risks at an AD facility. Operators need to be aware of these and must ensure that people are not exposed to hazardous situations.

Suffocation can be caused by reduced oxygen levels in the atmosphere. This can occur due to displacement by another gas, or by chemical asphyxiation, where the atmosphere contains gases that reduces the body's ability to absorb or use inhaled oxygen. This can be experienced in confined spaces where biological materials are stored or being processed, and other gases are being generated and accumulate in the air. *Table 1* lists some of the most common elements of biogas that can cause asphyxiation, the concentration level at which they are found in normal air, and the concentration at which they can become dangerous to life. Note that quantities of these elements fluctuate depending on the local environment.

Table 1: Concentrations of oxygen and of other gases found in biogas that pose a risk to health

Gas	Normal concentration in air	Concentration at which a health risk occurs
Oxygen	20.95%	Less than 19.5%
Hydrogen sulphide	Trace	Over 100 ppm
Ammonia	0.00048-0.00296 ppm[8]	Over 300 ppm
Carbon dioxide	400 ppm	Over 40,000 ppm

Notes: ppm = parts per million. This is a commonly used measure for concentration of small quantities of material in a gas or liquid. Methane itself is not inherently a risk to health other than by reducing the oxygen concentration.

[7] https://www.hsa.ie/eng/Publications_and_Forms/Publications/General_Application_Regulations/Explosive_Atmospheres_at_Places_of_Work.html
[8] https://www.epa.ie/researchandeducation/research/researchpublications/researchreports/EPA%20RR%20193%20Essentra%20web%20(1).pdf

Where these gases are likely to be present, operators should:

- Install fixed gas detection equipment;
- Ensure that all people working in and around gas vessels and pipework wear portable gas analysers that sound an alarm when those elements are present;
- Ensure that access points to areas that may contain asphyxiants, such as hatches or valves, are controlled via locks or mechanical fastenings; and
- Ensure that warning signs are placed on pipework and vessels holding harmful gases, and in places where there is a risk of those gases occurring.

3.2.4 Hazardous materials

An AD facility may need to store hazardous materials such as process chemicals and additives. The operator must ensure that all personnel are suitably protected and that the materials do not pose a threat to the environment.

Depending on the AD facility design, chemicals like ferric chloride, acids and alkaline substances, might be stored for use in the process. These are highly corrosive and very damaging to health, and the facility design should limit individuals' exposure to them. In addition, the storage tank and pipework must be designed so that any leaks or spillages are contained (for example, by using double-skinned pipework, and ensuring chemical areas are bunded).

3.2.5 Material storage

There are several health and safety risk factors associated with feedstock material storage.
These include:

- **Asphyxiation**

  Poorly ventilated bunkers and storage areas that contain organic materials carry a risk of asphyxiation caused by oxygen deficiency or the generation of gases such as hydrogen sulphide.
- **Fire**

  When organic feedstocks are stored for long periods of time, they may decompose and produce heat. If it is not managed correctly, this heat can cause spontaneous combustion. Operators should therefore monitor stored feedstock piles closely and install appropriate fire detection and suppression measures.
- **Explosion**

  Material that is dry and dusty or contains a lot of fine material is an explosion risk. The risk can be minimised by damping down the material or covering it to prevent the dust becoming airborne.
- **Biological risks**

  Feedstocks such as manures may contain pathogenic micro-organisms. Food may also attract vermin that can introduce harmful micro-organisms into the feedstocks, so access by vermin to the feedstocks should be minimised.

3.2.6 Confined spaces

Figure 3.4: Operative working in a confined space

A confined space is any place that is substantially enclosed, and where serious injury can occur from hazardous substances or conditions within the space or nearby (for example, lack of oxygen). An AD facility will have several tanks, sumps, bunkers and other enclosed areas that meet the definition of a confined space. Therefore, operators must exercise caution when people are working inside them.

Some of the dangers of working in a confined space are:

- Oxygen depletion;
- Poisonous gas;
- Filling of the tank while workers are inside;
- Fire or explosion from tank contents;
- Heat; and
- Movements of mobile and fixed plant.

Operators should also consider that any activities taking place within the space, such as welding, grinding or using solvents or other chemicals, could make the situation more hazardous. If access to an area is very restricted, this could complicate evacuating employees in the event of an emergency. In this case, the area is considered a confined space.

People who are required to enter confined spaces must attend the appropriate training course and be provided with any specialist equipment they may need, for example, breathing apparatus and gas monitors. To avoid putting employees at risk, a smaller operator should consider using a company that specialises in confined space working.

3.2.7 Handling waste

Organic waste such as manures, food waste and food processing waste, may contain microbial pathogens. Staff and visitors can be exposed to pathogens through breathing in bioaerosols generated when feedstocks are disturbed. Personnel should be made aware of the risks when handling these materials and maintain high levels of hygiene after working around the waste. Maintaining cleanliness around the facility and mobile plant also helps avoid contamination.

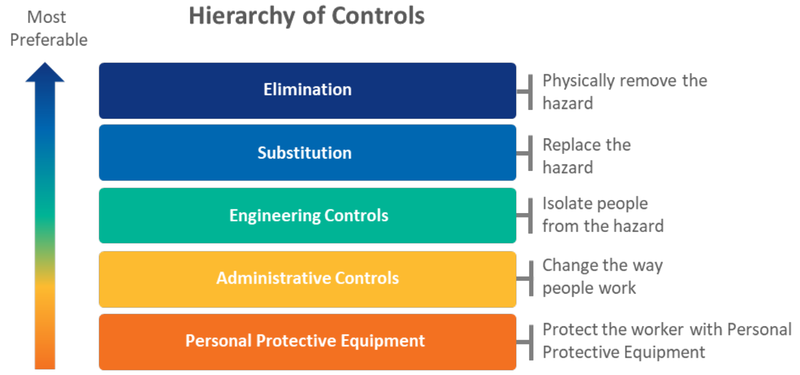
3.3 Risk mitigation

3.3.1 Facility design

When designing an AD facility, the hierarchy of hazard control (see *Figure 3.5*) should be implemented. These controls are:

- For all the hazards discussed in Section 3.2, the hazard should be eliminated at the design stage.
- If the hazard cannot be eliminated, the designer should minimise it as much as possible at the design stage.
- If the hazard cannot be designed out or reduced, then the designer should isolate people from the hazard using engineering controls, such as putting mechanical interlocks on access ways to hazardous machinery or providing a platform to access equipment located at height.
- If the hazard cannot be eliminated through design or engineering, then administrative controls should be used to limit or preventing people's exposure to the risk. This could take the form of training, signage, buddy working, or scheduling work to avoid busy times.
- The final option is the use of personal protective equipment to protect individuals. This should only be relied upon for low-risk activities. Personal protective equipment should be selected for the task in hand and maintained in good condition. Manufacturer’s instructions must always be followed.

Figure 3.5: Hierarchy of hazard control



3.3.2 Training

A key element in reducing risk is to provide adequate training for all site staff including:

- **Original equipment manufacturer training**

  Original equipment manufacturers are well-placed to carry out training as they know exactly how equipment functions and how it needs to be maintained. This training could also help to maintain equipment guarantees and warranties in the long term.

