Anaerobic Digestion for On-farm Uses - Implementation Guide

Anaerobic Digestion for On-farm Uses – Implementation Guide

Anaerobic Digestion for On-farm Uses – Implementation Guide

June 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.

Version Control

Version Number	Purpose/Change	Page	Date
V1.0	Published		14/06/2020

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 Usable food wastes include rejected or out-of-date products from manufacturers or retailers, and wastes from commercial and domestic kitchens.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.

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

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

expenditure on energy.
- The **Technology Guide** describes the main types of technologies that may form part of an AD 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 designed for those who are considering implementing a farm-based AD facility, but who may be unfamiliar with the technology. It has two principal aims:

- To provide the reader with a helpful checklist of key factors and an approach for the implementation of an AD system. It is assumed that readers are interested in the environmental and commercial potential of AD.
- To direct the reader to further sources of more detailed information on specific aspects of the technology and its implementation.

The implementation of an AD system should proceed in the following stages:

- A **feasibility study** to confirm that the project is technically and commercially viable;
- **Procurement**, securing the service providers to build the facility;
- **Construction** of the facility; and
- **Commissioning**, to ensure the facility performs as expected.

1.3 Scope

The four guides concentrate primarily on farm-based AD systems fed with farm-derived feedstock 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 (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. Overview

2.1 Anaerobic digestion

Anaerobic Digestion (AD) is the microbial degradation of organic matter in the absence of oxygen (O_2) to produce biogas, which is composed mainly of a mixture of methane (CH_4) and carbon dioxide (CO_2) (see *Figure 2.1*).

The energy present in the organic matter, originally derived from the sun and captured by plants, is then concentrated into the CH_4. An anaerobic digester enables the biogas to be captured, and the energy in the CH_4 is made available by combusting the biogas.
It can be:

- Combusted in a boiler to produce heat;
- Combusted in a gas engine to produce power and heat; or
- Upgraded (by removing the CO_2) to biomethane, which can then be pressurised and injected into the gas network or used as a fuel to run vehicles.

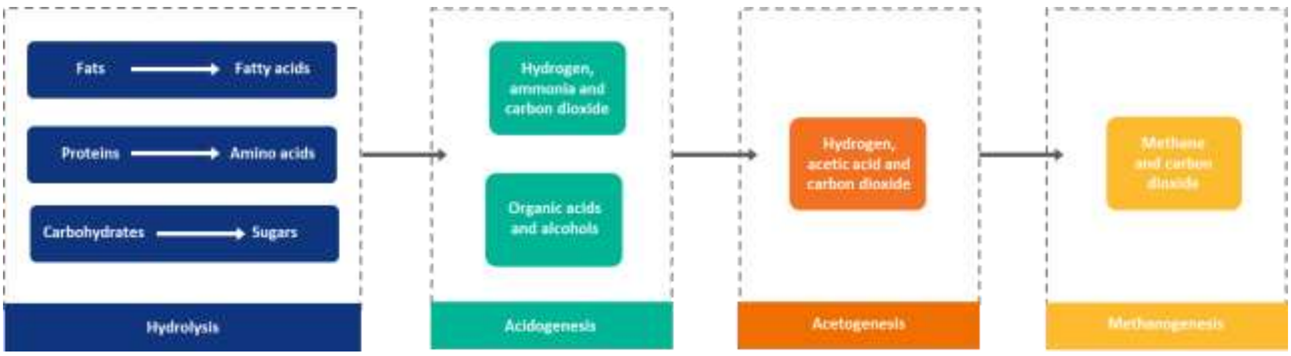
The micro-organisms involved in AD work together as a community to transform organic matter to biogas. Many of these micro-organisms are strict anaerobes, which means they cannot live when oxygen is present, therefore the process is called 'anaerobic' digestion. The output of one group in the community provides the food for another group in a food chain: what one set of organisms excrete; the next set eat. This means that the communal process is sensitive to individual disruption.

The microbial community acts together by progressively degrading a wide variety of large and complex organic materials into a limited number of small compounds – hydrogen and acetate), which are the immediate precursors of CH_4 production.

AD facility operators need to ensure the conditions are suitable for all the components of the microbial community. The main microbial groups are fermentation bacteria, acetogens and methanogens (see *Figure 2.1*). Collectively, these undertake four main stages in the microbial breakdown process. These stages are described below in the order of occurrence:

- **Hydrolysis** is when fermentation bacteria break down large biopolymers (for example carbohydrates, starch, cellulose, fats and proteins) into small molecules (for example sugars, fatty acids and amino acids).
- **Acidogenesis** is when fermentation bacteria break down the small molecules into smaller acids and alcohols (for example butyrate, ethanol and propionic acids) and lactate (fermentation products).
- **Acetogenesis** is when acetogenic bacteria further decompose the fermentation products to hydrogen, CO_2 and acetate (acetic acid).
- **Methanogenesis** is the final stage, and involves methanogenic bacteria converting acetate, hydrogen and CO_2 to CH_4.

Figure 2.1: Microbial degradation of organic matter to biogas during AD



As well as the anaerobic digester itself, a typical AD facility needs equipment for feedstock storage, feedstock preparation, digestate storage, biogas treatment and biogas utilisation. Many agricultural AD plants in Ireland also require pasteurisation and digestate processing equipment. AD units that send biomethane to the grid also need biogas upgrading and pressurisation equipment either on site or accessible via mobile upgrading trailers or trucks.

Figure 2.2 shows the typical components for a farm-based AD facility (although note that biogas upgrade is not typical), together with the flows of feedstock, biogas and digestate around the facility. Note that the location of the pasteurisation equipment (if included) may be before or after the anaerobic digester.

The various options for the AD process are summarised below. Further details of the components and technologies commonly employed at AD facilities are provided in the Technology Guide.

2.2 Anaerobic digestion facility design options and types

There are several generic anaerobic digester designs types that may be considered within the typical AD facility. When planning an AD facility, the most suitable options should be combined in a site-specific and needs-appropriate design.

