SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Anaerobic Digestion for On-farm Uses - Technology Guide

Anaerobic Digestion for On-farm Applications – Technology Guide

June 2020

Version Control

Version Number	Purpose/Change	Page	Date
V1.0	Published		16/06/2020

Report prepared for SEAI by
Ricardo Energy & Environment

Sustainable Energy Authority of Ireland
SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with homeowners, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of Communications, Climate Action and Environment.

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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 Usable food wastes include rejected or out-of-date products from manufacturers or retailers, and wastes from commercial and domestic kitchens.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 **Operation and Maintenance Guide** provides guidance on how to operate and maintain an AD facility to ensure it provides a high level of performance during its lifetime.

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 for those who are considering developing an AD facility. It explains the typical technology and infrastructure options available. This information will be useful during discussions with technology providers, construction companies, consultants, regulators, energy off-takers and feedstock providers. Its principle aims are:

- To provide a guide to the range of AD technologies and infrastructure available, good practice, and technical and regulatory issues; and
- To inform the reader of the options available and direct them to sources of more detailed information on aspects of the technology.

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;
- Other suitable biodegradable wastes and food processing residues that can be brought onto the farm.

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

Figure 1.1: Farm-based AD system

Outside the scope of these guides are the Support Scheme for Renewable Heat terms and conditions.[2] The Support Scheme for Renewable Heat 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/

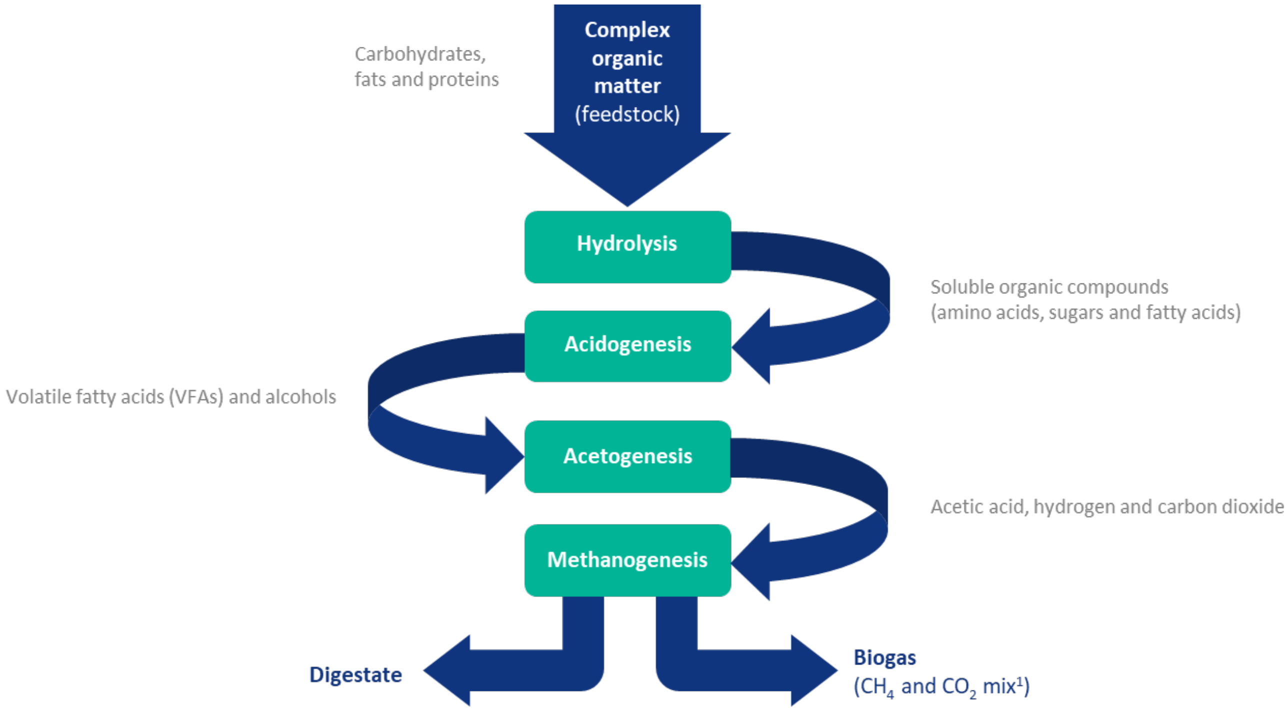
2. Overview

2.1 What is anaerobic digestion?

Anaerobic digestion (AD) is the microbial breakdown of organic material in the absence of oxygen to yield a methane-rich gas and digested material. These outputs are known as ‘biogas’ and ‘digestate’ respectively. Biogas can be used as a fuel, and digestate can be used as a fertiliser or soil conditioner. The biological process is not dissimilar to that taking place in a stomach or in a landfill that has received waste containing organic biodegradable materials.

An overview of the four-stage biological process is provided in *Figure 2.1* and a more detailed explanation appears in the accompanying Overview Guide.

Figure 2.1: Biological stages in AD



[1] Methane (CH_4) and carbon dioxide (CO_2)

2.2 Wet and dry digestion

AD may be carried out as a ‘dry’ process, where the feedstock is presented as a stackable material, or as a ‘wet’ process, where the feedstock is presented as a pumpable slurry. Wet AD is more commonly used, as it allows operations to run more consistently, and makes it easier to manage temperatures, mix the feedstock, and transfer material.

Many organic materials are suitable for AD, including liquids and solids. Solid AD feedstock is often mixed with water or liquid feedstocks to produce a pumpable slurry. Adding water makes the material easier to transfer and mix, as well as enabling the AD process to run effectively and continuously. Where water is added, however, the energy density of the feedstock is diluted. The biogas potential of the AD infeed material is reduced on a unit-input basis, and the overall AD input increases in volume. This calls for the following:

- Larger tanks and process equipment;
- Increased heat input;
- More processing; and
- Greater storage capacity for the outputs.

The proportion of solid to water in a feedstock is expressed as the mass of solid material remaining as a percentage of the original mass after drying a pre-weighed sample of the material. This is called, interchangeably '% dry solids', '% total solids' or '% dry matter'. This guide uses '% dry solids' and presents the information on a mass basis (weight for weight).

An AD feedstock prepared into a slurry of approximately 15-20% dry solids is stackable and not readily free flowing. To put this in context; cattle slurry is typically around 8% dry solids (although it can vary considerably), cattle dung is around 25%, and horse manure around 28%.

The point at which the process can be considered dry or wet is not fixed. Some process designs, notably dry batch systems, add minimal water or liquid and process low-moisture-content (approx. 50% dry solids) feedstocks. Biogas yields can be high on a unit-input basis, but the process will typically be undertaken in batches, with delays between each batch. Such dry AD processes are less common than wet AD processes and are not discussed further in this guide.[3]

At the other extreme, some wet AD processes treat liquid wastes, often at less than 0.1% dry solids (for example, in industries such as sewage treatment, brewing and pig-farm wash-water). These wet AD processes are often principally for the purpose of wastewater treatment, rather than energy production. Such processes involve specific AD technologies, such as upflow anaerobic sludge blanket reactors, and are not covered in this guide.

The most common method of undertaking AD is to produce a low-solids slurry (typically between 5% and 15% dry solids) for wet AD processing. Inputs of up to 20% dry solids are less common and require specialised pumping equipment. Sometimes, AD with inputs over 15% dry solids is termed 'dry AD', even though some water is likely to have been added.

This guide focuses on the typical technologies used in the most commonly employed process – wet AD, with inputs in the 5-15% dry solids range.

2.3 Main features of an anaerobic digestion facility

The AD process is controlled using engineered infrastructure and equipment. It is undertaken in sealed tanks with interiors that are isolated from outside air. Different, interchangeable, terminology is used to describe the tanks where the AD process takes place. These include:

- AD tanks
- fermenters
- bio-digesters
- digesters
- anaerobic digesters.

This guide uses 'anaerobic digester'.