- **Third-party training course**

  Third-party organisations exist to provide training, particularly for more generic activities such as cutting, grinding and welding. Providers of this kind of training are likely to be based locally and could carry out the training at the operator's site or at their own premises.

- **Specialist training**

  This type of training includes topics such as working in confined spaces or complying with the ATEX Directive. Courses may not be available locally, so are likely to be more expensive. Consequently, operators may consider using a third-party contractor to carry out such work.

- **On-the-job training**

  A great deal of training can be carried out on the job, using employees with the appropriate experience and qualifications to train others. This may be the only way to train new staff on facility-specific operation or maintenance tasks. Where possible, the training programme should be written up and stored electronically so that it can be easily accessed and repeated in a consistent way while reducing dependency on a single staff member to carry out the training.

3.3.3 Standard operating procedures

Standard operating procedures are a set of procedures for carrying out common, routine tasks. They are written out and filed in a secure location and are reviewed on a regular basis by the management team to ensure they are relevant and still reflect best practice. Examples of standard operating procedures are cleaning the plant and equipment, operating equipment, or carrying out sampling and testing.

Standard operating procedures can form part of the training process for new employees and provide an audit trail for an individual's training records with a package of training documents, which the employee can sign off on when completed. They also ensure all staff are operating the facility in a consistent manner.

3.3.4 Risk assessments and safety statements

Operators are responsible for the health, safety and wellbeing of all people on their site. This includes employees, third-party contractors, and visiting members of the public. It is therefore vital that operators have systems and procedures in place to control the safety of everyone on the premises, and that staff are given adequate safety training.

Under the Safety, Health and Welfare at Work Act of 2005[9], an employer is required to carry out risk assessments and prepare a safety statement for all potentially hazardous activities to be undertaken by its employees or by third-party contractors working on site. Risk assessments and safety statements enable operators to review all works to be carried out on site prior to commencement, and to comment on the methodology prior to approval. Once the works are underway, they provide a reference point for employees and third-party contractors, and details of how to respond in the event of an emergency.

If an accident occurs, Health and Safety Authority inspectors scrutinise the risk assessments, safety statement and the procedures as well as the work practices to review the management of safety and health at the facility.

Risk assessments and safety statements should contain key information such as names of staff carrying out the works, a nominated supervisor or project manager (with contact details), details of the local accident and emergency department, personal protective equipment requirements and some basic site rules.

[9] https://www.hsa.ie/eng/Topics/Managing_Health_and_Safety/Safety,_Health_and_Welfare_at_Work_Act_2005/

The common approach to risk assessment is to identify all hazards associated with the works, then score them between 1 and 5 on the severity of the consequence of the hazard, and the likelihood of it occurring (see *Figure 3.6*). The two scores are multiplied, providing an overall level of risk for each hazard. Any hazards that are thus identified as high risk should be assessed by the operator or contractor, or both, and one of the hierarchy of controls (see *Figure 3.5*) put in place to mitigate the risk, preferably eliminating the hazard.

Figure 3.6: Typical risk assessment matrix

0-5 = Low risk 6-10 = Moderate risk 11-15 = High risk 16-25 = Extremely high and unacceptable risk		Severity of the potential injury				
		Insignificant damage to property, equipment or minor injury 1	Non-reportable injury, minor loss of process or slight damage to property 2	Reportable injury, moderate loss of process or limited damage to property 3	Major injury, single fatality, critical loss of process and damage to property 4	Multiple fatalities, catastrophic loss of business 5
Likelihood of the hazard happening	Almost certain to occur 5	5	10	15	20	25
	Will probably occur 4	4	8	12	16	20
	May occur 3	3	6	9	12	15
	Remote possibility 2	2	4	6	8	10
	Extremely unlikely 1	1	2	3	4	5

The risk assessments and safety statements should be reviewed by the operator and staff members or third-party contractors when commencing the work and signed by all parties involved to confirm they have been read and understood. Contractors and the staff carrying out the work should keep copies with them throughout the duration of the work, and the operator should retain copies on file for future reference.

More information on risk assessments and safety statements are available from the Health and Safety Authority website[10] including a guide to Risk Assessments and Safety Statements[11].

[10] https://www.hsa.ie/eng/
[11] https://www.hsa.ie/eng/Publications_and_Forms/Publications/Safety_and_Health_Management/Guide_to_Risk_Assessments_and_Safety_Statements.pdf

3.3.5 Induction

The operator should provide induction training for everyone entering the site. The level of detail required in the induction depends on the complexity of the site and the interaction a person will have with it. For example, a visitor (observer) will require a shorter induction than an employee. As a guide, the induction topics for three separate groups of people are shown below:

- **Visitor induction**

  A day visitor who will not be carrying out any physical work on site and will likely be accompanied by an appropriate member of staff in potentially hazardous areas, should be furnished with:
  - Details of evacuation procedure, fire alarms, escape routes, assembly points, etc.;
  - Personal protective equipment required for areas to be visited;
  - Information about restrictions, for example on smoking, photography and use of mobile telephones;
  - Information about hygiene precautions, for example, washing hands following visits to particular areas;
  - Location of welfare facilities, first aid points, toilets, canteen, changing rooms, etc.; and
  - Warning of any hazards they may encounter, for example, traffic, noise, stairs and uneven ground.

- **Contractor induction**

  Third-party contractors carrying out works at the site must be furnished with the above, plus:
  - Site rules;
  - More details on hazards around the site and any specific precautions required, (for example, areas that must comply with the ATEX Directive, and chemical storage guidelines;
  - Additional personal protective equipment requirements for the work being undertaken; and
  - Any specific working requirements such as permit to work, electrical isolation, etc.

- **Staff member induction**

  Staff members must be furnished with the same as contractors, plus:
  - Details of the processes and associated hazards;
  - Training in the standard operating procedures that the employee will need to observe when carrying out work; and
  - Details of any role-specific training such as driving plants or operating equipment.

Operators should keep a record of everyone who has undergone induction training. Induction refresher training should be delivered on a regular basis – usually annually – to bring employees, contractors and visitors up to date with any changes to the facility or its procedures.

3.3.6 Emergency response plan

Operators should have an emergency response plan for their site. This is a detailed action plan that shows people working at the site how to respond to a major incident. It also allows third parties who may attend the site to familiarise themselves with the facility and the emergency response procedures in place.
An emergency response plan should cover the following events where applicable:

- Fire
- Explosion
- Injury to staff member, contractor or visitor
- Power loss
- Flood and other environmental incidents
- Control system failure
- Details of nearest accident and emergency unit
- Contact details for local police, fire department, relevant regulator, and relevant local authority
- Site plans showing location of emergency equipment such as fire extinguishers, fire hoses, fire hydrant points, first aid kits, emergency showers and spill kits
- Site staff organisation tree, including contact details
- Emergency response action plan including site staff roles and responsibilities
- Details of facility start-up procedures following an incident.

The emergency response plan should be included in the training programme for all employees. A copy should be kept in an accessible area like a control room or canteen so that employees and visitors can familiarise themselves with it and refer to it during an emergency. It should be reviewed on a regular basis, at least annually, to ensure any changes to the facility or procedures have been included.