Firstly, the AD facility may be either a wet or dry AD type, depending on the feedstock:

- **Wet AD** is where the feedstock is prepared as a pumpable liquid slurry (typically with a dry solids content of between 5% and 15%). The process then takes place in a reactor (anaerobic digester) where the slurry is continuously mixed so that the contents are evenly distributed. This is the type most commonly applied for on-farm based AD systems.
- **Dry AD** is where the prepared feedstock is a much drier 'stackable' material (dry solids of over 20%). In this case, the process is often a plug-flow system where raw feed enters at one end of the reactor and the degradation occurs along the length of the reactor. The digestate is removed from the other end.

Secondly, the facility may be operated either at a temperature similar to or just above the normal surrounding temperature, or at an elevated temperature:

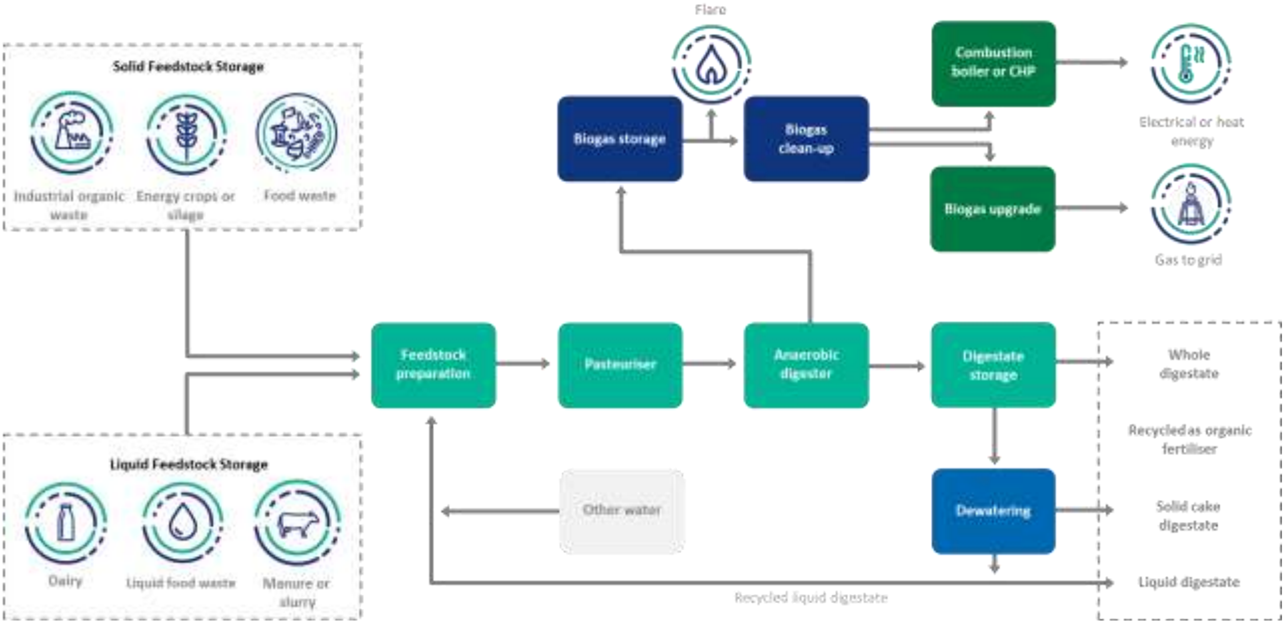
- **Mesophilic AD** systems typically operate at between 30°C and 40°C.
- **Thermophilic AD** systems typically operate at between 50°C and 60°C. Manufacturers often claim that thermophilic digesters operate at higher biogas production rates and yields. If a thermophilic process is chosen, then usually the digester requires an external source of heat to be supplied.

Lastly, there are several process configurations possible for the anaerobic digesters:

- There may be either **a single digester** or **more than one digester**.
- **Multiple digesters** may be operated **in parallel** or **in series**.
- A smaller **hydrolysis tank** proceeding the main digesters is included in some designs. This results in the microbial processes being split, with the hydrolysis reactions occurring in the first hydrolysis tank and the remaining reactions (especially CH_4 production) occurring in the main digester.

See the Technology Guide, Section 4, for further details.

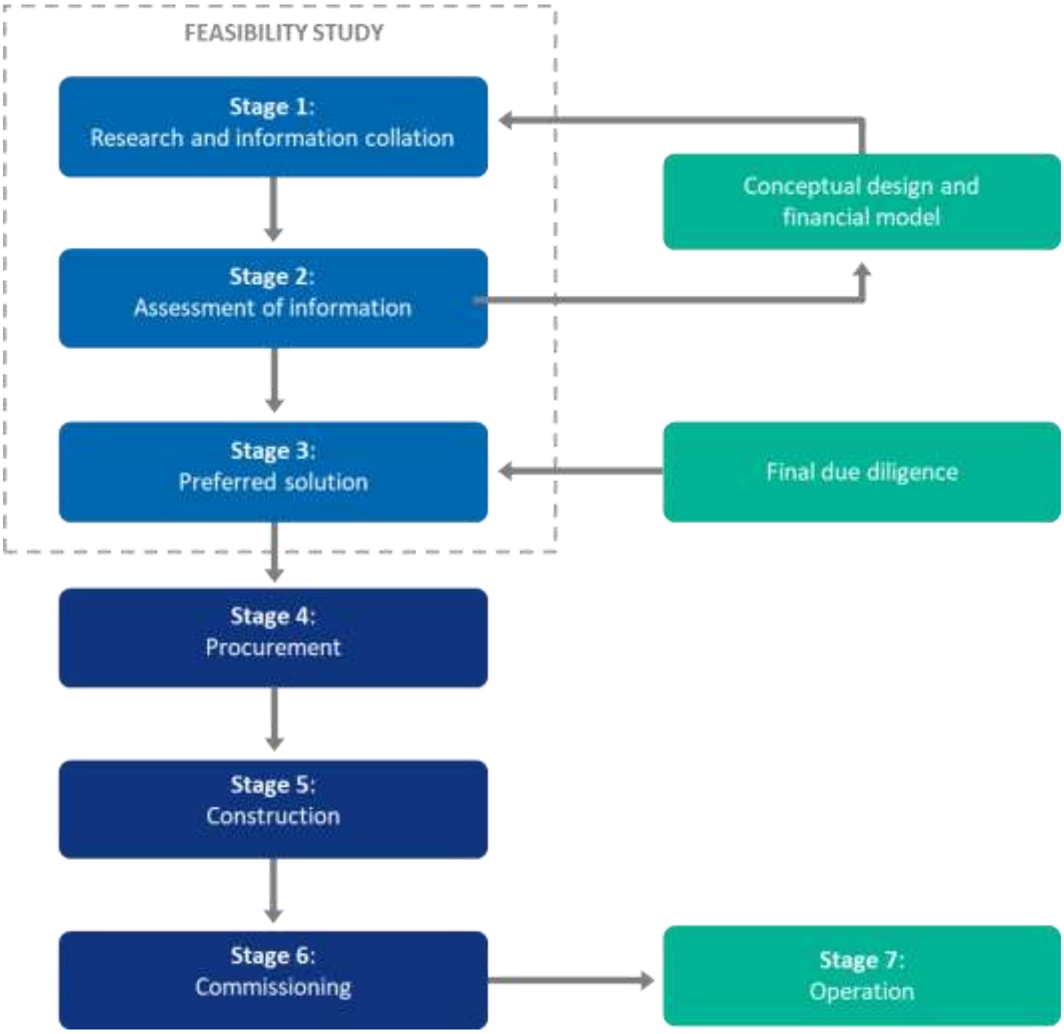
Figure 2.2: Simplified process flow scheme for a farm-based AD facility