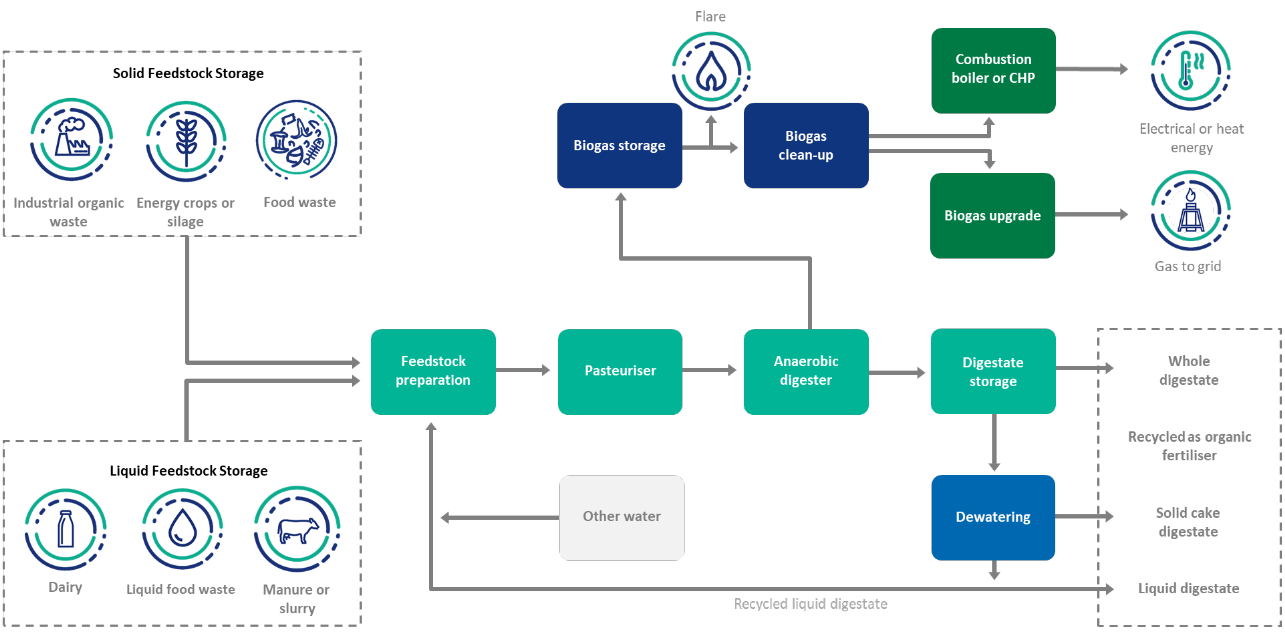
An AD facility often involves other tanks for a range of purposes, including storage and preparation of feedstock and digestate, but the term 'anaerobic digester' specifically refers to the vessel in which the biological process takes place.

[3] For further explanation of dry AD systems, see Section 2.2 of Biogas from Crop Digestion (IEA Bioenergy, September 2011). (https://www.ieabioenergy.com/wp-content/uploads/2011/10/Update_Energy_crop_2011.pdf)

This guide discusses technologies commonly found at AD facilities.

- **Feedstock** (Section 3):
  - Storage and handling; and
  - Pre-treatment and processing prior to AD.
- **Anaerobic digestion** (Section 4):
  - Anaerobic digesters, including all ancillary equipment (for example, for heating, mixing, and controlling pressure and gas quality);
  - Containment, surfacing and security; and
  - Sanitation (pasteurisation when processing waste that contains animal by-products and keeping separate 'clean' areas for handling and storing pasteurised material away from 'dirty' areas where unpasteurised material is handled and stored).
- **Biogas management** (Section 5):
  - Biogas cleaning; and
  - Biogas utilisation for energy production.
- **Digestate handling** (Section 6).
- **Air quality and emissions abatement** (Section 7).
- **Wastewater management** (Section 8).
- **Control and instrumentation** (Section 9).

Figure 2.2: Simplified process flow scheme for a farm-based AD facility



2.4 Design variability

Different feedstocks require different methods of storage and processing. Even amongst facilities processing the same feedstocks, many facility designs exist. This guide aims to explain the typical technology options available without reviewing all the available technologies.

3. Feedstock

3.1 Characteristics

The feedstock is the organic material that goes into an AD facility. It can be solid or liquid, and may be a waste, by-product or purpose-grown energy crop.

Some organic material is unsuitable for AD, for example woody biomass, and some can only be used following extensive pre-treatment, for example the removal of inorganic contaminants. Some wastes are normally used in limited quantities or mixed with other feedstocks, due to their characteristics. For example, poultry litter has a good biogas potential, but it generates significant amounts of ammonia (NH_3), which when uncontrolled can be toxic to the microbes in the anaerobic digester. Poultry litter also has high grit content that can wear pumps, pipework and can accumulate in tanks. Poultry litter, therefore, tends to be used in limited quantities alongside other feedstocks, so the benefit of its biogas yield can be obtained with control over its adverse impacts.

Many types of feedstock have limitations, including incompatibility with other types. For example, mixing certain combinations of feedstock can cause foam to form rapidly on the top surface of the tank contents, which can block gas off-take piping, causing pressure to rise and potentially damaging the tank.

AD facilities can use a single type of feedstock, or a mixture. The type of feedstock (or mix) is a fundamental consideration that affects the technology and infrastructure requirements of the facility.
The influencing characteristics include:

- The **availability** of feedstock across the seasons of a year, determines what combinations of feedstock will be used over time and affects the storage requirements;
- The balance of **liquid and solid** determines storage and handling requirements, and whether size reduction of the feedstock is required and if there is a need to add water;
- Whether highly **putrescible** (decomposes rapidly) – only suitable for short-term storage and typically has a high odour potential;
- The **volatile solids** (VS) content are those materials lost on ignition and its laboratory determination allows a measure of degradability in AD. Degradability indicates how quickly the biogas potential in a feedstock is released.
- The **biogas potential** of the feedstock affects the time needed in the AD, with high biogas potential and high degradability typically requiring less time, and allowing full digestion to be achieved with smaller tank sizes;
- Whether a material has a **propensity to sink or float** in storage tanks and anaerobic digesters affects the mixing requirements and equipment needed to prevent or break-up floating layers;
- The **presence of contaminants** (for example, soil, grit, packaging materials and cutlery) determines what equipment and processes are needed;
- The **presence of animal by-products** determines the sanitation (pasteurisation) requirements and can mean that the facility must have separate areas – one where pasteurised material is handled and stored, and the other where un-pasteurised material is handled and stored; and
- The **micro-nutrient (trace metal) content** affects whether micro-organisms must be added to maintain process stability.

3.2 Storage and handling

Crop-based feedstocks that are harvested at specific times of the year will require storage in outdoor clamps, concrete walled bays or silos for extended periods of time before they are needed. Measures to prevent spoiling are like those used when storing fodder crops.

Figure 3.1: Clamp storage of feedstock at an agricultural AD facility

Crop-based feedstocks are typically removed from storage and added to the process by a mobile plant fitted with front buckets. The feedstock is typically deposited into a feed hopper, which regulates flow. It also provides some degree of mixing and, if required, milling (for size reduction). A feed hopper is an open-topped container, typically with a conveyor at its base. Sometimes it has milling drums at the discharge end or vertical shaft-mounted mixers to help loosen, mix and regulate the flow of the feedstock. It is good practice to install load cells to enable recording of the mass of material added to the anaerobic digester, and visual displays help operators determine the appropriate proportions of different feedstocks that are fed in together.

Liquid feedstocks require tank storage and the tanks may need to be linked to an odour-collection pipework and an odour-treatment facility.

Figure 3.2: Clamshell grab at a food waste AD

Solid feedstocks, subject to type and facility characteristics, often require storage systems served with air collection and odour treatment. They can be stored on open floors, with sealed drainage, in walled bays, or within sunken tanks or bunkers. Feedstocks deposited on floors and within bays will require removal by mobile plant, while feedstocks in sunken tanks or bunkers will require removal by auger screw, clamshell grab, or petal grab. Grabs can be mounted on the mobile plant, fixed hydraulic arms, or steel cables suspended from overhead cranes.

Where rapidly putrescible feedstocks are stored, the storage should allow for limited-duration storage (for example, to accommodate deliveries at times when the facility is not operating), but not so long as to lead to putrefaction, excessive greenhouse gas emissions, excessive odour, and a reduction of biogas potential. Discussions on storage should be held at an early stage with the local authority or the Environmental Protection Agency (EPA), which regulates waste processes.

3.3 Pre-treatment

Pre-treatment is used where the feedstock requires preparation to make it suitable for the AD process. This can involve contaminant removal (including de-packaging), size reduction, and mixing with other feedstocks and water to produce a homogenous and uniform material.

Grains biodegrade better if they are milled first. Silages, manure containing straw, and root vegetables require shredding, pulping or macerating to produce particles small enough to be transferred by auger screw or pump and pipework, and to render them readily accessible by micro-organisms. Waste root vegetables may require prior washing to minimise inert soil and grit entering the anaerobic digester.

Out-of-date or spoilt packaged food waste needs to be de-packaged and the food pulped or mixed with water to produce a suitable feedstock. Source-segregated kitchen waste from households, restaurants and canteens often contains around 5% contamination, usually in the form of plastic bin liners, food packaging, cutlery and bones.

At present, biodegradable kitchen caddy liners do not biodegrade in AD processes and should be removed as much as possible to prevent blockage, floating layers and contamination of the digestate product.

Contaminants can cause premature wear of pumps, pipework and nozzles, as well as blockages in pumps and pipework. If settled material (for example, grit) accumulates, it reduces the effective working volume of the anaerobic digester or other tanks and can cause problems with digestate extraction and mixing. Accumulations of floating material can cause similar problems and may also hamper gas extraction. In both instances, the reduction in effective working volume in an anaerobic digester will reduce the hydraulic retention time (that is, how long the material stays in the anaerobic digester). This has the potential to lower the biogas yield, which will adversely affect the economics of the system.