3.3.7 Personal protective equipment

Although personal protective equipment should never be relied upon to prevent accidents and injuries occurring, it is still a vital element of on-site health and safety. Requirements will vary from site to site depending on the equipment that is in use. As a minimum, it generally includes a hard hat, high visibility tabard or jacket, safety boots, ear defenders, safety glasses and gloves.

Particular attention should be paid to make sure the correct personal protective equipment requirements (such as gas monitors, dust masks, goggles or visors and chemical-resistant suits) are met for any high-risk activities or locations.

3.3.8 Insurance

Operators should ensure that suitable insurance is in place for the facility for business continuity and public liability. It is advisable for operators to consult with their insurer during the planning and design phases of the facility. This enables the operator to take on board any insurer requirements and design them into the facility.

Lack of consultation with insurers can lead to high insurance premiums or difficulty in obtaining insurance. It can be costly to retrofit elements required by insurers after the facility has been commissioned or has begun operation.

3.3.9 Incident logging and reporting

Careful records should be kept of all incidents including 'near misses' to provide information to improve operations and so prevent future incidents. Employees and visitors should be encouraged to report all incidents and observations that might lead to incidents.

Incidents and health and safety statistics may also need to be reported to appropriate regulatory bodies.

4. Facility maintenance

4.1 Introduction

Effective maintenance is key to operating a safe, efficient anaerobic digestion (AD) facility and ensuring the long-term success of the operation. When planning a facility, an operator should consider the issue of future maintenance; how to ensure adequate access for maintenance, and how to make it as easy as possible to look after the equipment efficiently. This section provides an overview of planning and best practice for maintaining the facility.

Facility maintenance:

- **The manufacturer's operation and maintenance manuals form the basis for an effective facility maintenance regime, as they provide details of the equipment and the recommended maintenance schedule;**
- **Operators should plan for preventive and reactive maintenance to rectify issues as they arise;**
- **Operators should hold a lifecycle plan to provide for major expenditure as plant items wear out over time; and**
- **Operators should adopt safe systems of work in all maintenance activities.**

4.2 Operation and maintenance manuals

Operation and maintenance manuals are provided by original equipment manufacturers for any items of equipment they provide.
The operation and maintenance manual will usually include:

- Specifications for the equipment
- Health and safety aspects of the equipment
- Operating procedures
- Maintenance schedule
- Maintenance instructions
- Recommended spare parts list.

An operation and maintenance manual offers a useful fault-finding reference for the equipment and provides the basis for the overall maintenance plan. The operator should maintain equipment in accordance with the operation and maintenance manual and keep maintenance records. Such records may be required as part of the warranty conditions for a particular supplier's equipment.

4.3 Design and as-built drawings

Any potential operator of an AD facility should engage a qualified designer of AD systems to provide the design and specification. The designer should provide a scheme that is compliant with the relevant health, safety and environmental legislation, and ensure that best available technology is used throughout.

The person or organisation responsible for the construction of the facility, which could be the operator or a third-party contractor working on behalf of the operator, should appoint a project manager to oversee the construction and commissioning of the facility. The project manager should ensure all contractors employed during the construction of the facility have the appropriate experience and track record. The project manager or operator, or both, should review and approve all designs before construction commences to ensure all requirements have been met. If an operator does not have the knowledge or experience to do this, then it may be advisable to employ a suitably experienced third-party consultant to ensure the proposed AD scheme is fit for purpose and will comply with legislation and permit conditions.

Following installation, the project manager should ensure all parties involved in the design, construction and installation process provide operation and maintenance manuals for all equipment, and accurate and final as-built drawings for the facility. As-built drawings are useful for maintenance planning, and vital when considering future extensions or updates to the facility.

4.4 Maintenance planning

Every AD facility needs a comprehensive maintenance plan to ensure that all equipment is in a safe and operable state, issues are identified before the equipment fails (reducing downtime), and the operational life of the facility and equipment is maximised.

Figure 4.1: Plant cleaning with jet wash

Ways of managing the maintenance plan range from a relatively simple programme with regular scheduled checks, to a fully automated computerised maintenance management system for large and complex facilities.

The basis of the maintenance plan should always be the operation and maintenance manuals. Operators should note the maintenance activities and schedule for each piece of equipment, and draw these together into a single, co-ordinated plan. This plan can then be broken down into a series of tasks, which will allow the operator to ensure maintenance is carried out at the required frequency.

4.5 Reactive maintenance

Breakdowns and equipment failures are inevitable when operating a facility. It is important in the event of a breakdown to minimise downtime. AD is a biological process, so an inability to feed the facility will quickly result in reduced gas yield and potentially cause harm to the microbial community in the anaerobic digesters.

Operators must consider how reactive maintenance will be carried out at their site. For a larger site, it may be cost-effective to have a dedicated maintenance technician, or team of technicians, who can carry out routine maintenance tasks and respond to breakdowns or equipment failures as they occur.

For a smaller site, the operator could consider maintenance contracts with specialist third-party contractors or with the original equipment manufacturers or supplier. Such providers are likely to charge call-out fees for attending the site on short notice in the event of a failure, but this drawback needs to be offset against the cost of employing a dedicated resource on site, when maintenance arrangements are being made.

4.6 Lifecycle maintenance and replacement of parts

Over time, equipment will wear out and require restoration or replacement. Equipment failure can be expensive if it causes the facility to shut down for a lengthy period. A lifecycle maintenance or replacement plan is therefore advisable.

As part of this plan, the operator will forecast when significant, expensive maintenance or complete replacement of items of equipment will be required. This can be done in consultation with the original equipment manufacturers and adjusted as wear rates are monitored during the operation of the facility. Some facilities require period shutdowns for major maintenance overhauls such as clearing settled grit from tanks, and scheduled parts replacement. This may disrupt operations for several weeks.

Having an idea of when these large costs are likely to occur, allows operators to allocate funds to cover exceptional costs. It also means that the maintenance plan can allocate sufficient time to carry out the work and make adequate provisions for resources and equipment. If the facility is taken out of service for an extended period, it could be advantageous to carry out other maintenance tasks at the same time.

4.7 Safe systems of work

The importance of health and safety awareness in the operation of an AD facility is discussed in Section 3. Maintenance activities can be particularly dangerous as protective guarding may need to be removed, and exposure to moving parts and live electrical connections is likely. Additionally, parts being maintained could be difficult to access (for example, at height or in an area with restricted access).

Therefore, operators must ensure that all site staff adopt safe systems of work when undertaking maintenance activities, such as:

- Using padlocks to lock off power supplies to equipment at the isolator to ensure the power cannot accidentally be turned on whilst work is in progress;
- Mechanically locking drive shafts or moving parts to ensure they do not move when exposed;
- Wearing a harness and lanyard when working at height; and
- Ventilation and atmosphere testing prior to entry into confined spaces and other relevant high-risk areas.

These safe systems of work should be documented as standard operating procedures and employees should receive appropriate training before they do any work.

4.8 Spares and storage

To minimise downtime in the event of equipment failure, a stock of critical spares should be kept on site. These are items that may not be immediately available to purchase and are necessary to keep the facility in operation. This is often the case for large items that are manufactured to order and may have a long lead time, or equipment that is manufactured abroad and needs to be shipped to the facility.