2.3 Developing an anaerobic digestion facility

Developing an AD facility and successfully bringing it into operation requires considerable effort in several areas, including ensuring the project is feasible, procuring suitable contractors for its detailed design and construction, and then commissioning the facility. The overall process for developing the plant is summarised in *Figure 2.3.*

Figure 2.3: Stages for implementing an AD plant



Several of these aspects are introduced here and covered in more detail in other sections of this guide.

2.3.1 Communications

Regular communication with external parties at all stages of the project is very important. This includes formal communications with planning and permitting authorities for obtaining consents, and communication with the local community to alleviate their concerns and to encourage the development of opportunities of mutual benefit (for example employment and energy supply). Section 3 gives more information on this aspect.

2.3.2 Feasibility study

The first stage in developing an AD facility is to assess its feasibility.

Key points to consider are:

- **On-site waste feedstock**
  The quantity and type of available feedstock affects the choice of AD facility. It is important to ascertain what manures and potential farm-grown crops (for example, grass, silage) might be available from the farm, and in what quantities. It is worth considering whether there are benefits to partnering with neighbouring farms, and it is important to assess how AD might help to reduce the environmental impact of farm waste.
- **Facility location**
  The site must be suitable for the development. Location should be chosen to be of maximum benefit, and to have minimum negative impacts.
- **Technical design**
  The technical design of the facility will affect costs and performance. It is necessary to gauge the size and design

of the facility for handling the feedstock, the AD process itself and the handling of the digestate. The estimated biogas yield from the available feedstock should be considered, and it is important to decide whether it should be used on the farm to generate electricity and heat for local consumption or sold. Key aspects to be considered in the technical design are outlined in *Table 1*.

- **Digestate management**
  It is essential to be able to estimate how much digestate would be produced, and how it could be used beneficially on the farm as a fertiliser.
- **Commercial feasibility**
  The development of an AD facility, whilst providing environmental improvements, must also be commercially feasible. The capital and operating costs should be considered in balance with the savings to the farm from producing its own energy and fertiliser, and from revenues generated from the sale of excess electricity or heat.
- **Ownership and operating arrangements**
  As part of the commercial feasibility assessment, different potential ownership and operating arrangements, which may include partnerships with developers, neighbouring farms, and other funders, should be considered.

Further guidance on carrying out a feasibility study is given in Section 4.

Table 1: Key aspects to consider in the technical design of the facility

Aspect	Points to consider
Environmental impact	How the design would help to mitigate the environmental emissions from the farm those associated with the management of manures and slurries, in particular emissions of greenhouse gases and ammonia.
Feedstock availability and types	What types and amounts of feedstock is available? Different feedstocks have different physical, chemical and biological characteristics, and offer different levels of biogas yield. They also may need various means of storage and pre-processing to be integrated into the facility design.
AD facility technology	The facility process system and technology should be selected according to aspects such as feedstock storage and preparation, and the type and size of anaerobic digester needed.
Biogas end use	The biogas produced is normally used to generate electricity and heat, or both, for use on the farm, with any excess exported to the electricity network or in the case of heat to nearby heat users. Biogas can also be upgraded to biomethane for injection into the gas network, or stored and transported for other uses, particularly as a vehicle fuel.
Biogas quality	The biogas quality requirement associated with its anticipated end use. This, in turn, affects the technology needed to provide the required quality.
Digestate management	Digestate is a major output from AD. In most cases, this is applied to land as an organic fertiliser. Therefore, appropriate consideration needs to be given to digestate quality, its storage and treatment by the facility and available landbank for fertiliser spreading.
Regulatory control	The AD facility must have planning permission from the local authority and a permit or licence from the appropriate environmental regulatory authority. Other regulatory controls may also need to be complied with.
Health and safety	Biogas and potential contaminants of biogas such as hydrogen sulphide are potentially hazardous materials. The design must therefore conform to safe operation, and health and safety regulations in this and all other respects.

The first stage of a feasibility study would be to collect and assess high level information on key factors affecting the technical and commercial viability. Following this initial assessment, an initial feasibility assessment may conclude whether to proceed further or not.

If the feasibility study suggests that the project should progress further, then the various aspects can be revisited, often several times, in more detail as the study progresses. This will consider in more depth each of the above aspects, contributing to the development of a more detailed design and financial model for the facility. This should include factors such as planning, environmental and other regulations at this early stage to ensure the development is likely to obtain the necessary permissions for construction and consents for operation. The feasibility study will ideally include a conceptual technical and financial model of the project that can be revised and refined as it develops.

At some point in the feasibility assessment it may be useful to have an independent review of the emerging preferred solution to ensure that the concept is technically and financially robust. If outside financial investment is being sought, this kind of 'due diligence' may be a requirement of the funders.

Overall, this feasibility study should provide assurance that:

- All aspects have been considered to a reasonable depth;
- The risks have been identified; and
- The project is technically and commercially sound.