Removing contaminants is also important to ensure the digestate meets quality standards and to reduce the risk of land contamination. Some facility designs include contaminant removal at all stages – during pre-treatment, in the anaerobic digester and from the final product. Whether or not that is required depends on the feedstock and the nature of the processing.

To transfer feedstocks between pre-treatment equipment and an anaerobic digester or buffer tank, a pump, auger screw, belt conveyor or chain conveyor – or a mix of two or more of these methods – is typically used.

A wide variety of proprietary pre-treatment equipment, and equipment configurations are available.

When selecting a process, it is worth:

- Establishing the track record of the technology provider, the equipment and the overall design in treating the proposed feedstock types and quantities; and
- Identifying its limitations, operator control requirements and maintenance requirements.

It is worth visiting a reference facility (that is, a fully operational facility using the same equipment) and talking to its operators.

4. Anaerobic digestion

4.1 Anaerobic digesters

4.1.1 Semi-continuous, plug or batch

Most anaerobic digestion facilities operate on a wet, semi-continuous flow basis. This means a small and regular infeed with a small and regular discharge of digestate. The level in the tank remains close to full, fluctuating within a small range.

Plug flow involves input and output that is less regular and of greater volume compared with that for semi-continuous flow.

Batch AD, is where there is a single input, followed by AD, and then removal of the material. In batch digestion, a small amount of digestate is left to act as a seed material (bacterial inoculant) for the next batch.

The rest of Section 4 describes technologies used in wet, semi-continuous flow AD facilities.

4.1.2 Single and two-stage anaerobic digestion

In single-stage AD, the entire biological process takes place in one anaerobic digester or more than one in parallel. In two-stage AD, the process takes place in a series of primary and secondary anaerobic digesters. It is possible to have several anaerobic digesters operating in parallel at each stage. Whether single- or two-stage AD is used, having more than one anaerobic digester at each stage can provide resilience during maintenance or breakdowns (that is one can be taken out of service while still maintaining some facility throughput). In a large capacity facility, it might not be feasible to have a single large anaerobic digester because of the visual impact or mechanical limitations, such as ease of mixing or removal of settled contaminants.

Where space is constrained, single-stage AD can make more efficient use of space. Capital costs may also be reduced by not having to duplicate equipment.

In two-stage AD, different stages of the biological process (see *Figure 2.1*) take place in the primary and secondary anaerobic digesters respectively. Therefore, the biological process can be optimised at each stage. This allows greater operational control, improved biological stability and improved AD efficiency.

Some designs use a 'tank in tank' design where the space between each wall (the annulus) serves as the primary anaerobic digester and the inner tank serves as the secondary anaerobic digester. However, it is most common to have two separate tanks.

Table 1: Summary of single and two-stage AD

Method	Advantages (not exhaustive)
Single stage (one or more anaerobic digesters)	• Can make more efficient use of available space. • Capital costs may be reduced by not having to duplicate equipment. • Several anaerobic digesters in parallel can provide resilience at times of maintenance and breakdowns.
Two stage (one or more anaerobic digesters at each stage)	• Allows increased control over the biological process, enabling optimal conditions for different biological stages (see Section 2.1). In turn, this can increase gas yields relative to the hydraulic residence time. • Can improve biological stability. • Several anaerobic digesters in parallel can provide resilience at times of maintenance and breakdowns.

4.1.3 Tank construction materials

Common construction materials include:

- Pre-cast, pre-stressed, concrete sections joined together with circumferential internal steel ties, and sealant applied;
- In-situ poured reinforced concrete;
- Stainless steel; and
- Sectional mild steel panels coated with fused glass that are bolted together on site, with sealant applied where panels overlap.

The options differ in terms of cost, ease of construction, strength, lifespan and maintenance inspection requirements. In-situ poured concrete tanks are likely to have a relatively high cost, but give good protection against damage, and failures are rare. Mounting equipment on the wall and roof interiors and exteriors is more straightforward than with metal tanks. The inner surfaces of concrete tanks, notably in the gas headspace at the top of the tank, require special membrane surfacing or coating to protect the concrete from the corrosive operating environment.

Figure 4.1: Pre-cast sectional concrete tank

Some steel anaerobic digesters use a twin wall arrangement where the outer wall functions as a bund (secondary containment) and the space between the two walls is filled with insulation. In other steel-tank designs, outer cladding (for example, plastisol-coated steel cladding) covers and protects insulation around the tank. Typically, mineral fibre wool batts are used for insulation. Where rigid roofs are present, the roof can also be insulated.

In steel and concrete designs, rigid roofs can be used, or a flexible membrane roof can be used for gas storage purposes. The latter option limits opportunities for placing equipment on the tank roofs. Gas storage options are explained in Section 5.2.

Table 2: Summary of commonly used anaerobic digester tank construction materials

Material	Typical advantages and disadvantages (not exhaustive)[4]
Pre-cast and pre-stressed sectional concrete	• Easy and quick construction. • Good longevity. • Compared with metal tanks, equipment can be mounted on the tank with relative ease (less supplementary support required).
In-situ poured, reinforced concrete	• Long on-site construction time. • Good longevity but can be expensive. • Compared with metal tanks, equipment can be mounted on the tank with relative ease (less supplementary support required). • Low risk of failure.
Stainless steel	• Good longevity and corrosion resistance but can be expensive.
Mild steel panels coated with fused glass and joined with bolts and sealant	• Easy and quick construction at relatively low cost. • Care needs to be taken to appropriately support equipment attached to the tank. • Special care needs to be taken during construction and operation to avoid damaging the glass coating.

[4] Typical advantages and disadvantages are listed. However, the quality of fabrication and construction are also important factors that affect a tank's properties.

4.2 Anaerobic digester volume

Anaerobic digesters vary in size – from very small (220-litre oil-drum size) to very large (tens of metres in height or diameter), sometimes with several tanks.

Sizing an anaerobic digester relative to the volume and characteristics of the intended feedstock is important. The rate of infeed, volume of water addition and size of the digester dictates the time that the material stays in the anaerobic digester; this is known as the hydraulic retention time. If the hydraulic retention time is too short for full degradation to take place, then the maximum biogas yield will not be obtained. If it is too long, the anaerobic micro-organisms will become starved of organic material, which could cause them harm. It will also lower the biogas yield.

Another consideration when sizing an anaerobic digester is how fast the feedstock will degrade. Fast-degrading feedstock, such as household food waste, requires a lower hydraulic retention time and therefore a smaller anaerobic digester than a slow-degrading feedstock, such as maize silage. It is possible to mix feedstocks of varying degradability. In such cases, the hydraulic retention time, and anaerobic digester size, is normally based on the material with the lowest rate of degradation. There are many sources of published data on biogas potential and degradation rates for different feedstocks at different dry solids content. Alternatively, laboratory analysis can determine these or provide confirmation.

Degradation can be affected by process temperature, efficacy of substrate (contents of digester) mixing, nutrients present and the nature of the infeed pre-treatment. AD processes operating at thermophilic temperatures (50-60ºC) tend to degrade substrate faster than AD processes operating at the lower mesophilic (30-40ºC) temperatures (see Section 4.4), potentially with an increase in the overall biogas yield, enabling smaller anaerobic digesters to be used.

The ideal hydraulic retention time is subject to many factors but is typically between 20 and 50 days. Furthermore, some degree of variation on an ongoing basis can be expected as feedstock properties fluctuate.

The substrate level in an anaerobic digester should be kept relatively constant between upper and lower limits, known as set-points. The level will fluctuate by only a small amount on infeed or digestate off-take. A space needs to be maintained above the top water level where biogas can collect prior to extraction. This is known as the headspace and should be accounted for when sizing an anaerobic digester. There should be windows in the tank sidewall or roof so that the headspace, water level, and any build-up of undesirable floating layers, is visible.

4.3 Anaerobic digester shape and dimensions

Most anaerobic digesters are cylindrical tanks with dimensions that suit the chosen mixing method. The maximum diameter may be restricted where certain equipment (for example, central post-mounted floor scrapers) is used.

A cylindrical tank has advantages for mixing compared with square or rectangular tanks as it is less likely to contain unmixed zones. The ideal shape for effective mixing is an egg shape, although such a shape is difficult to construct.

Where solid roofs are constructed, these tend to be conical (sometimes with a central flat crown area) for steel tanks, and flat reinforced concrete for concrete tanks.

Bases are typically constructed of concrete and are either flat or conical, sloping in towards a central sump, from which digestate can be extracted.

4.4 Temperature control

AD is undertaken at mesophilic (30-40ºC) or thermophilic (50-60ºC) temperatures.