The operation and maintenance manuals for the equipment will often provide a list of recommended spares, from which the critical spares can be identified. Alternatively, the operator can have critical spares held in stock at a nearby source for delivery to the site within an agreed timescale.

Critical spares must be stored correctly to ensure they will function correctly. Failure to plan for secure storage of spares and equipment is a major oversight, which can cause logistical difficulties when the facility is in operation.

Spares should be clearly labelled in storage. The operator should maintain an up-to-date record of spare parts held in stock so that replacements can be ordered.

It is helpful for facility designers to make provision for open areas at the site for storage of large items such as mobile plant, skips and bins for waste materials, and other equipment that may be required from time to time.

4.9 Record-keeping

Maintaining detailed records holds several advantages:

- If a warranty claim is made, the manufacturer will often ask to see records to check the equipment has been maintained in accordance with the operation and maintenance manual;
- In the event of an incident arising from malfunction of equipment, maintenance records will allow the condition of the equipment to be investigated and provide detail on the level of maintenance carried out; and
- The condition of plant can be monitored over the course of several maintenance intervals to allow wear rates to be tracked and lifecycle predictions to be updated.

A specific computerised maintenance management system will usually allow users to provide comments on maintenance tasks carried out, then automatically archive maintenance records. If a manual system is used, these records may be kept as computer files or hard copies.

5. Facility start-up

Facility start-up:

- Prior to starting the facility, operators should ensure that all civil engineering works and equipment installation have been completed as per the specifications;
- The commissioning process should be carried out in phases to allow the plant and equipment to be thoroughly tested prior to operation;
- Acceptance testing should be undertaken to ensure that the facility can meet the required performance standards; and
- Operators should put in place a defect liability period with the contractor and suppliers to ensure any defects found during the commissioning and ramp up (to full operating capacity) phase are rectified.

5.1 Construction completion

Prior to starting up the mechanical and electrical systems at the facility for the first time, the construction and installation work should be complete, and the site safe for operation. Upon completion of the facility by the responsible contractor(s), the operator (or the operator's representative) should thoroughly inspect the facility to ensure the construction work meets the agreed specification and is of the required quality. Any outstanding issues can be listed in a defects list to be rectified. If an operator is not from a construction background, then it may be better to use the services of an experienced third-party contractor to act as 'owner's engineer' and inspect the installation.

Figure 5.1: Farm-based AD facility

5.2 Commissioning

Commissioning is commonly carried out in two phases: cold commissioning and hot commissioning.

- **Cold commissioning**
  Cold commissioning involves powering the equipment up and running it without any feedstock material. This should include pressure testing with air and water to ensure there are no leaks in the system. Cold commissioning enables the operator to check that the fundamental installation of the equipment is correct and that there are no electrical or mechanical issues with the installation. It is also a good opportunity to test control sequences and make changes without having to manage feedstock at the same time.
- **Hot commissioning**
  Hot commissioning occurs upon satisfactory completion of cold commissioning and involves operating the facility with feedstock material running through it. This allows the operator to check that the facility can handle the material it was designed to process, and to check for unforeseen issues such as blockage points. It also enables the process contractor and operator to optimise the configuration of the plant and equipment with the feedstock to ensure the facility is running as effectively as possible.

It should be noted that it can take several months to fully commission an AD facility, as it takes time for the micro-organisms in the anaerobic digester to become fully established and adapted for optimal biogas production. It is common for anaerobic digesters to be seeded with AD sludge from another similar facility to speed up the establishment of an appropriate microbial community in the anaerobic digester.

5.3 Acceptance testing

Once hot commissioning has been completed to the satisfaction of all parties, acceptance testing should be carried out. This comprises performance tests with clearly defined specific and measurable pass criteria agreed by the contractor and operator or final client. Typical acceptance test parameters include:

- Facility throughput (tonnes/hour)
- Facility availability (available for processing 85% of the operational hours)
- Dry solids concentration of the infeed material
- Volume of biogas produced (m^3/hour)
- Quality of biogas produced (minimum methane level to be met)
- Quality of digestate produced (agreed specification)
- Facility energy consumption (kWh/day).

The procedure for each acceptance test should be agreed between the process contractor, the operator and any other interested parties (for example, lenders). Acceptance tests should be programmed to run for a defined period and should recreate full-service operation of the facility as closely as possible. As a minimum, the tests should be witnessed by the contractor and the final client, or their representatives, to ensure both parties are satisfied they are being carried out correctly.

The test data should be recorded at the frequency agreed in the test procedures. At the end of the acceptance test period, the data should be presented in a format that allows a clear pass or fail decision against each test. For a larger facility, or one that has various stakeholders (for example, an end user and bank lender), it is common for a third-party independent certifier to be appointed to act as an impartial observer and resolve any disputes over whether the tests are passed or failed. Independent certifier services are commonly offered by consultant engineering firms.

If the acceptance testing is successful, the contractor will request a completion certificate that marks the end of the works. The responsibility for the facility will then be taken over by the operator. If any of the acceptance tests fail, then the operator will need to liaise with the contractor to agree a path forward. This could involve facility modifications, additional process equipment to be installed, or retesting with the equipment in a different configuration. The independent certifier is a useful mediator in discussions like these.

The operator should ensure they are protected contractually from the costs of any additional modifications and delays that might occur.

5.4 Facility ramp-up

As mentioned in Section 5.2, it will take time to establish a robust and productive bacterial population in the anaerobic digester. It is important that the operator ramps up the feed to the digester over time to allow the biology to develop and adapt to the feedstock. If too much feedstock is added early on it could disrupt the developing microbial community to the extent that re-seeding is necessary.

The operator should monitor the anaerobic digester in the first few months of operation regarding biogas production, volatile fatty acid content, and dry solids and volatile solids concentration. These will give an indication whether the biology is stable, and loading can be increased. More details on anaerobic digester operation can be found in Section 6, and throughout the accompanying Overview Guide.

Operators should be aware that feedstock requirements may fluctuate during this ramp-up period and anaerobic digesters must not receive more feedstock than they can process.

5.5 Defect liability period

An operator who uses a single or several third-party contractors to deliver the facility should consider including a defect liability period in the contract. This is essentially an extended warranty period during which any construction, manufacturing or installation defects found are the responsibility of the contractor to rectify. In a complex facility it may take weeks or months for some defects or installation issues to become apparent.

6. Facility operational principles

Facility operational principles:

- Anaerobic digestion (AD) is a biological process and the conditions in the anaerobic digester need to be monitored to ensure the right environment is present to enable bacterial colonies to grow;
- Feedstocks can include energy crops, farm wastes or food waste, and should be selected, prepared and fed to the anaerobic digester with care to ensure stable biology is maintained;
- Operators should ensure that adequate mixing is carried out and that equipment is properly maintained, to encourage optimal conditions and to provide visibility of anaerobic digester health;
- How the digestate is going to be used should be considered from the beginning, and care should be taken to ensure its quality is suitable for that use.

6.1 Feedstock

6.1.1 Feedstock characteristics

The key to successful AD is a secure, stable, long-term supply of feedstock. To maintain biogas production, the AD process will require constant feeding throughout the year. Therefore, operators should make sure that a stockpile of feedstock is always held.