2.3.3 Procurement

Having decided to proceed with the AD project, the next stage is to find and engage appropriate contractors to design and build the facility.

The development up to now may have been in conjunction with a selected supplier or engineering, procurement and construction (EPC) contractor, or both. In this case the procurement route may already be decided. However, a competitive procurement process allows a wider range of technologies to be considered. A sole supplier may not be the most appropriate or cost-effective option.

2.3.4 Construction and commissioning

Construction should follow soon after a construction contractor has been appointed. Once constructed, the facility will be commissioned with actual feedstock. Finally, acceptance or take-over tests must fully demonstrate that the facility achieves the required level of performance that has been specified. The accompanying Operation and Maintenance Guide, Section 5, provides more details of plant commissioning.

2.3.5 Timeline

As well as including all the project development stages, with sufficient time for each, the timeline for developing an AD facility should, at an early stage, cover:

- Raising development funding;
- Planning, community engagement and conducting an environmental impact assessment;
- Securing feedstock supplies if not sufficiently available on the farm;
- Securing any infrastructure and purchase contracts for the export of any energy generated; and
- Submitting planning and permit applications.

The proposed timeline should include a margin for unforeseen delays. Any critical deadlines (for example the plant commissioning date) should be incorporated into the project timeline as key milestones. Contracts can include incentives to encourage the project to meet milestones within the agreed timeline.

The implementation timeline for an AD facility can vary significantly and depends on many factors. For example, the construction phase may be longer if reinforced concrete tanks poured in situ are being used. By contrast, pre-constructed stainless-steel tanks can be brought to site for rapid installation onto foundations.

As a guide, once the relevant permits have been granted, the construction of farm-based systems is likely to take between six and twelve months depending on size, digester construction method, and overall complexity. The overall timeline from initial conception to construction may take anywhere from eighteen months to three years, depending on scale and complexity.

Table 2: Timeline considerations

Stage	Considerations
Feasibility study	Allocate enough time to the feasibility study to ensure it is thorough, and sufficiently detailed on all aspects. Appropriate due diligence at this stage will help prevent later delays. Ensure that all necessary planning permissions are obtained.
Procurement	If choosing competitive procurement, do not rush the process. Avoid impossible deadlines on bidders' proposals and bid evaluations. A rushed process carries the risk that some bidders may drop out, and significant aspects of the project may not be fully agreed before the contract is signed.
Detailed design and construction	Following contract signing, the estimated time required for finalising the detailed design and construction of the plant should be included in the timeline.
Commissioning and testing	Commissioning can take time. Carefully check the time allowed for this step by your supplier to ensure it is not underestimated. The owner (purchaser) may be responsible for supplying feedstock for commissioning; for farm crop feedstock. This will require significant pre-planning to match the growing season.

3. Communications

3.1 Introduction

The development and implementation of an anaerobic digestion (AD) project requires communication with a wide range of external stakeholders and organisations throughout the life of the project.

Communicating effectively with members of the local community is key, both in understanding their concerns about the project and in informing them of potential benefits, such as renewable energy production that might help local community developments. Engaging with local community groups, such as SEAI's Sustainable Energy Communities, can help the engagement with other stakeholders in the project. Some projects also benefit from engaging professional services to help with communications.

Stakeholders for communication and consultation:

- **Local communities**
- **Regulators**
- **Funders**
- **Feedstock suppliers**
- **Digestate users**
- **AD technology providers**
- **Biogas users.**

3.2 Benefits

Early communication with the local planning body, the Environmental Protection Agency (EPA) and other regulatory bodies is recommended. At a technical level, early communications with key parties – especially those associated with the supply of feedstock, AD technologies, and outputs (energy and digestate) from the facility – can highlight potential constraints.

Meeting local residents may help to alleviate any concerns they have and limit possible opposition to the proposal. It is advisable to anticipate these concerns and prepare answers to common questions.

Typical local community FAQs:

- **Will it smell?**
- **How much heavy traffic will there be?**
- **How noisy will it be?**
- **Will the facility spoil the view?**
- **How safe will it be; is there any risk of explosion?**
- **Will it encourage rats and vermin?**
- **Will it cause pollution in the rivers?**
- **How would it benefit our local community?**

Social media can be used to inform local residents about how the development is progressing, especially if they will benefit from the outputs from the facility.

During operation of the facility, routine communications with stakeholders, the public and the media may arise. Employees at the facility should be briefed on the high-level details, goals and benefits of the project and on how to manage queries and complaints in a sensitive manner based on factual information. It is better to communicate proactively, rather than simply reacting to issues. A professional PR company can be engaged to deal with communications with the media if necessary.

4. Feasibility study

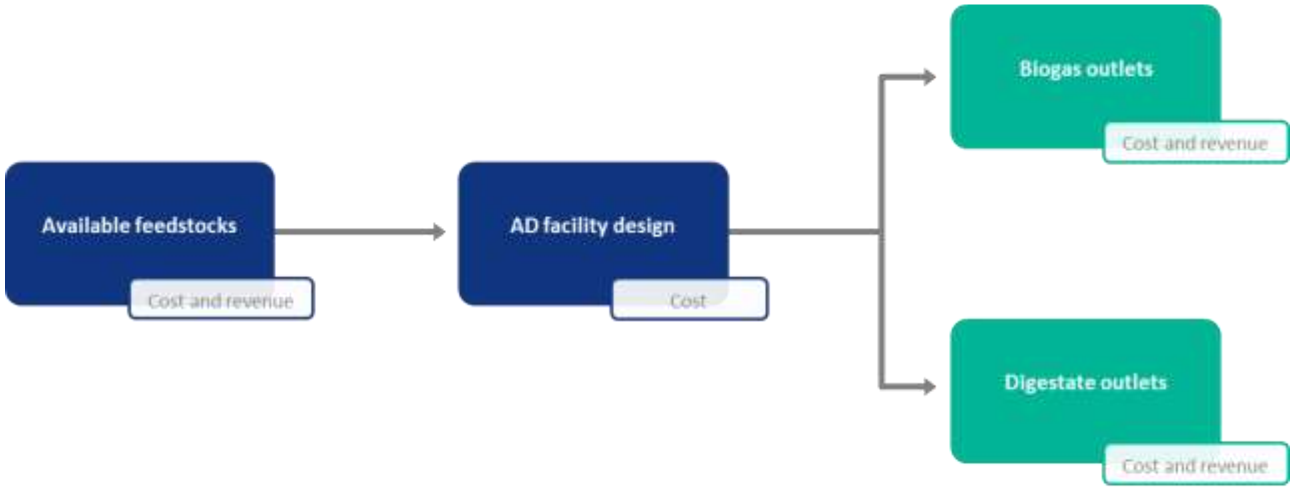
A feasibility study should create a working model of the whole anaerobic digestion (AD) facility project.