The advantages of thermophilic AD compared to mesophilic AD are:

- **Reduced hydraulic retention time**, meaning a smaller anaerobic digester can be used (or more feedstock can be processed in the same size anaerobic digester) (see Section 4.2); and
- Typically, **higher biogas yields** with increased rate of biogas production.

The disadvantages of thermophilic AD compared to mesophilic AD are:

- The biological process can be **less stable** (for example, more sensitive to a change in feedstock type, quality or rate of input) with increased risk of issues that can suppress biogas yield or stop the biological process; and
- **Increased energy use** to heat the anaerobic digester.

Maintaining a stable temperature during operation is important. In Europe, it is normally necessary to add heat and to insulate the anaerobic digester. Heat is added by using some of the biogas produced to directly fuel a boiler, to raise hot water or steam, or by recovering heat from a combined heat and power (CHP) engine. Heat can be transferred directly to the anaerobic digester via hot-water pipework mounted inside it, or by the circulation of substrate through an external heat exchanger.

If required, pasteurisation (see Section 4.12) can be undertaken on undigested prepared infeed material or on the digestate product. Typically, pasteurisation requires the material to be heated to at least 70ºC and held at or above that temperature for at least one hour. Where the infeed material is pasteurised, the heated infeed can then be added to the anaerobic digester, which will then normally require cooling to maintain the desired temperature. Cooling can also be achieved using some of the biogas produced (using an absorption chiller). However, many AD processes heat the anaerobic digester and carry out post-digestion pasteurisation of the digestate. Because digestate has a consistent composition with lower dry solids and no fats (if food-waste AD), it is easier to pasteurise than the less-consistent prepared feedstock.

4.5 Pressure control

Biogas generated in an anaerobic digester accumulates in the headspace (above the substrate in the tank), from where it is extracted and piped to storage vessels, upgraded to biomethane or used on site. The system should be sized for the anticipated biogas yield. In operation, biogas should be free to flow to equalise pressure across the system (that is, between anaerobic digesters and any gas storage vessels); this is sometimes aided by modulating valves. The operating pressure is primarily dictated by the back pressure created by the pipework diameter and configuration as well as the storage method. All equipment and infrastructure should operate safely at the operating pressure and at maximum design pressures. Typical operating pressures vary, often being around 500 Pa (5 mbar), but some designs operate at pressures of around 2,000 Pa (20 mbar).

Regular small volumes of infeed addition and digestate extraction help to maintain the substrate level in the tank and avoid very large fluctuations in gas production. An undesirable fluctuation in biogas pressure can occur for a range of reasons, including:

- Unanticipated change in the substrate level;
- Infrequent feeding;
- A one-off input of infeed material with high biogas-potential;
- A problem with the gas storage arrangement;
- A biogas leak to atmosphere;
- A rapid build-up of foam in the anaerobic digester and/or a blockage in the pipework; and
- Incorrectly set valves on pipework or pipework restrictions (for example, accumulation of condensate).

Figure 4.2: Example of water-based pressure relief valve

To avoid damage to tanks and equipment, with potential system failure, it is necessary to install a pressure relief valve (PRV) on tanks to protect against overpressure and negative pressures (gauge pressures). Pressure relief valves can either be mechanical or rely on a water trap that allows biogas out at high pressure, and air in at low pressure. A mechanical PRV (for example, a weighted rubber seal) can sometimes stick open if it is not maintained in a clean condition. A water-based PRV will, subject to design, require regular monitoring of water levels to ensure that it vents biogas at the correct pressure. If the water level drops, the PRV will vent at a lower pressure than desired, causing emissions, the loss of biogas and potentially non-compliance with regulation.

Should a rapid build-up of foam occur at the top surface of the anaerobic digester, the pressure of the biogas in the headspace can increase rapidly, especially if gas pipework becomes blocked. Therefore, some anaerobic digester designs include a 'blast panel' (for example, a weighted flap with a rubber seal on the roof that will open in such scenarios). These are sometimes used in addition to PRVs.

Venting of biogas or entry of air will be apparent from the pressure trend data for the tanks (see Section 9.3). Regular venting indicates a problem that should be investigated and is highly undesirable due to the environmental impact of biogas escaping and the loss of valuable biogas. (Monitoring sources of methane leakage is considered in Section 7.4). Air entry is also undesirable as it can affect the biological process and can cause problems in downstream biogas utilisation equipment. Despite biogas venting and air entry being undesirable, it is important that a correctly functioning PRV is installed to protect against tank damage caused by over or under-pressure events. Such damage can allow large quantities of biogas, which is flammable and odorous, to escape, as well as allowing digestate to leak, which can cause significant pollution to watercourses.

4.6 Mixing

Mixing the contents of an anaerobic digester is important to:

- Ensure that micro-organisms and organic material are available to each other;
- Prevent stratification (solid material accumulating on the base, or floating layers, or both);
- Allow ease of digestate withdrawal; and
- Maintain consistent substrate residence time (for example, prevent short circuiting between input and withdrawal from the tank or long retention in poorly mixed areas of the anaerobic digester).

Mixing is also often necessary within infeed buffer tanks and digestate storage tanks. All options for mixing have strengths and weaknesses. Therefore, it is important to choose an option with proven success for the intended feedstock, dry solids level and anaerobic digester or storage tank dimensions. Options include:

- Mechanical agitation (hydraulic or electric stirrers, impellers or propellers);
- Pumped hydraulic (jet) mixing to recirculate the contents through pumps and discharge it back through nozzles mounted on the sides of the tank; and
- Gas mixing, extracting gas from the headspace, compressing it and reintroducing it at low level in the tank to cause substrate circulation.

All three options are available in a range of designs and allow intermittent or continuous mixing.

Some anaerobic digester designs enable mechanical mixing equipment to be removed without having to drain the tank, which is a considerable benefit for maintenance. Some designs also allow adjustments to be made to the impeller or propeller direction and height, and some can be used to help prevent or break up layers of floating material. These are just some of the many factors to consider.

Careful consideration should be given to selecting the appropriate mixing system for an AD facility as the choice will not only affect maintenance requirements and ease of operation but will also be important for maximising biogas production.

Table 3: Summary of mixing methods

Mixing method	Advantages and disadvantages
Mechanical agitation (stirrer, impeller, or propeller)	• Suitable for a wide range of feedstocks, including those with a high dry solids content. • Subject to design, the direction and height of the agitators can be changed in operation. • With some designs, access for maintenance can be problematic. • The inside of the tank is a harsh environment for mechanical components and frequent maintenance can be required.
Hydraulic (jet) mixing	• Ease of maintenance as all moving parts are external to the anaerobic digester. • Where grit is present, pump wear can demand high maintenance requirements. • Best suited to substrates with a low dry solids content.
Gas mixing	• All moving parts are external to the anaerobic digester, which assists with maintenance. • Maintenance requirements are generally lower than those for mechanical or hydraulic mixing. • Can be problematic for feedstocks with particles that float, or for feedstocks that tend to foam.

4.7 Contaminant removal from tanks

Dense material (for example, grit) that has settled in an anaerobic digester can be removed with bottom rakes and scrapers. There are systems available that extract floating debris from the top of the anaerobic digester, so that it can be screened before digestate is discharged back into the anaerobic digester. However, not all facility designs have such equipment. Whether such equipment is necessary depends on the level of contaminants in the feedstock, and the extent of contaminant removal in pre-treatment stages.

Some designs have no contaminant removal stages at all and, subject to the feedstock, may eventually cause serious processing issues resulting in the need to empty, clean and recommission the anaerobic digester.

4.8 Foam control

Foaming occurs where biogas exiting the substrate in an anaerobic digester forms small bubbles at the substrate surface that accumulate to a foam. The causes of foaming are numerous, and the phenomenon is not fully understood. Commonly cited contributing factors include:

- Excessive organic loading of the anaerobic digester;
- Irregular and large in-feeds; and
- Excessive gas recirculation and mixing of incompatible feedstocks.

Foaming, especially where floating debris is present, can cause issues with gas extraction, and rapid pressure increases can cause significant damage to the tank and roof structure, ultimately resulting in releases of biogas and substrate to the environment.
Some anaerobic digesters are fitted with roof-mounted hinged panels (blast panels) that will open when a rapid increase in pressure occurs (see Section 4.5).

Control measures include:

- Monitoring;
- Modifying the feed regime;
- Lowering tank levels to enable the impellers or propellers to break up the foam; and
- Modifying the mixing regime and using water spray systems, sometimes with foam control agents.

4.9 Hydrogen sulphide control

Hydrogen sulphide (H_2S) is a corrosive and toxic gas, harmful to the microbiology of the anaerobic digester. The presence of sulphur in input feedstock leads to the generation of H_2S. High levels of H_2S in biogas can damage downstream gas collection and utilisation equipment (energy recovery in a boiler or combined heat and (CHP) engine). Many equipment suppliers will specify an upper limit of H_2S in the biogas that is suitable for the equipment and breaching the limit may invalidate warranties.