In addition, it is important to maintain a consistent feedstock in terms of physical, chemical, and biological characteristics. Sudden changes in feedstock composition can result in the micro-organisms in the anaerobic digester being 'shocked'. This can affect gas yields and, in worst-case scenarios, cause total anaerobic digester failure. New feedstocks must be introduced to the anaerobic digester gradually to allow the microbial community to adapt to the new substrates.

For a farm-based AD facility that relies on energy crops as a feedstock, careful planning will be required to ensure material is available to feed the anaerobic digester all year round. This includes consideration of crop rotation to maximise the yield of the available land and ensiling to preserve feed material through the winter and spring months. Ensiling holds additional benefits as the fermentation that occurs during the process starts to convert the material into a more easily digestible form, allowing it to yield gas more quickly once in the anaerobic digester.

It is common for crops to be blended with other crops or farm wastes, like manure, before being fed into the anaerobic digester. The advantage of this is that some materials will convert to biogas very quickly, while others will take longer to break down. By blending different feedstocks, a stable gas yield and robust conditions in the anaerobic digester will be achieved.

For an operator relying on organic wastes, it is essential to establish a good supply base, and secure long-term contracts with suppliers for suitable material. The type of wastes accepted should be carefully considered. Reliance on too many, very high biogas yielding feedstocks may limit the amount of waste that can be accepted (potentially reducing gate-fee revenue for the operator) and could result in an unstable anaerobic digester.

Organic waste feedstocks will require careful management to ensure the material is consistent and not contaminated. Suppliers of the material should be vetted and laboratory analyses to establish the feedstock characteristics should be carried out regularly on the material prior to acceptance.

Figure 6.1: Feedstock for the AD process

From an operational perspective, the operator should consider the physical properties of the feedstock in terms of material handling, storage, mixing and feeding. A dry material, if not added directly, may require a large volume of water to form a slurry that can be readily pumped. Dry material may not readily take up water and will require more aggressive mixing to create a slurry that is suitable for infeed. Packaged waste will require some pre-treatment to separate out the organic material from the packaging as described in Section 3.3 of the accompanying Technology Guide. Implications of feedstock characteristics on the facility design should have already been considered during the design stage, as referred to in the Technology Guide, Section 3.

Operators should ensure there is sufficient space and equipment to prepare the feedstock for digestion when planning their facility.

6.1.2 Feedstock biogas yield

The accompanying Implementation Guide, Section 4.2.4, provides information on the biogas yield of various feedstock materials. This and other sources of yield information should be referred to when considering possible feedstocks to determine likely gas yields under different options.

From the planning phase, operators should be considering available feedstocks and their biogas yield as this will have an impact on the fundamental operation of the facility. A feedstock with a high gas yield has the potential to generate a lot of energy, but this will require a final gas consumer (for example, a boiler or gas engine) with the capacity to use it all. In addition, when the biogas is used as a fuel to generate electricity, the infrastructure downstream from the facility needs to be able to handle the generated electricity.

While using a feedstock with a lower gas yield will generate less energy, it could potentially allow a level of material to be processed before the biogas consumer on site has reached full capacity. There are other considerations, such as the required residence time in the anaerobic digesters, and storage space on site. However, the ability to process more feedstock is advantageous if the operator can charge a gate fee.

6.1.3 Blending feedstocks

Blending feedstocks presents several advantages:

- Several different waste streams or energy crops can be processed;
- Operators of a farm-based anaerobic digester can put in place crop rotations to help ensure soil health is maintained;
- Farm waste materials (for example, manure and slurry) can be used alongside crops in the anaerobic digester; and
- Operators can balance materials that provide high, short-lived energy release, with slow-release materials, to establish robust and healthy bacterial activity in the anaerobic digester.

When choosing materials to blend as feedstock, operators should ensure they only use materials that they are permitted to process; in particular, they must consider whether the feedstock includes animal by-products and whether this means the digestate can be applied to the intended agricultural land. Section 6.3 of the accompanying Overview Guide summarises the requirements.

The operator should consider how they will blend feedstocks from a practical perspective. The anaerobic digester will respond better to receiving a consistent composition of material. Therefore, operators should avoid feeding material into the anaerobic digester in ‘campaigns’ and should instead deliver a consistent blend of material day-to-day, making any changes to the feedstock gradually.

Section 3 of the accompanying Technology Guide provides details on the blending (mixing) and technologies available in relation to anaerobic digester feeding. Operators will need to consider how the various feedstocks are stored, and how they will physically be managed in terms of moving and loading while monitoring the weight of each type to ensure a consistent blend.

6.2 Maintaining good microbial activity and biogas production

6.2.1 Operating conditions

Several fundamental elements are required in the AD process to ensure good microbial activity and, consequently, to maintain a robust and high-yielding anaerobic digester. These are described below.

- **Temperature**

It is essential to maintain a stable temperature. AD facilities typically run within two distinct temperature ranges: **mesophilic**, with temperatures of 30-40ºC; and **thermophilic**, with temperatures of 50-60ºC.

Mesophilic digestion tends to be a simpler system to operate and is suitable for digesting a wide range of feedstocks, including energy crops and organic wastes.

Thermophilic digestion can accelerate the digestion process when using certain feedstock, and can incorporate the pasteurisation process, which removes the need to pasteurise separately. However, it is complex to operate, requires more energy to heat up the feedstock, and can be less stable than mesophilic digestion. Various means of controlling temperatures in anaerobic digesters are discussed in the Technology Guide, Section 4.4.

- **Organic loading rate**

The organic loading rate is the mass of volatile organic matter that is treated per cubic metre (m^3) of anaerobic digester volume per day – in other words, the measure of the digestible material being put into the anaerobic digester.

The optimal organic loading rate is different for each anaerobic digester and will depend on the type of feed material and the biological activity present. If the organic loading rate is **too low**, the microbial community may starve and gas yields will drop; if the organic loading rate is **too high**, the micro-organisms will not be able to break down all the organic material that might be converted to biogas.

Too-low loading rates result in lost gas potential (that is, lost revenue) and produce a more biologically active digestate that can cause problems with odour and may continue to release greenhouse gases including methane (CH_4) and carbon dioxide (CO_2) after leaving the anaerobic digester.

- **Hydraulic retention time**

The hydraulic retention time is the duration of time for which the organic material is held in the anaerobic digester.

In a **batch process**, the hydraulic retention time will be an absolute figure; in a **continuous feeding process**, it will be an average value based on the anaerobic digester's rate of feed and discharge.

If the hydraulic retention time is **too short**, the bacteria will not have sufficient time to fully digest all the potentially degradable organic matter, and biologically active material will be discharged from the anaerobic digester as digestate; if the hydraulic retention time is **too long**, the gas yield from the material will plateau and ultimately drop as degradable organic matter is consumed.

The optimal time is based on the feedstock being processed to deliver the best gas yield and gas production rate according to the size of the anaerobic digester. When calculating this time, the operator must take account of any pre-treatment applied to the feedstock that may accelerate the degradation of the material.

The hydraulic retention time can be changed by adjusting the volume of feedstock added to the tank. Feeding less material into the system will effectively increase the retention time. This is due to the tank volume remaining fixed, so the less material that is fed, the longer it will remain in the tank.