The facility design must provide detail on how it will operate and its expected performance and calculate the associated costs. This shows investors that the project is economically viable and sustainable over its anticipated lifetime. Key aspects of a feasibility study are discussed in more detail in the following chapters of this guide.

Ideally, the study should begin as soon as possible, so that it develops along the project as elements of the facility become defined in more detail. This detail should encompass associated financial costs and anticipated benefits. At the end, the study should provide assurance that the system is viable and can operate successfully.

The feasibility study should consider all the aspects of the project as an integrated whole. The assessment of feedstocks, AD facility design, biogas outputs and digestate management represent the four main technical elements that should inform an initial conceptual design. Further consideration and refinement in the light of project finance should help to develop a project that is technically and financially robust. *Figure 4.1* summarises the main influencing factors for the conceptual design, each of which is considered in detail in the following sections.

Figure 4.1: Main areas of an AD facility to consider for development of the feasibility study



A prospective facility owner, particularly one lacking in experience of AD, should consider using independent consultants to provide expert advice during this process on technical, commercial and legal aspects. Areas in which advisers can offer useful input in the feasibility study and later development stages are summarised in *Table 3*.

Potential owners should be wary of involving suppliers in the development process at too early a stage. While such suppliers can offer free input and advice, they will be focused on selling their specific technology, which may not be the best solution for the project. Suppliers often have designs for a fixed size and capacity that they have already installed at several locations, and they may attempt to promote this fixed design rather than proposing a bespoke design suitable for the location.

Engaging independent experts (who have not previously been involved) to carry out a due diligence review of the project at the conclusion of the feasibility study provides further assurance that the project is sound. Experienced independent consultants with a strong track record are recommended at this stage. Suppliers willing to provide early stage design concepts free of charge generally offer such services in a bid to become the sole technology supplier. Employing an independent consultant ensures that:

- No technology or supplier is preferred at an early stage;
- Exaggerated claims of performance do not form the basis of the design; and
- An appropriate design concept is chosen.

Additionally, the client (owner) is required to appoint a **Project Supervisor for the Design Process** (PSDP) whose principal duty is to ensure the design meets all health and safety requirements.[3] This role continues during construction.

Table 3: Advisory roles

Specialist	Role
Technical advisers	• Should be independent of original equipment manufacturers and suppliers so that all technology types may be considered. • Can offer assessments of suitable technology, feedstock sources and characteristics, biogas use, digestate management and overall conceptual design. • Can develop the conceptual model and mass balance for the facility.
Specialist technical advisers	• Can help with specific aspects such as planning and permit applications, environmental impact assessments and community engagement.
Financial advisers	• Offer independent commercial feasibility assessments of the project. • Should work closely with the technical adviser to add realistic costs and revenues to the conceptual model to establish a robust assessment.
Legal advisers	• Advise on land ownership and contracts (for example, for selling the power generated). • Develop robust legal contracts between, for example, the client (owner) and contractors used for construction.

4.1 Facility location

First consider if the proposed location for the facility is appropriate and identify any significant factors that would either rule it out at an early stage or need to be addressed.

A farm-based AD facility might be a small plant located and operated by a single farm, or a larger project involving a consortium of local farms.

4.1.1 Site selection

Key questions include:

- Is the required feedstock available from within a reasonable distance?
- Are similar developments planned or present in the vicinity that would compete for feedstock and outlets for energy products and digestate?
- Are there any planned developments in the locality that could benefit from the AD system and vice versa, such as potential heat and electricity users?
- Are there available connections to national electricity and gas networks – and if so, do these have sufficient capacity to export electrical power and biomethane from the system?
- Is there local land available with the capacity to accept the expected volume and quality of digestate?
- Is the site well connected with roads and services for construction and operation?
- Are there any issues with ground conditions, such as instability or contamination?
- Would the facility fit comfortably with local and regional development plans – for example, reducing the environmental impact of farming, enhancing local employment or energy requirements?

4.1.2 Local environmental conditions

Key questions include:

- Is the location in or near to a sensitive environmental area that needs protection – for example, designated sites such as nature reserves?
- Are there nearby sensitive environmental sites that are at risk from pollution from emissions from the facility?
- Is the location in an area susceptible to flooding?

[3] https://www.hsa.ie/eng/your_industry/construction/construction_duty_holders/project_supervisor_design_process/

- Are there neighbours that might be adversely affected by noise, vehicle movements, vermin, dust, odours and other nuisances from the facility?

Any such conditions could mean that the facility design needs to incorporate more specific environmental controls, which might be required for planning and permits. Reference would need to be made to them in the environmental impact assessment that forms part of the planning application.

4.2 Feedstock

It is critical to consider the available feedstock. For farm-based AD, there should be a strong focus on managing wastes, such as manures, in a more environmentally friendly way, and an overarching goal to reduce the impacts of the farm on the environment.

It is crucial to understand the amount and rate of biogas production from the available feedstock when planning an AD facility. Ideally, biogas production should be consistent throughout the year. The conceptual sizing of the AD facility is largely determined by this consideration. The energy content of the biogas is based on the estimated percentage of methane (CH_4) in the biogas.