H_2S levels must therefore be controlled. Suitable control measures at the digester do not require complicated technology beyond a means to dose the headspace. Other technologies and approaches are described further in Section 5.1.

4.10 Nutrient addition

Subject to the quality of feedstock, nutrient addition (for example, micro-nutrients such as trace metals) may be required to maintain stable and optimum digestion. Pipework and pumps are required to enable the nutrients to be added to the anaerobic digester.

4.11 Other tanks (non-anaerobic digester)

Many facility designs have a buffer tank between pre-treatment and the anaerobic digester. While feedstock pre-treatment often operates for only part of the day, buffer tanks allow continuous feed to the anaerobic digester. The pre-treated feedstock in the buffer tank is pumped to the anaerobic digester in controlled automatic mode for fixed durations at fixed intervals over 24 hours a day, seven days a week. It may be necessary to design the buffer tank with enough capacity to 'feed' the anaerobic digester over the weekend if no waste pre-processing is to take place. The buffer tank should have a mixer or mixers and, subject to feedstock, will often have a roof and many of the features of an anaerobic digester, notably a pressure relief valve (PRV) (see Section 4.5). Buffer tanks are often made of the same materials as anaerobic digesters (see Section 4.1.3). The level of the tank contents will fluctuate notably.

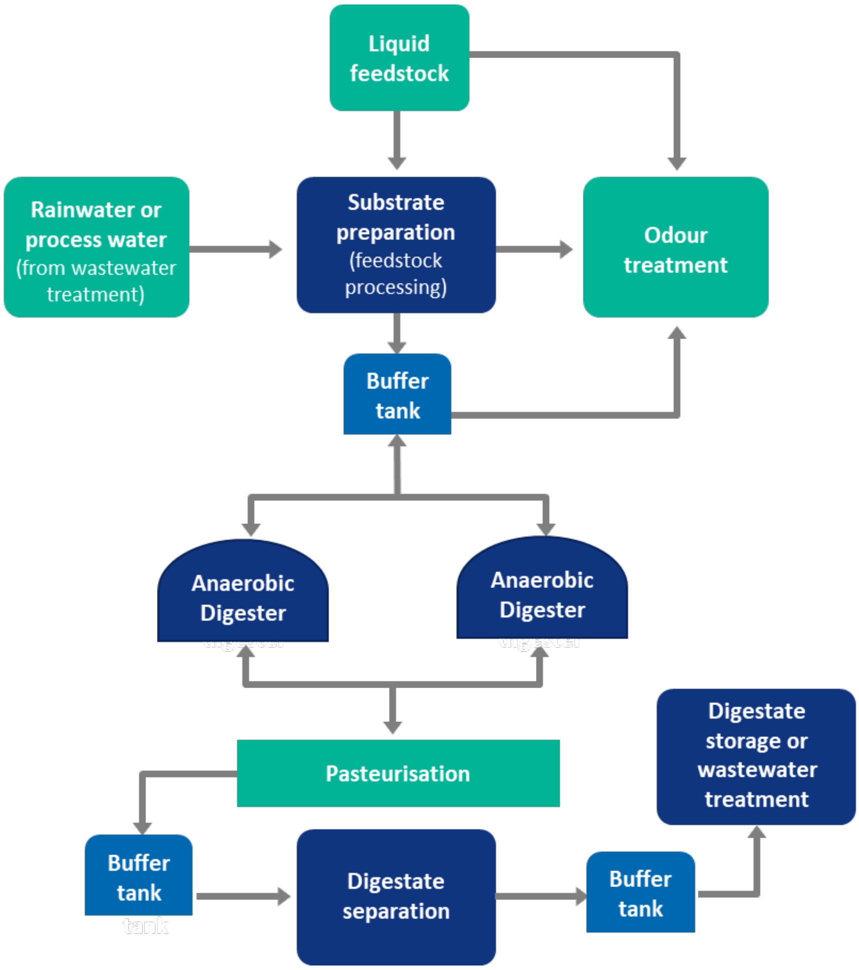
The buffer tank can be used as a hydrolysis tank. Hydrolysis is the first of the four main biological processes of AD, the others being acidogenesis, acetogenesis and methanogenesis (see *Figure 2.1* and the accompanying Overview Guide, Section 2.1.2, for an explanation).

Conditions such as temperature and pH are maintained to promote hydrolysis. Hydrolysis can be undertaken under aerobic (with free oxygen) or anaerobic (absence of free oxygen) conditions. If undertaken under aerobic conditions, and subject to feedstock properties, the tank headspace should be connected to odour collection pipework and an odour treatment facility. As high levels of odour can result if areas without oxygen develop in the tank during hydrolysis, good mixing is essential. If hydrolysis is undertaken under anaerobic conditions, it will be necessary to link the tank headspace to the facility's biogas collection system.

If there is no pre-treatment, then the feedstock store effectively acts as a buffer or the solid feed hopper can act as a buffer (see Section 3.2). It may be possible to load a feeder hopper once a day.

A tank, sometimes a lagoon, is often used to store the digestate after the AD process has been completed. Typically, this tank has many of the features of an anaerobic digester, but without heating or the facility to add nutrients. Other tanks involved in an AD facility (see *Figure 4.3*) can include liquid feedstock storage tanks, rainwater harvesting tanks, process water tanks, buffer and process tanks for pasteurisation (see Section 4.12), and tanks associated with air or odour treatment systems (see Section 7.3). Note, not all AD facilities include all the tanks and process stages shown in *Figure 4.3*.

Figure 4.3: Examples of non-anaerobic digester tanks that can be used at an AD facility



4.12 Sanitation

4.12.1 Purpose

Where feedstocks contain animal by-products, which are included in kitchen or canteen waste, there is a requirement to register with the Department of Agriculture, Food and the Marine. The facility design will require prior approval from the Department, which will inspect the works. It will then be necessary to pass pathogen kill tests to the satisfaction of the Department before the facility can be registered to process animal by-products. The Department will conduct periodic inspections and expect certain records to be maintained.

Further information on animal by-products, and the background to the applicable legislation and regulation is provided in the accompanying Implementation Guide, Section 4.6.4, and in documents available from the Department of Agriculture, Food and the Marine.[5]

The design requirements for an AD facility that processes animal by-products include drafting a hazard analysis, and a critical control point plan. The plan ensures process control to keep pasteurised and unpasteurised materials separate, and maintain adequate pathogen kill.

There are three main requirements for ensuring adequate sanitation:

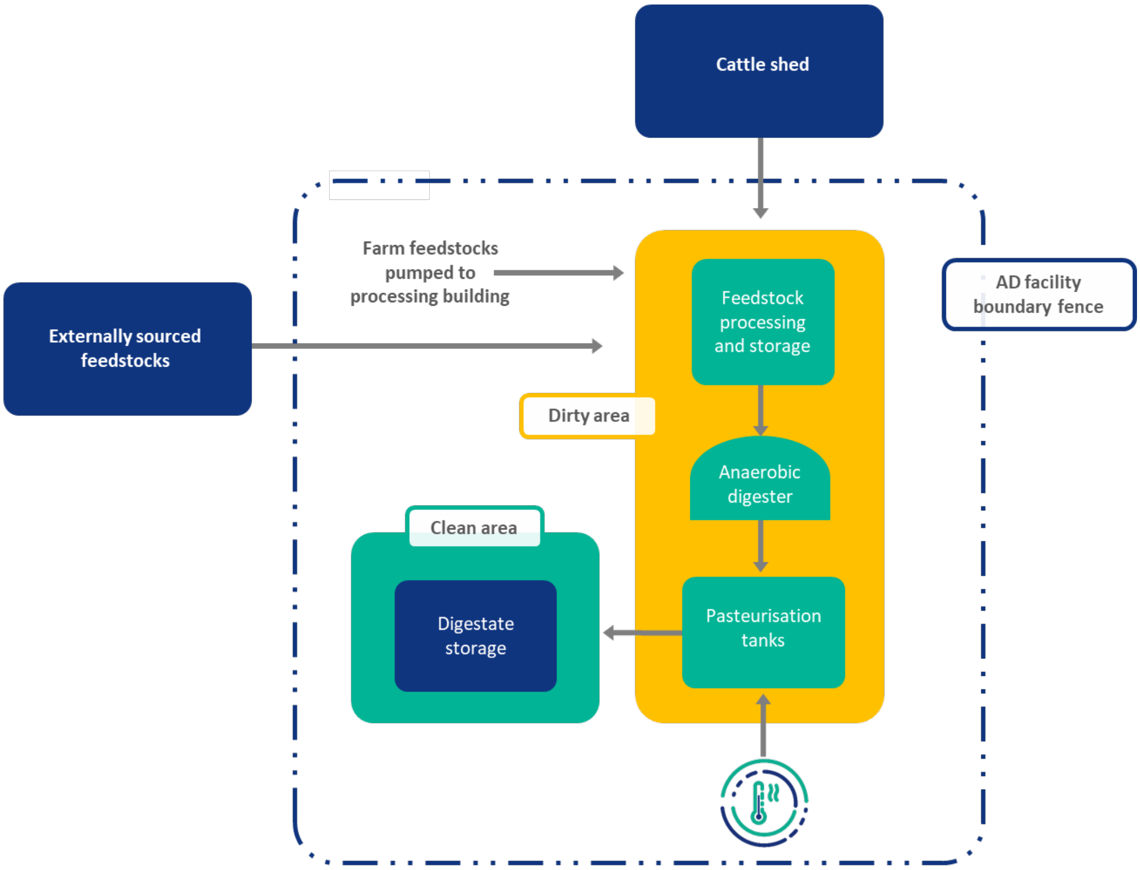
- Segregating clean and dirty areas;
- Ensuring the particle size is within specification (<12 mm); and
- Ensuring the pasteurisation process meets temperature and time requirements.