- **Mixing the contents of anaerobic digesters**

This can be carried out in several ways, as described in Section 4.6 of the accompanying Technology Guide. It is important that the contents are well mixed to **ensure a homogenous material**, so the entire contents are exposed to the biological agents to produce gas and the solids do not settle out of the mixed substrate.

Operators should ensure that the mixing equipment is kept in good condition as any mixing problems can have significant implications on the gas production from the anaerobic digester and its long-term operation. Where mixing equipment is within the sealed anaerobic digester, preventive or remedial maintenance may be challenging, unless the design accommodates easy access. Operators can use sensors to monitor mixer performance, like the power drawn, temperature of the motor, and torque on mechanical paddle mixer shafts.

Mixing efficacy should be adjustable depending on the operation of the anaerobic digester at any one time.

6.2.2 Monitoring anaerobic digester contents

It is important to closely monitor the anaerobic digester contents to ensure that conditions are optimal for gas production and long-term operation. Various parameters of the anaerobic digester's biological performance need to be monitored at different rates of frequency.

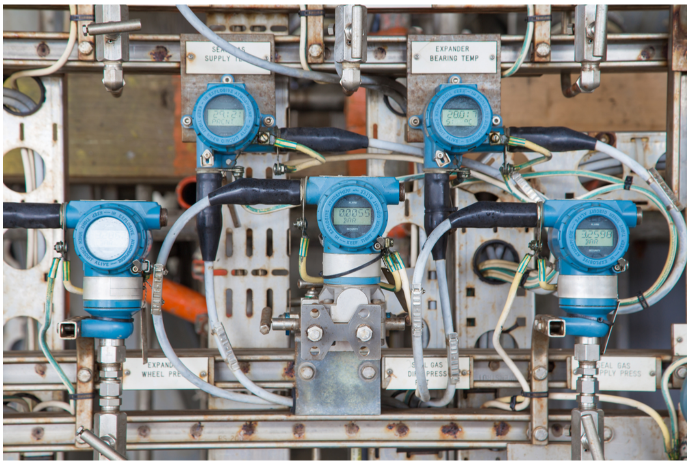
- **Real-time monitoring**

Instruments in the tank and associated equipment will allow the operator to monitor the anaerobic digester's activity on a constant basis. Typical parameters include:

  - Tank temperature
  - Tank level
  - Headspace pressure
  - Gas pipeline pressures
  - Gas production
  - pH.

It is recommended that the operator records the above data and plots it in charts that are reviewed daily. This will allow any trends in anaerobic digester performance to be identified quickly and responded to accordingly. This data should also be linked to the facility control system to sound alarms if any parameter moves outside acceptable operating limits.

Figure 6.2: Typical electronic pressure and temperature instrument



- **Laboratory analysis**

Other important anaerobic digester parameters can be established using laboratory tests of samples taken from the digester. These include:

  - % dry solids
  - % volatile solids
  - Volatile fatty acids
  - Ammonia
  - Chloride
  - Biogas potential
  - Essential nutrient levels for optimal microbial activity.

These tests are quite simple to carry out and many operators will have a laboratory on site where they can be run. Alternatively, many third-party laboratories will carry out the required testing on a supplied sample. Third-party analysis may be required to maintain regulatory compliance. For example, to comply with the Animal by-products Regulation, the Department for Agriculture, Food and the Marine requires that a sample is tested for certain pathogens by an accredited laboratory at an agreed frequency.

- **Gas analysis**

In addition to monitoring tank contents, the gas quality should be tracked. Methods for testing gas quality include fixed in-line gas analysers, a hand-held analyser connected to a sample point in the gas pipework or gas detection tubes. The following characteristics should be tracked as a minimum:

- % methane (CH_4);
- % carbon dioxide (CO_2); and
- Hydrogen sulphide (H_2S) (parts per million).

To ensure accuracy of data, it is important that all instruments are serviced and calibrated in line with manufacturers' guidelines. Operators should maintain a register to keep track of instruments requiring calibration, and to schedule the calibration as required.

6.2.3 Microbial nutrients

Micronutrients is a term given to the suite of vitamins and minerals that living organisms require to maintain health. An AD facility will generally function satisfactorily on its own by digesting the feedstock presented to it, but studies have shown that the addition of micronutrients can increase CH_4 yield and allow the bacteria to maximise digestion of the feedstock material, resulting in more effective use of the feedstocks.

Different types of micronutrient supplements are available for AD which are suited to different feedstocks and different types of biological activity. It is recommended that operators monitor nutrient contents in the anaerobic digester and consult a specialist that can offer advice on the type and dose of micronutrients suitable for the anaerobic digester.

6.2.4 Signs of microbial stress

If the biology in the anaerobic digester is not healthy, or is under stress in some way, it is important that the operator identifies this as early as possible and makes efforts to rectify it. Failure to do so could have an impact on gas production and, in a worst-case scenario, could cause the biogas production in the anaerobic digester to fail completely. The AD tank monitoring, discussed in Section 6.2.2, enables operators to identify any inconsistencies in the performance of the anaerobic digester or parameters of the substrate and investigate further. Some common signs of microbial stress:

- Drop in gas production that does not reflect changes in feedstock loading rate;
- Inconsistent gas production;
- Change in the CH_4 concentration of the biogas;
- Swing in pH outside of optimal operating ranges;
- Changes in temperature;
- Higher volatile fatty acid content of the anaerobic digester contents;
- Higher ammonia concentration of the anaerobic digester contents; and
- Increase in foaming in the anaerobic digester.

Operators should ensure they monitor these parameters closely and be aware of how to react to signs of microbial stress. Overall, consistent feedstock feed rates and characteristics will support stable operations.

6.3 Maintaining biogas quality

6.3.1 Biogas volume monitoring

Biogas volume can be monitored by an in-line flow meter. Biogas production should be monitored continuously and tracked to ensure that any sudden changes in volume are flagged and can be investigated.

6.3.2 Biogas dehumidification

The nature of the AD process at an elevated temperature means that the biogas tends to be warm and moist as it leaves the anaerobic digester. This can cause issues with the downstream use of the gas – as the moisture condenses out and mixes with other contaminants in the gas it can cause corrosion. Therefore, a dehumidifier or dryer of some sort is usually installed in the gas line between the anaerobic digester and the gas processing infrastructure. Care should be taken in the operation and maintenance of this, as it must comply with the ATEX Directive (see Section 3.2.2).

Site staff working on the dehumidifier should be suitably trained. Otherwise, a specialist sub-contractor should be hired to maintain the equipment.

6.3.3 Biogas contamination removal

Depending on the composition of the feedstock, the biogas generated may contain contaminants that require removal prior to the gas being used in a boiler, combined heat and power (CHP) engine or other infrastructure. The most common of these are:

- Hydrogen sulphide (H_2S)
- Ammonia (NH_3)
- Oxygen (O)
- Nitrogen (N)
- Particulates (PM)
- Siloxanes.

Section 5.1 of the accompanying Technology Guide describes in further detail the techniques for removing these contaminants.

Operators should carry out regular checks on the biogas quality and the concentration of contaminants. Many suppliers of biogas-using plants such as CHP systems and boilers will specify upper limits for certain contaminants. If owners are found to be operating the equipment in breach of these limits, then the manufacturers' warranties and lifecycle guarantees will be invalid.