The facility size should be determined in one of the following ways. Most commonly, the decision is based on a combination of both approaches:

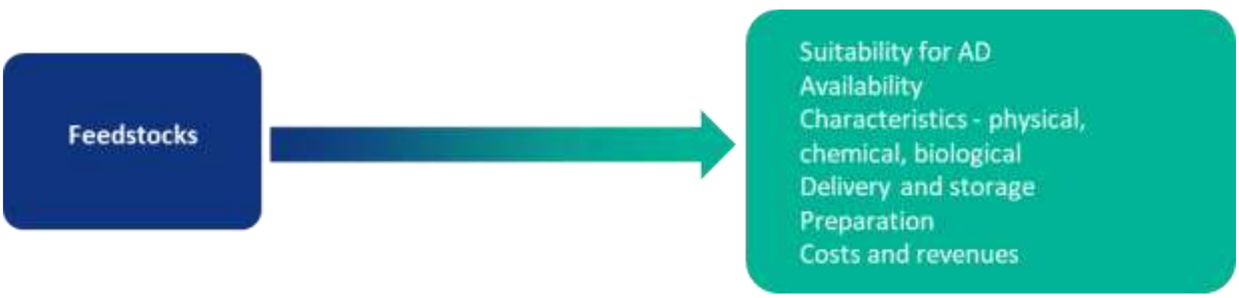
- **Input-led**
  Plans are informed by an assessment of the feedstock available for the facility. The more reliable the feedstock availability, the more accurate the assessment of the facility size. The task of finding outlets for the biogas comes after the consideration of the feedstock.
- **Output-led**
  Plans are informed by an assessment of local energy demands that could be served by the facility. This involves back-calculating the size of facility needed to generate the energy required and then thinking about the amount and type of feedstock necessary for the relevant quantity and quality of biogas.

The input-led approach is more common for on-farm AD where the feedstock is likely to be composed of manure and crops grown for AD such as grass silage. Using AD to manage the manures is likely to bring benefits to the farm in terms of reduced environmental impact, resource recovery, and renewable energy generation. Excess energy products can be exported as a further benefit.

The assessment of the quantity and characteristics of the available feedstocks for the AD facility is crucial. It influences the type and size of equipment needed as well as the number of units. The details of the feedstock will influence the economic feasibility of the system, as they dictate the amount of capital investment required and the ongoing operating costs. Some feedstocks, such as organic waste, requires investments in treatment areas, but the AD site may receive ongoing revenue for accepting this type of feedstock. Other types of feedstock require less capital investment to process, but the site may need to buy in these feedstocks. The machinery and energy required for moving feedstock around the site also vary according to the type of feedstock.

This section discusses several aspects of feedstock (*Figure 4.2*). Additional information is also given in Section 3 of the Technology Guide and Section 5.1 of the Operation and Maintenance Guide.

Figure 4.2: Key aspects of feedstocks to consider



4.2.1 Feedstocks suitable for anaerobic digestion

Sustainability should be a priority when deciding if feedstock is suitable for an AD facility. The use of an AD facility to process the feedstock should be beneficial in reducing greenhouse gas emissions and recovering otherwise wasted resources.

An AD facility is typically expected to operate in excess of 20 years and therefore the supply of feedstock should meet this timescale. Ideally, it should also be based on a consistent supply of feedstock over this period, as a consistent feedstock means increased stability of the micro-organisms in the digester. For feedstock to be considered sustainable in this context, its continued production must not present a risk of long-term damage to the environment.

Manure from conventional livestock management can be considered sustainable feedstock, and its management through an AD facility beneficial in reducing the environmental impacts of livestock farming. This benefit is largely due to the reduction of greenhouse gas emissions, especially CH_4, and ammonia (NH_3), from the storage of untreated manure.

Changing the farm to grow substantial amounts of crops as feedstock for the AD facility, so that the AD feed is dominated by such crops, may not result in substantial or acceptable levels of greenhouse gas reductions. Sustainability criteria (please refer to Section 4.6.1) indicate that an AD facility fed with a substantial feed of grass silage is sustainable, but the situation is better if clover is grown with the grass as this fixes its own nitrogen (N) levels, ultimately recycled as nitrogen fertiliser in the digestate. Growing certain crops as feedstocks for an AD facility may cause other adverse environmental impacts. For example, maize silage is under scrutiny because of the adverse impact repeated maize crops have on soil quality and soil erosion.[4]

Some aspects of AD operation support Ireland's national aims for a high level of environmental sustainability, including reducing the impacts of agriculture on the environment.

Ideally, AD feedstocks should biodegrade well under anaerobic conditions (absence of oxygen) to produce a high yield of biogas. Such organic feedstocks are often described as 'putrescible' (to distinguish it from less biodegradable organic material that is unsuitable for AD).

Feedstocks typically considered suitable for AD include:

- Organic farm wastes such as manures and slurries, unusable farm crops (waste root vegetables, hay, silage, grains);
- Farm energy crops grown specifically as feedstocks, such as grass silage, corn silage, clover crops;
- Industrial food manufacturing wastes (whey from dairies, brewing wastes, fats, oils and greases); and
- Food waste including out-of-date retail supermarket food (including packaged), catering waste from businesses, and food waste from the home.

The selection of feedstocks is discussed further below. The discussion focuses on wet AD systems, which are more commonly applied in farm-based and municipal food waste AD facilities. Further details may be found in the accompanying Technology Guide, Section 2.2.

4.2.2 Feedstock availability

To ensure the commercial viability of the system, it is important to be confident that enough feedstock will be available for the extended life of the project – 20 years or more. For those intending to produce crops as feedstock, this means considering the use of the farmland over this period.

Seasonally produced feedstocks, such as grass, need to be stored under preservation conditions (ensiling) so that they are available all year around for AD. If crops are grown specifically for AD, this will have an impact on farm revenues and costs. For an AD facility reliant largely on farm-grown crops as feedstocks, the implications of a poor harvest and the availability of substitute feedstocks need to be considered.

[4] https://www.soilassociation.org/media/4671/runaway-maize-june-2015.pdf

For AD facilities that receive food waste, long-term contracts should ensure a stable supply. Funders of the facility are also likely to insist on some 'baseload' secure contracts for food waste prior to making a final investment decision.

Developers should keep abreast of renewable energy incentive schemes from which they could benefit. These may also require the sustainability of AD as an option for managing the intended feedstock to be demonstrated, particularly for energy crops.

4.2.3 Feedstock characteristics

The fundamental characteristics of feedstocks, described below, significantly influence their treatment requirements, biogas yield and the overall design of the AD facility. The design of AD facilities should be flexible but also aim at maximising the potential biogas production of the feedstocks.