These are discussed in the following sections.

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

4.12.2 Clean and dirty areas

Figure 4.4: Segregating clean and dirty areas



Aspects of the facility design relating to the separation of clean and dirty areas, to ensure pasteurised and unpasteurised material are kept separate, include:

- Personnel and vehicle routing in and out of clean and dirty areas must be kept separate, and bio-security measures put in place (for example, appropriately placed changing rooms, over-shoes, disinfection pads and wheel cleaning);
- Feedstocks should be stored separately from other products, with separate drainage and spill containment;
- Vessels and pipework that contain unpasteurised animal by-products may only be kept in areas that are separate from where pasteurised material is processed or stored; and
- Livestock and other animals must not have access to any areas of the facility, or the materials and products contained within.

4.12.3 Particle size

The maximum particle size of pre-treated feedstock or digestate should be no more than 12 mm to ensure effective pasteurisation. Pre-treatment technologies are discussed in Section 3.3.

4.12.4 Pasteurisation

Feedstock containing animal by-products can be pasteurised before AD, or the digestate can be pasteurised after the AD process. In either situation, the material to be pasteurised should have a particle size of no more than 12 mm.

Pasteurisation temperatures must be continually monitored, and the material must be maintained above 70^{o}C for no less than one hour. If these conditions are not met, then the material must be reprocessed in the pasteurisation system before release to the remainder of the process.

The pasteurisation process is often fully automated via supervisory control and data acquisition, using a computer-based control system. The process design needs to consider the time required to fill and empty vessels, with allowance for failed batches and maintaining the correct anaerobic digester feeding and emptying regimes. Sometimes buffer tanks are used either side of the pasteurisation process to balance flows. It is good practice to pasteurise in batches rather than in a continuous flow.

Material is often pre-heated using heat exchangers, with heat supplied from a biogas boiler, or a combined heat and power (CHP) engine, before it enters insulated tanks, where further heating may occur using electric heating or heat from a boiler or CHP engine. The material is held in the tanks at the required temperature for the appropriate time to achieve pasteurisation. Plate heat exchangers or twin wall 'pipe in pipe' (shell and tube) winding pipework heat exchangers are commonly used to bring the material up to temperature. This approach is often preferable to heating a full tank of material from cold to the required temperature. The design should include more than one pasteurisation tank to allow a smooth regular operation of filling, holding and emptying (that is, one empties and fills while another is held at temperature).

Figure 4.5: Example of a three-tank pasteurisation system

The points covered in this section outline the main principles and typical approach. It will be necessary to hold discussions with the Department of Agriculture, Food and the Marine early in the design process, to gain a full understanding of what an individual site will require to achieve consent.

Table 4: Pre- or post-AD pasteurisation

Pasteurisation location	Advantages and disadvantages
Pre-anaerobic digestion	Substrate is warm when it enters the anaerobic digester, although the anaerobic digester is likely to require cooling.
Post-anaerobic digestion	Digestate will have lower dry solids and a lower fat content (food waste AD facilities), which allows it to be transferred, recirculated and mixed with greater ease. Residual heat can be recovered.

4.13 Site containment, surfacing and security

To prevent spilt or leaking digestate escaping, it is important that site containment methods (for example, the use of impermeable bunds or kerbing) are in place, and impermeable ground surfacing and contained drainage (drainage that drains to a sump, rather than direct to a point of discharge) are used.

Security measures must be in place to prevent unauthorised access and access by farm and wild animals. Such measures should meet all requirements dictated by the Environmental Protection Agency (EPA),[6] local authority and, where animal by-products are in the feedstock, the Department of Agriculture, Food and the Marine.[7]

Figure 4.6: Example of a bund wall and sealed surface

[6] http://www.epa.ie/pubs/advice/licensee/guidancetostorageandtransferofmaterialsforscheduledactivities.html

[7] https://www.agriculture.gov.ie/agri-foodindustry/animalbyproducts/applicationformsconditionsforabpprocessingoperations/conditionsforabpprocessingoperations/

5. Biogas management

5.1 Biogas cleaning

5.1.1 Purpose

Biogas should be cleaned and treated to protect the equipment that is in contact with it from corrosion, and to optimise combustion efficiency and exhaust emission pollutant levels. This is especially important for combined heat and power (CHP) engines. Engine and boiler suppliers will normally stipulate limits, and warranties can be invalidated if these are breached. Contaminants to be removed typically include:

- Moisture (which will be acidic)
- Hydrogen sulphide (H_2S)
- Ammonia (NH_3)
- Oxygen (O)
- Nitrogen (N)
- Particulates
- Siloxanes.

Depending on the feedstock, contaminants may not be found at problematic levels or at all facilities. If upgrading to biomethane, more stringent clean-up will normally be required prior to the removal of carbon dioxide (CO_2) from the biogas. This is discussed separately in Section 5.3.2.

5.1.2 Technologies

Methods for treating biogas before combustion in boilers and/CHP engines, and before upgrading systems (that is, biomethane plants) are listed in *Table 5*. Some are alternative methods that will achieve the same objective.

Table 5: Biogas clean-up methods

Method	Purpose
Filters	For particulate removal.
Knock-out pots (condensation pots) on gas pipework	For capture of condensate liquid. This will also help to remove NH_3, which is soluble.
Chillers	For de-humidification (which also helps to remove NH_3 and siloxanes). Other methods include compression, absorption and adsorption (these are most commonly applied when upgrading to biomethane).
Adding ferrous chloride, ferric chloride or ferrous sulphate to the anaerobic digesters	To precipitate elemental sulphur to reduce hydrogen sulphide levels.
Micro-aeration of the anaerobic digester tank headspace	To remove H_2S via sulphide-oxidising bacteria, often located on nets within the headspace of the anaerobic digester.
Activated carbon filters (external to the anaerobic digester)	To remove H_2S and siloxanes.
Iron oxide-coated media (usually in a column arrangement and external to the anaerobic digester)	Adsorption with a catalyst to remove H_2S and siloxanes.
Membranes	To remove oxygen and nitrogen (which should not be present) and CO_2 when upgrading to biomethane (see Section 5.3.2).
Absorption in liquid hydrocarbons, silica gel or activated aluminium	To remove siloxanes.

5.2 Gas storage

5.2.1 Purpose and size

Biogas storage creates a buffer between the anaerobic digester and where the biogas will be used or upgraded to biomethane. Appropriate storage allows ease of pressure management and the operation of downstream equipment in a steady state, irrespective of fluctuations in biogas production. It is also valuable when biogas may not be needed (for example, short-duration downtime of equipment) as it avoids the need to wastefully flare biogas.

As biogas is not compressed in the storage vessels, storage is normally limited to around two to three hours' gas production, sometimes less. Many AD facility operators would like to increase biogas storage, but space is often limited. The more storage that can be factored into the facility design, the better.

5.2.2 Technologies

Technologies often used for biogas storage include:

- Flexible dual membrane dome, mounted on the top of the anaerobic digester or digestate storage tank (*Figure 5.1*);
- Single-skin membrane bag;
- Spherical floor-mounted dual membrane store (separate from any tank and commonly referred to as a gas bladder or gas bubble) (*Figure 5.2*); and
- Fixed dome or conical tank roof.

Figure 5.1: Flexible dual membrane on top of tanks

Figure 5.2: Spherical floor-mounted dual membrane 'gas bubble'

All anaerobic digesters, digestate storage tanks[8] and gas storage arrangements should be linked by pipework and should be at a similar pressure – assuming pipework is appropriately sized. Modulating valves are often used to assist with pressure equalisation, especially where anaerobic digesters are operated in parallel.

All anaerobic digesters, digestate storage tanks[9] and gas storage arrangements should be linked by pipework and should be at a similar pressure – assuming pipework is appropriately sized. Modulating valves are often used to assist with pressure equalisation, especially where anaerobic digesters are operated in parallel.