Methods for testing gas quality include fixed in-line gas analysers, hand-held analysers connected to a sample point in the gas pipework or gas detection tubes (see Section 6.2.2). Gas detection tubes are small glass tubes containing material compounds that react with individual gases, turning a different colour. The extent of the colour change indicates the concentration of the individual element in the overall gas stream.

The CH_4 content of biogas is typically between 55% and 60% depending on the biology in the anaerobic digester, the feedstock, and the design of the anaerobic digester. This needs to be monitored closely because it is an indicator of the health and performance of the anaerobic digester, and because the downstream gas consumer is often sensitive to the CH_4 content.

For example, a CHP engine will be configured to operate most efficiently at a defined CH_4 concentration. Should the concentration move out of the defined range, the engine will start to run too rich or too lean, which will reduce its efficiency and could cause wear and stress to the engine. Other biogas consumers such as a boiler may be less sensitive to the CH_4 content but will still operate most effectively with a stable and known concentration.

6.4 Maintaining digestate quality

6.4.1 Digestate deployment options

Figure 6.3: Injection of liquid fertiliser into the soil

Digestate can be exported as whole digestate (liquid) or as separated fibre and liquor fractions. Whole digestate is easy to extract from the anaerobic digester and is usually easy to use in an agricultural environment, although its use will be seasonally dependent. The principal disadvantage is the requirement to store the digestate during the winter when there are restrictions on using it on land.

Fibre fraction (solid) digestate is produced by dewatering the whole digestate. This holds the advantage of being easier to store and can be a more attractive product for land remediation.

As the fibre fraction is less moist, it is lighter, which can lead to significant cost savings for long distance transport. However, to produce the fibre digestate, dewatering equipment such as a centrifuge is needed. A flocculent often must be added to obtain the required dry solids concentration, which is an additional cost. The separated liquid element of the digestate (liquor) can be re-used in the process to make up the infeed material or applied to land, but in some cases excess liquor may have to be disposed of as waste.

If the anaerobic digester is processing non-crop material, which has originated from another site or contains food waste, it may need to comply with the Animal by-products Regulation. The regulation contains a range of measures to ensure that any pathogens in the material are killed off before it is applied to land. The methodology to do this is described in more detail in Section 6.4.2.

6.4.2 Sanitation monitoring

Sanitation (pasteurisation) of the digestate may be required if the facility is receiving animal by-products as feedstock. Any non-crop material that has originated from another site (for example, manure from another site, food waste, or animal by-products) will need to meet the treatment requirements of the Animal by-products Regulation, which includes specifications for particle size, elevated temperature, and minimum time at this temperature to ensure destruction of pathogens. The efficacy of this treatment is assessed by monitoring the levels of indicator pathogens (for example, Escherichia coli (E. coli) and Salmonella) remaining in the digestate and being spread on the land.

Several time and temperature combinations are permissible under the Animal by-products Regulation, to pasteurise the material. One of the more common in wet AD is to increase the temperature to ≥70˚C and to hold it at that temperature for at least an hour, but it is also possible to use lower temperatures and hold for longer periods. If using thermophilic digestion, it may be possible to avoid a separate step for pasteurisation depending on the operating parameters of the anaerobic digester.

A plant involved in the anaerobic digestion of animal by-products or derived products must be approved by the Department of Agriculture, Food and the Marine.[12] The conditions contained in the certificate of approval will depend inter alia on whether the animal by-product material is all derived from animals on the same holding as the biogas plant or not. If not, one of the requirements is that the operator must have in place a hazard analysis and critical control point plan. This identifies critical control points that are maintained to ensure the criteria for compliance with the regulations are in place. Key critical control points are:

- **Particle size**
  Controls must be in place to ensure particle size does not exceed the maximum value stated in the hazard analysis and critical control point plan. This is to ensure that all the material is subjected to the required temperature.
- **Temperature**
  The temperature must be monitored during the pasteurisation step, using temperature sensors or probes, and then recorded. The sensors must be calibrated on an annual basis and several may be needed to ensure that the temperature of the material is consistent throughout the batch.
- **Time**
  The time that the material has been held at its required temperature must be recorded to ensure the required sanitation has been achieved.

6.4.3 Site management for Animal by-products Regulation compliance

Avoiding contamination of pasteurised material with raw untreated waste is another key aspect of the Animal by-products Regulation. Operators will need to consider material handling, storage and making sure anything that meets pasteurised material is not contaminated by unpasteurised material. In addition, operators will need to consider pest control and the use of disinfectant footbaths at entrances to sanitised areas to prevent staff members spreading contamination.

The site layout should also ensure the sanitation requirements of the Animal by-products Regulation can be met. This should include storage of input and output materials, drainage, and segregation of sanitised and dirty areas. More information on the regulations can be found in Section 4.12 of the accompanying Technology Guide and on the Department of Agriculture, Food and the Marine website.

[12] https://www.agriculture.gov.ie/agri-foodindustry/animalbyproducts/

6.4.4 Digestate quality monitoring

Operators should monitor the quality of the digestate to ensure that its composition is as expected and that it is not going to cause any damage when applied to land. This compositional analysis is best carried out by a third-party laboratory.

If using food waste, contamination such as plastic and other packaging waste may be an issue when applying the material to the land. When dealing with packaged food waste, depackaging equipment is required to release the organic material. It is important that the packaging is separated from the feedstock effectively to prevent it entering the process. If the packaging materials cannot be completely removed prior to treatment, there are screens and other technologies available that can remove contamination from the final liquid phase digestate. It is vital that all non-biodegradable packaging materials are removed from the digestate prior to application to land. Any particles of contamination put into the soil will be very difficult to remove and could be ingested by livestock or wild animals.

7. Maintaining environmental compliance

Maintaining environmental compliance:

- **The operator must comply with the conditions stipulated by the relevant regulators, who may include the local authority, the Environmental Protection Agency and the Department for Agriculture, Food and the Marine.**
- **Odour is an issue experienced by many AD facilities and, and is often a focus for regulators, particularly if complaints are received by nearby residents and businesses. Odour abatement systems designed for the type of feedstocks being processed should be installed.**
- **Dust, biogas, combustion gases and wastewater are other emissions that are likely to be generated at the facility.**
- **The consequence of these emissions will vary depending on their concentration, the proximity of the facility to population centres and the context of the facility (a farm can be an odorous environment irrespective of the AD facility).**
- **Operators should liaise with the local community to ensure complaints are dealt with promptly and effectively.**

7.1 Air emissions monitoring

It is inevitable that any AD facility will generate emissions. This could be from storage areas, liquid storage tanks involved in the process, and from the combustion of biogas. Different types of emissions will be treated differently by regulators. Some of the key emissions that operators need to be aware of are described below.

Figure 7.1: Stack from an odour treatment plant

7.1.1 Odour

No matter what the feedstock, odour is likely to be generated at some point in the process. The odour emission control measures required depend on two principal factors: the concentration of the odour; and the distance to the nearest sensitive receptor (for example, a dwelling or school).

The concentration of the odour will depend on the feedstock being used, the storage facilities and the treatment process used. Relatively dry, crop-based feedstocks may generate very little odour. Silage and manure slurries are likely to generate considerable odour, as may food waste. Processing that generates significant odour is likely to be required to take place inside a building with air extraction and an odour control system.