4.2.3.1 Feedstock physical form

Many feedstocks need pre-processing to facilitate biodegradation and biogas production due to large particle size or a particular natural state, such as an outer protective layer resistant to decomposition by the micro-organisms. Waste root crops such as potatoes, carrots and parsnips need to be macerated and grass-based feedstocks are best chopped. If the feedstock includes animal by-products, these may need to be macerated to particles of <12 mm before processing to comply with the Animal by-products Regulation.

4.2.3.2 Moisture and dry solids content

Like most natural organic materials, feedstocks contain solid material (referred to as dry solids (DS) or dry matter (DM)) and moisture. The dry matter is, effectively, the material remaining after the moisture has been removed by heating at temperatures of about 100-105°C. The quantity of dry matter is typically expressed as a percentage of the weight of the wet original material. The moisture content is also expressed as a percentage of the wet original material and is then 100 minus the dry solids content. The dry matter contains the organic material of the feedstock plus the inorganic material, such as sand, grit and minerals.

Different feedstocks have different moisture contents. In the more common wet AD systems, the feedstock needs to be prepared so that its dry matter content falls within the design parameters. This is important to the facility design as the slurry needs to be wet enough to be pumpable and to keep the contents of the AD reactor tanks well mixed. A slurry with a high level of dry matter will be too thick and viscous to be easily pumped and mixed.

Typically, dryer feedstock needs to be mixed with large amounts of water to reduce the overall dry matter content. This water may be recycled process water (including liquid digestate if the process includes dewatering of digestate), surface-collected rainwater, liquid feedstock or tap water. If there is no recycling of process water, then the design should recognise that the tonnage of output digestate may be substantially more than the tonnage of input feedstock.

4.2.3.3 Soil and grit contamination

Soil and grit can contaminate many farm-based feedstocks, particularly waste root crops such as carrots, parsnips and potatoes. Soil and grit can cause abrasion of the metal in pipelines and pumps and can also settle in tanks, effectively reducing the working volume of reactors (and consequently biogas production rates). Excess soil and grit therefore can increase maintenance costs and the risk of failures as well as reducing plant performance.

While feedstock with high soil and grit contamination may benefit from washing as a pre-treatment step, this creates further effluent and solid wastes (sediment). The management of wash water and sediments needs to be considered as part of the design.

4.2.3.4 Plastic, paper, metal and glass contamination

Contamination of digestate by plastics, metal, paper and glass is undesirable and unacceptable in digestate applied to land. Plastics in the soil environment may pose a hazard to grazing animals if ingested, and plastics may break down in the soil over time into microplastics, which are currently an environmental issue of high concern, in light of the potential adverse impacts on the soil ecosystem and, consequently, on the food chain.[5] Such contamination would be minimal for a farm-based AD facility fed only with manures and farm-grown crops.

Contamination by these materials may arise if the feed includes packaged commercial food waste. Such a feedstock would require a de-packaging process. Such pre-processing may not be 100% efficient, in which case the AD may be contaminated. This would mean that the digestate is most likely unsuitable for application to land and would need to be disposed of by some other means. Plastics and paper can also cause blockages in pumps and pipes. They can wrap around mechanical equipment such as conveyors and accumulate in AD tanks as a floating layer that can interfere with the collection of the biogas. Glass and metals may also cause damage by abrasion and accumulate in the bottom of the digester tanks.

Separately collected household food and kitchen waste from residents should contain less contamination. However, it is important to note that many householders may use biodegradable bags to collect their food and kitchen waste, and that these do not decompose significantly in an AD facility and hence can cause similar issues with AD operations to non-biodegradable plastic bags.

Some businesses operate a packaged food waste de-packaging plant and then supply a 'soup' of de-packaged and macerated food waste as a feedstock to AD plants. This removes the need for the AD facility to invest in de-packaging equipment and gives an option to manage the risk of residual contamination through the supplier contract.

4.2.4 Organic matter content, biodegradability and biogas yield

A key attribute of the available feedstocks is the biogas yield from the feedstocks. The facility design, and in particular the sizing of the facility process units, is largely based on this parameter in combination with the moisture content of the feedstocks. Performance and economic feasibility may be compromised if the expected biogas yield is not met. Hence, economic and financial analyses should take care to examine the sensitivity of the business case across the range of possible biogas yields. The following sections discuss these factors in more detail.

4.2.4.1 Organic matter content

Organic matter comprising of the carbon-based material, such as carbohydrates, fats and proteins, is the only part of the feedstock that has the potential to biodegrade and produce biogas. The organic matter content is typically measured as the percentage of the dry matter content derived by heating the feedstock to temperatures of 350-550°C.The organic matter burns off, leaving inorganic dry solids (often referred to as the ash content) remaining. The organic matter is typically reported as a percentage of the dry matter, either as volatile solids (VS) or loss on ignition content (LOI).

It is important to consider the organic matter content of feedstocks in conjunction with the measurement of the dry solid and moisture content, as this has implications for the sizing of the facility. As the following hypothetical example in *Table 4* illustrates, the dry feedstock has four to five times the amount of organic matter of the wet feedstock. It therefore has a potentially greater value in terms of biogas yield per tonne of feedstock, assuming all the organic matter was decomposed to biogas. This means that about four to five times the amount of wet feedstock would be required to give the same amount of biogas as the dry feedstock.

Dry feedstock is far too dry to make a pumpable slurry without diluting it with water, so it must be mixed with a large volume of water before it can be fed to the digester. Wet feedstock can be added to the digester without the need for additional water. Consequently, for AD plants fed with either the dry or wet feedstock, and generating similar amounts of biogas, a similar tonnage of prepared feedstock is needed, and the size of the AD facility must be similar. Due to dry feedstocks requiring dilution with water, the amount of digestate generated is greater than the input feed tonnage.

[5] https://www.unenvironment.org/news-and-stories/story/plastic-planet-how-tiny-plastic-particles-are-polluting-our-soil

Table 4: Hypothetical impact of feedstock moisture content on organic matter content

	Wet feedstock	Dry feedstock
Moisture content (MC) as % of feedstock.	80	20
Dry solids (DS) content as % of feedstock.	20	80
Organic matter (VS or LOI) content as % of the DS content.	70	80
Organic matter (VS or LOI) content as % of the original wet material. (Calculated from 100 x dry solids (DS)/100 x volatile solids/100)	(20% x 70%) 14%	(80% x 80%) 64%

The organic matter content added per m^3 of digester volume per day is often used to measure the loading rate of feedstock to the digesters. Most on-farm wet AD systems are fed at rates in the range of 0.4 to 0.5 kg volatile solids/m^3.day. Feeding at higher rates, runs the risk of over-accelerating microbial reactions, which can lead to an imbalance and cause the biological reactions (and biogas production) to fail.