Dual membrane gas storage arrangements are attached to the top of the tank sidewalls and form the sealed roof to the tank. The space between the two membranes is ventilated with a fan to maintain the outer membrane fully inflated, and the inner membrane rises and falls subject to how much gas is present. A floor-mounted 'gas bubble' operates in a similar manner, but the outer membrane is sealed to the ground and the inner membrane forms a bladder suspended from the top of the outer membrane.

[8] If these are still generating and so contain biogas. It should be noted that some are aerated to halt the biological process and biogas production.

[9] If these are still generating and so contain biogas. It should be noted that some are aerated to halt the biological process and biogas production.

A gasometer-style arrangement (a rigid container, shaped like an upturned cup, which is sealed with water, and rises and falls subject to gas production and consumption) can also be used, but is uncommon in Europe.

5.3 Biogas utilisation

5.3.1 Heat and electricity

Biogas can be combusted in a combined heat and power (CHP) plant, also known as a co-generation plant, to produce heat and electricity.

A CHP plant at an AD facility could consist of a boiler, a steam turbine and an electricity generator. However, a purpose-made internal combustion engine is more commonly used. This drives a generator to produce electricity, which can be used by the facility and in a local private network or supplied to the national electricity network. High-grade heat (at above 175°C) can be recovered from the engine exhaust and lower-grade heat (around 80°C) can be recovered from the engine cooling circuit. By using heat exchangers, recovered heat can be used for the anaerobic digesters and, where there is one, the pasteurisation process. Excess heat can be exported to a local heat network or used in neighbouring commercial and industrial processes. Gas turbines, including micro-turbines, can also be used as the basis of CHP plant.

Figure 5.3: Containerised CHP internal combustion engine

A biogas boiler can also be used instead of, or in addition to, a CHP engine to raise heat via hot water or steam. Whether or not there will be a CHP engine, or a biomethane plant (see Section 5.3.2), having a dual-fuel boiler (for example, biogas and natural gas, or biogas and fuel oil) enables the process to be heated during start-up and at times of CHP downtime. If no boiler is incorporated into the design, the hire or retention of a mobile fuel-oil boiler may be necessary on site for initial commissioning and subsequent process start-ups.

The Environmental Protection Agency (EPA) or local authority should be consulted for the information on the latest requirements for CHP plant and boilers.

5.3.2 Biomethane production

Biogas can be upgraded to biomethane to enrich its methane content and to give it properties comparable to those of natural gas.

Biomethane can be injected to the national gas grid owned and operated by Gas Networks Ireland. It can also be compressed for storage or transport by tanker for uses such as fuelling vehicles.

Biomethane production typically involves:

- Further cleaning the biogas to remove unwanted contaminants;
- Removing CO_2, typically by
  - Compression and membrane filtration,
  - Pressurised water scrubbing (water-wash),
  - Pressure swing adsorption, or
  - Amine scrubbing;
- Cooling (after membrane filtration) or drying (after pressurised water scrubbing);
- Adding a high calorific fossil fuel gas in small quantities (for example, propane) to finely control the calorific value of the biomethane so that it is equivalent to natural gas;
- Adding an odorant; and
- Compressing (or letting down) to the required pressure.

Where the national gas network is to be supplied, a grid entry unit allows the network operator to monitor quality remotely and to stop the supply if the required standards are not met. If this occurs, the off-specification biomethane will need to be re-processed or flared.

Although it can be undertaken at any scale, biomethane production does not tend to take place at very small AD facilities, due to the cost of gas cleaning and upgrading equipment.

5.3.3 Flare

Figure 5.4: Enclosed flare at an AD facility[10]

A flare is an essential safety device to combust biogas, or biomethane, when there is over-production that cannot be stored or, more typically, when CHPs, boilers or biomethane plants are unavailable due to breakdowns or maintenance. A flare should not be used routinely. It should have a slam-shut valve to prevent passive venting, and be enclosed by a shroud (that is, there should be no visible flame).

The EPA or local authority should be consulted for the latest requirements for flares.

[10] Photograph courtesy of Iona Capital Ltd

6. Digestate handling

6.1 Storage

Whole or liquid fraction digestate should be stored in covered tanks. Uncovered tanks and lagoons allow the residual biogas produced to escape with a resultant environmental impact and the loss of valuable fuel. Storage of digestate in covered tanks also reduces ammonia (NH_3) emissions, which is another environmental concern associated with farming. Tanks are typically constructed like anaerobic digesters, complete with pressure release valves (PRVs), mixing, and sometimes with flexible membranes on top for biogas storage. Biogas collection and storage is not required where the digestate is aerated to stop the anaerobic digestion (AD) process. A storage tank is typically larger than the anaerobic digester to allow for extended storage (for example, during periods when land spreading cannot be carried out).

Where digestate has been separated into a liquid and solid (or fibre) fraction (dewatered), the solid digestate is generally stored in skips or bins within a building.

Figure 6.1: Separated solid fibre fraction digestate

6.2 Separation

Technologies that separate digestate into solid and liquid fractions include the screw press, the ram press, the belt press, screens and sometimes centrifuges (decanters). The operation is best undertaken within a building to mitigate odour release, especially at facilities processing food wastes

Separation can also be used to allow reuse of water to prepare feedstocks. When reusing the liquid fraction in this way, it is sometimes treated or used in limited quantities to prevent the accumulation of undesirable components such as NH_3 and salts.

Figure 6.2: Example of a screw press digestate separator

6.3 Drying

Digestate can be dried for use as a soil improver. This is generally only done if the digestate is unsuitable for applying to land where food crops are grown, or pastures for livestock grazing. Belt dryers or rotary drum dryers are typically used to dry the digestate, along with heat recovered from CHP systems. Fires have occurred during this process so, it is important to consider fire prevention, detection and suppression measures.

7. Air quality and emissions abatement

7.1 Combustion products

Point source (from a single location, such as an exhaust) combustion products are emitted by flare stacks, boilers and combined heat and power (CHP) plants.

The location of the flare stack, CHP and boiler plant will require consideration during any planning and licence or permit application. Dispersion modelling may have to be undertaken at this time.[11]

7.2 Fugitive odour

If appropriate control measures are not in place, feedstocks can cause odour nuisance issues during delivery, storage and processing. Control measures may include one or more of the following:

- Delivery in enclosed vehicles or containers;
- Unloading (unless directly discharged into tanks), storing and processing feedstocks in a well-sealed building with ambient air extraction to maintain negative pressure in the building and with treatment of the extracted air (see Section 7.3);
- Point source air extraction at specific pieces of equipment or storage areas, with treatment of the extracted air;
- Using air curtains on doors to prevent odours escaping;
- Using fast-acting doors that are triggered by the approach of a vehicle;
- Not leaving vehicle and personnel doors open longer than necessary; and
- Using sealed storage tanks and buffer tanks (with odour collection ductwork) that treat the extracted air.

Where negative pressures are required in a building, it is necessary to install louvers that allow outside air to enter the building. The design should enable the louvers to be closed to prevent odour escaping in the event of the building ventilation system being switched off.

Digestate processing and storage can also be a source of fugitive odour, especially at AD facilities that use food waste as a feedstock. In such instances, processing (that is, the separation of solid and liquid fraction digestate) should occur in a building. The digestate storage tank headspace is often linked to the biogas collection network as some residual biogas may be produced. Some facility designs include aeration of the digestate storage tank to stop the anaerobic process, in which case connection is not made to the biogas network, but instead to the odour collection and treatment network.

7.3 Odour treatment of extracted air

Extracted air can be treated using a variety of methods; the most common are:

- Biofilters
- Wet chemical scrubbers
- Carbon filters.

Biofilters are open-topped or enclosed units containing a large surface area medium, such as bark, woodchip or pumice. However, a range of other organic and inorganic materials are used. The medium becomes self-populated in a biological film (biofilm) that biodegrades contaminants in the air. Odorous air is introduced at the base so that it passes through the medium and exits at the top surface. The medium requires irrigating with water and, subject to quantity, some of that water may require periodic disposal or treatment. A common mistake, especially with simple biofilters that are not enclosed or controlled by supervisory control and data acquisition, is a failure to irrigate sufficiently or evenly, which can cause ineffective odour abatement. Conversely, a biofilter that is not sheltered or situated within an enclosed structure can receive too much water when it rains.
The micro-organisms that form the biofilm on the surface of the medium need an environment where pH, moisture, temperature and nutrients meet their requirements. The biofilter design, especially the choice of medium, and dimensions of the filter bed should suit the flowrate of extracted air to enable it to reside in the biofilter for long enough to be treated effectively.

[11] See the following guidance on engines and flares, originally intended for engines and flares located at landfills (http://www.epa.ie/pubs/advice/air/emissions/guidancenoteonlandfillflareandenginemanagementandmonitoringag7.html)

Figure 7.1: Open woodchip biofilter

When designing a biofilter, it is important to consider access for remedial work or replacement of the medium. Common issues with biofilters include the compaction and the fouling of the medium, and preferential pathways being formed that allow the airstream to effectively bypass the medium, resulting in insufficient residence time.