Section 7.3 of the accompanying Technology Guide describes common odour control technologies. It is important to monitor the airstream emitted from the site to ensure the odour control system is effective and the facility is not causing undue pollution.

Odour monitoring can be carried through an olfactory analysis of the air from an odour control system stack, and by qualitative 'sniff' testing by an operator roaming the site and its boundary. Other specific odorous compounds may also be monitored, such as volatile organic compounds, hydrogen sulphide and ammonia. Increases in concentrations from base-line levels may indicate increasing emissions of odours and need to be investigated.

7.1.2 Dust

Dust is unlikely to be an issue unless the operator is handling very dry material or using a pre-treatment method that agitates the feedstock. If the facility is likely to generate dust, then the environmental permit for the facility will include a limit for dust emissions and the operator may need to incorporate dust filtration into the air handling system. Dust emissions may be tested by a third-party contractor using specialist equipment.

7.1.3 Combustion gases

If biogas is being combusted on site in a boiler, engine, or flare, then the emissions are likely to require monitoring and reporting to the permitting regulator.
Key pollutants that may need to be monitored include:

- Sulphur dioxide
- Nitrogen dioxide
- Volatile organic compounds
- Carbon monoxide.

Combustion gas monitoring should be carried out by an independent third party using calibrated equipment. The frequency required will be set out in the permit.

7.1.4 Biogas

It is important that operators maintain the integrity of gas storage vessels and pipework. Any emissions of biogas to the atmosphere are not only a significant health and safety risk but are likely to breach the permit conditions and reduce environmental benefits.

The first indicator of a potential biogas release is through a reduction in system pressure. The facility designer will have configured the biogas system to operate within a defined pressure range. As the anaerobic digesters produce gas, a positive pressure in the system will build up, and the biogas-handling system downstream of the anaerobic digester will work to maintain the working pressure. Pressure sensors monitor the system pressure.

Figure 7.2: Biogas pipework and anaerobic digester tanks

Most facility control systems allow operators to program alarms that will activate if the pressure falls or rises too far beyond the designed operating pressure. Operators should take immediate action if an alarm is triggered.

A low-pressure alarm could indicate a failure of containment (for example, a leak in a pipe, or a failed seal in a piece of equipment). Those investigating the issue must have a gas monitor and observe the requirements for working in a potentially explosive atmosphere.

A high-pressure alarm could indicate that the downstream gas-handling equipment is not functioning correctly (for example, there might be a failed booster fan, or a closed valve). The gas system should have pressure relief valves (PRV) built in. These automatically allow passage of biogas when a set pressure point is reached, to prevent damage to the tank or biogas pipework through over pressurisation. They allow air in from outside if the tank or pipework is subject to low pressures. Operators should ensure that PRVs are carefully maintained, as a failure could have serious consequences for the facility.

If biogas pressure is rising, operators should investigate the cause before the pressure gets to a point at which the PRV vents biogas. It will usually be a requirement that operators inform the relevant regulator of any biogas release to the atmosphere (accidental or otherwise).

7.2 Wastewater emission monitoring

The AD permit regulator or Irish Water are likely to place limits on any wastewater discharged from the facility. This could be surface water that is running to a local watercourse, surface drainage, or contaminated or surplus process water discharged to sewer under a Trade Effluent Discharge to Sewer Licence.[13] To enable samples to be taken for testing, the drainage layout should feature a sample point where a representative mixed sample can be taken for analysis prior to discharge. Analysis should be carried out by an accredited, third-party laboratory at a frequency set out in the relevant permit or license. Operators may want to carry out more frequent in-house analyses to ensure that the facility is complying with its permit.

7.3 Environmental compliance reporting

The facility permit or licence will specify the operator's reporting requirements. The relevant regulator will define exactly the information it requires.
This is likely to include data on:

- Tonnage processed
- Feedstock types processed
- Gas production
- Power generation (if applicable)
- Power imported
- Wastewater discharged
- Water imported
- Combustion emissions.

Operators should ensure that all information required by the regulators is recorded regularly and accurately.

7.4 Community liaison

An AD facility can have an impact on its local environment in several ways including odour, noise, dust, vehicle movements and other factors. Therefore, it is important that operators consider the local community in which the facility operates.

Depending on the scale of the facility, operators may host liaison meetings to address the concerns of the local community and to familiarise local people with the operation of the facility.

Operators should adopt a complaints procedure to ensure that any concerns or complaints lodged by members of the public or businesses locally can be investigated, and feedback provided using a consistent approach.

[13] https://www.water.ie/for-business/trade-effluent/

Glossary

Anaerobic	Absence of free oxygen.
Anaerobic digestion (AD)	The process of anaerobic microbial degradation of organic matter to produce biogas.
Anaerobic digester	Vessel (tank, reactor) in which AD takes place. Sometimes referred to as a fermenter or bio-digester.
Animal by-product (ABP)	Animal carcasses, parts of animals, or other materials which come from animals but are not meant for humans to eat (includes catering waste).
Biogas	Mixture of methane and carbon dioxide produced by AD.
Boiler	Equipment for heating hot water or producing steam.
Bunker	Open sunken pit for the storage of waste or feedstock.
Combined heat and power (CHP)	Combustion plant used to generate both electricity and useful heat.
Digestate	Anaerobic digester output of digested feedstock.
Whole digestate	Digestate from the anaerobic digester.
Liquid digestate	Liquor produced from dewatering of whole digestate.
Solid digestate	Solid digestate produced from dewatering of whole digestate. Sometimes referred to as cake or fibre fraction.
Dried digestate	Solid digestate that has been thermally dried to a low moisture content. Sometimes referred to as dried cake.
Dry solids (DS)	Material remaining after drying (for example, drying of feedstock or digestate) at about 105°C. Typically expressed as a percentage of the original wet weight. May also be referred to as dry matter or total solids.
Facility	Refers to the whole integrated infrastructure associated with the AD process.
Feedstock	Organic materials suitable for and used in AD.
Energy crops	Crops such as grass and silage grown specifically for use as AD feedstock.
Food processing waste	Solid and liquid organic waste derived from food processing.
Kitchen waste	Waste food from home and catering establishments (may or may not include animal by-products).
Manure	Farm livestock manures and slurries.
Packaged waste	Packaged waste food and drinks.
Waste crops	Farm crops that are unsuitable for their intended uses and considered as a waste by the farms, for example, old unusable silage, root crops such as potatoes, carrots and parsnips, rejected by the food industry as unsuitable for human consumption.
Flare	Emergency combustion plant for safe disposal of excess biogas.
Gas engine	Cylinder-based gas combustion plant.
Gas turbine	Turbine-based gas combustion unit.
Loss on ignition (LOI)	See 'Organic matter'.
Organic matter (OM)	The carbonaceous matter (for example, in feedstock or digestate) typically expressed as a percentage (by mass) of the total matter wet mass, but also sometimes expressed as a percentage of the dry solids (called organic dry solids, oDS, or organic dry matter, oDM). Measured by weight loss of dry solids during heating in air at 450-550°C. Sometimes referred to as volatile solids (VS) and loss on ignition (LOI).
Volatile solids (VS)	See 'Organic matter'.

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