Enclosed biofilters discharge the treated air via a stack. The choice of the stack location may involve detailed odour dispersion modelling at the time of any planning and Environmental Protection Agency (EPA) licence or permit (for example, Industrial Emissions Licence) application.

Wet chemical, or water, scrubbers can be used on their own or in addition to a biofilter. They are primarily used to remove high levels of ammonia, as well as other contaminant gases. They have a tower-shaped tank, sometimes containing structures to maximise contact time. Inside the tank, the odorous air passes upwards through a spray of water or an acid or alkaline solution, or through a packed bed (inert material with high surface area) that ensures the re-circulation of the solution. Multiple-stage scrubbers can be used to remove different contaminant gases. They occupy less space than a biofilter.

Activated carbon filters require humid air to work properly. Ammonia (NH_3) is not effectively removed, so carbon filters are used in addition to wet scrubbing, or where NH_3 levels from the facility are low. Activated carbon filters require periodic replacement.

7.4 Monitoring

Environmental Protection Agency (EPA) licence and permit conditions will require the combined heat and power (CHP) systems and boiler stacks to be monitored periodically. Therefore, suitable access and a port on the stack for monitoring purposes will be required. Mobile monitoring equipment is generally used.

EPA licence and permit conditions may also require the monitoring of the odour and the air treatment stack. Again, access and a suitable monitoring port at the stack will be required. Air flow rate, odour level, and sometimes dust and bioaerosol monitoring may be required. Mobile equipment is typically employed for these purposes.

For process control and, potentially, EPA licence and permit condition reasons, large facilities may be served by a continuous environmental monitoring system to monitor parameters such as air flow, temperature and humidity.

Loss of methane (CH_4) to the environment can arise, for example, from the operation of digester pressure relief valves (PRVs), as unburnt fuel via combustion plant exhausts, and from biogas upgrade plants as a result of imperfect separation. Some loss through these routes is unavoidable but should be minimised by careful plant management and control. Quantifying such losses is also relatively straightforward using plant monitoring data and the addition of specific monitoring equipment at known point sources, such as PRVs.
Leakage from sources such as faulty pipework joints, inadequately sealed tank membranes, etc. is less easy to detect and quantify, particularly if individually the flaws are small. Further information on this topic can be found in the International Energy Agency's Task 37 Report, 'Methane Emissions from Biogas Plants'.[12]

CH_4 losses affect both the economic and environmental performance of an AD facility. Operators should endeavour to ensure that losses are minimised, by making the plant as gas-tight as possible, minimising any venting, and optimising the performance of combustion.

[12] https://task37.ieabioenergy.com/files/daten-redaktion/download/Technical%20Brochures/Methane%20Emission_web_end.pdf

8. Wastewater management

8.1 Requirements

Surface water runoff (for example, rainwater from clamps and roofs), and process area wash-water, if free of contaminations (chemicals, oils, fuels and grit), can be mixed with the feedstock.

If useful digestate is being produced where solid and liquid fractions can be used, separately or as whole digestate, there should be a limited amount of wastewater that requires management.

However, when the two fractions are separated, the liquid fraction can be recycled (often after being treated) at anaerobic digestion facilities with limited water availability. This can help if digestate off-take arrangements are limited. In this case, it is essential to design the process so that ammonia (NH_3) or dissolved salts cannot build up to problematic levels. Some input of freshwater is likely to be necessary, with some process water being removed for disposal.

8.2 Management options and technologies

Many treatment options commonly used to treat organic wastewaters can be used at AD facilities, such as those in *Table 6*.

The treatment option will be dictated by the intended recycling end use or disposal method (for example, surface water discharge, sewer or road tanker) and the respective quality requirements.

Table 6: Wastewater treatment

Typical methods	Purpose
Screening	Particulate removal.
Filtration	Necessary if salt levels are so elevated that they would build up and harm the biology of the AD process when recycling water for reuse in the AD process for feedstock preparation.
Aeration to strip ammonia	Necessary if ammonia levels are so elevated that they would build up and harm the biology of the AD process when recycling water for reuse in the AD process for feedstock preparation.
Aeration to reduce organic content	Often necessary for final disposal, for example, to sewer, to meet discharge consent conditions.

9. Control and instrumentation

9.1 Supervisory control and data acquisition

A supervisory control and data acquisition (SCADA) system is necessary for ease of operation and monitoring of the process. This system comprises hardware and software components to monitor and control industrial processes. The degree of sophistication of the SCADA system will be dictated by the complexity of the process and the extent of automation.

9.2 Feedstock

Feedstock mass flow can be measured by weighbridge, load cell on feed hoppers or belt weighers (load cells on conveyor belts). While belt weighers can be useful for process control, they can be problematic as a primary means of recording feedstock mass flow, as they often have lower accuracy and more maintenance issues than weighbridges and feed-hopper load cells.

Flow meters can be used to monitor liquid feedstock volumes.

9.3 Process

Instrumentation and control infrastructure linked to SCADA commonly allow monitoring and control of the items listed in *Table 7*.

Many process operations can be controlled automatically by the system, with larger and more complex facilities generally having higher levels of automation. Processes that are automated at most facilities include pasteurisation, anaerobic digester feeding, mixing and discharge.

Equipment set points (that is, operations that are initiated by process conditions such as low or high level in tanks) can be programmed into the control system and adjusted to modify the process. SCADA systems also show alarms on the screen when undesirable situations arise (for example, an alarm might indicate high pressure, a failed pasteurisation batch, an equipment outage, or the triggering of emergency stops). They can provide data trending, which helps the operator to troubleshoot operational issues. For example, biogas leaks or venting through the pressure relief valve (PRV) (see Sections 4.5 and 7.4) will be apparent from a review of the pressure trend data for the tanks. A sudden drop in pressure can indicate a leak. Biogas venting through a PRV, will be evident through a rise in pressure at the point of venting, after which it will stabilise at a flat level as the PRV will prevent further increase in pressure. Similarly, under-pressure events that draw air in through the PRV will also be apparent from a review of pressure data and an increase in oxygen or nitrogen in the biogas extracted from the anaerobic digester. Trending also shows operators how an AD facility reacts to different feedstock blends and feed rates.

Table 7: Typical areas of data acquisition

Area	Data
Feedstock	Mass of solid and liquid feedstocks (weighbridge) Mass of feed hopper contents (load cell) Volume of liquid feedstocks (flow meter)
AD operation	Mass of mixer (pulper) contents Mixing running time Tank levels Temperature (anaerobic digesters and pasteurisation process) Anaerobic digester pH Liquid flow rates Pasteurisation duration Gas pressure Equipment run time
Biogas and biomethane management and utilisation	Gas flow rates Gas composition Gas pressure Gas temperature Equipment run time Energy generation
Digestate management	Mass Tank levels
Wastewater treatment	Liquid and air flow rates Tank levels Equipment run time
Odour control system	Air flow rates Air temperature Air pressure Tank levels Equipment run time

10. References and other sources of information

- The Anaerobic Digestion and Bioresources Association, 'The Practical Guide to AD'. Available at: http://adbioresources.org/library/purchase-the-practical-guide-to-ad/

- Composting and Anaerobic Digestion Association of Ireland, 'Guidelines for Anaerobic Digestion in Ireland', January 2018. Available at:http://www.cre.ie/web/wp-content/uploads/2018/03/Guidelines-for-Anaerobic-Digestion-in-Ireland_Final.pdf

- Irish Water, 'National Wastewater Sludge Management Plan'. Available at: https://www.water.ie/docs/Final-NWSMP.pdf

- International Energy Agency, 'Task 37 Technical Reports', December 2018. Available at: https://task37.ieabioenergy.com/technical-brochures.html

- SEAI, 'Sustainability Criteria Options and Impacts for Irish Resources'. Available at: https://www.seai.ie/publications/Sustainability-Criteria-Options-and-Impacts-for-Irish-Bioenergy-Resources.pdf

- Statutory Instrument No. 605 of 2017, European Union, 'Good Agricultural Practice for Protection of Water' Regulations 2017. Available at: http://www.irishstatutebook.ie/eli/2017/si/605/made/en/print

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 or 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).
Bay	A walled floor-level waste or feedstock storage area.
Biogas	Mixture of methane and carbon dioxide produced by AD.
Biomethane	Methane product produced by separating methane from biogas.
Boiler	Equipment for heating hot water or producing steam.
Bunker	Open sunken pit for the storage of waste and/or feedstock.
By-product	Material of value co-produced with the main output from a process. In this context digestate is considered a by-product of AD.
Combined heat and power (CHP)	Combustion plant used to generate both electricity and useful heat.
Clamp	Bay or other structure used to store energy crop feedstocks.
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 (DM) or total solids (TS).
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 matter (DS) (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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