4.2.4.2 Biodegradability

Section 4.2.4.1 above assumes that all the organic matter in the dry and wet feedstocks is biodegradable. However, this is not the case in practice and only a portion of the organic matter will decompose to generate biogas. The portion that will decompose will be different for different feedstocks, depending on several factors.
As well as referring to the portion of the organic matter that may decompose, biodegradability relates to how rapidly this portion decomposes. The amount of biodegradable material, as a proportion of the organic material, and its rate of degradation, are important characteristics of feedstocks because they affect the size of digester required; feedstocks that take longer to digest need to be kept longer in a digester to extract all their biogas producing potential. Therefore, these require larger AD tanks and more capital investment, all else being equal.

The factors that affect decomposition are examined below.

- **Content that is resistant to AD** - Not all the organic matter is necessarily biodegradable under the anaerobic conditions in the digester. For example, lignin is a common constituent of plant material that provides structural support to the plant cells and is resistant to AD. Therefore, the higher the lignin content, the lower the potential biogas yield. Woody materials such as twigs and branches are high in lignin content and are thus resistant and unsuitable for anaerobic degradation. Most plant material contains some lignin. This means that not all the organic matter present is biodegradable in the digester.

- **Content that is only slowly digestible -** Organic matter may include complex polymers such as cellulose, which degrade slowly under anaerobic conditions. It is beneficial to have some of this material in the feedstock, but too much can mean that not all the potential biogas can be harnessed from the feedstock, because the timescale in the digester is not long enough to deal with the level of complex polymers. Increasing the timescale would require significant increases in the size of the digester to an unrealistic and uneconomic level. Materials that contain a high content of slowly biodegradable cellulose include straw, cereal grain husks, dead autumn leaves and grass sward contaminants (dock leaves, rushes, etc.).

- **Physical barriers to digestion -** Feedstock may not be in the appropriate physical form to allow free access for micro-organisms to the organic matter. Micro-organisms generally need to attach to soil substrates in order to degrade them, and therefore the higher the surface area available for such attachment, the better the degradation rate. For example, grass sward in silage may still be in a grass-like form and chopping this to as small a size as possible as part of the pre-processing is beneficial. Whole cereal grains contain organic material that is readily biodegradable, but it is protected from microbes by the outside husk. Milling such feedstock allows micro-organisms to access to the biodegradable components.

Laboratory tests of biogas production are a good way of assessing the potential yield from different feedstocks, and the suitability of different feedstock preparation procedures. Such tests can only be indicative of production potential, providing a valuable comparison to assist decision making. In the absence of such specific laboratory tests on the actual feedstocks intended for the facility then literature values may be used as a guide, at least for the initial design. Actual testing of actual feedstocks is, however, advised to give added assurance of the feedstock biodegradability, as this may vary considerably for the same feedstock type grown and harvested under different conditions.

Figure 4.3 illustrates the varying biogas production and biogas yield patterns that may arise from different feedstocks. The biogas production curve of the feedstock chosen will influence the facility design, and especially the size of the anaerobic digester. It is clear that:

- Feedstocks with a high biogas yield and high rate of biogas production are the most desirable, as this means that high conversion rates of the energy in the feedstock to that in the biogas are realised.

- Feedstocks with a low biogas yield may not seem so attractive. However, if, as in the case of manures, they mean that greenhouse emissions are reduced then they are beneficial for other reasons. Some low biogas inputs can also be considered if they attract a gate fee to offset the lower biogas yield.

- Feedstocks with a high biogas yield but slow rate of biogas production are also potentially valuable as it means the overall rate of microbial decomposition may be phased evenly while it is in the anaerobic digester, rather than in spurts of activity immediately following fresh feedstock addition. This helps to support steady state conditions for the microbial community.

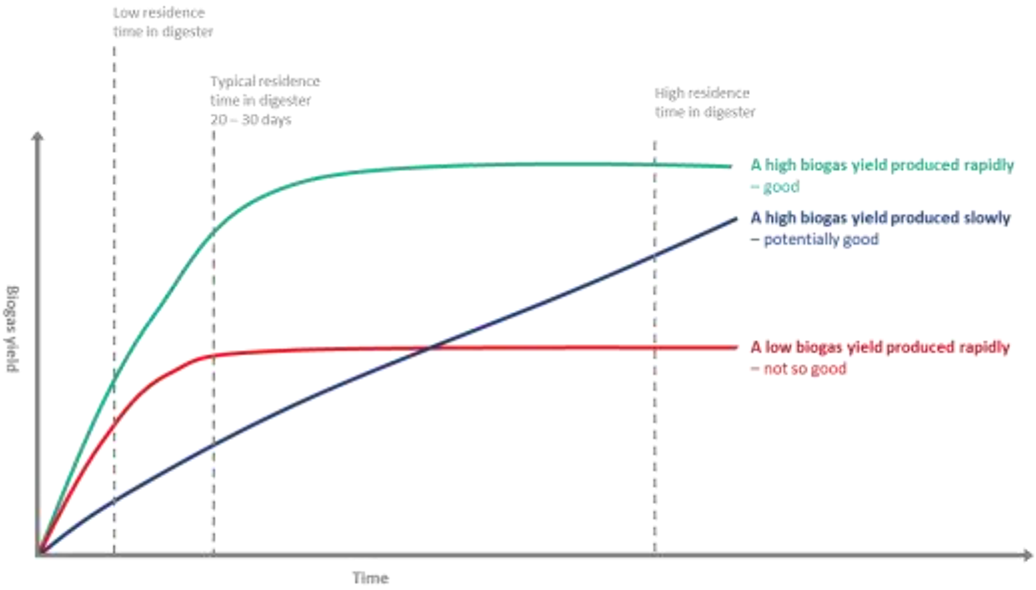
Most AD facilities, whether mesophilic or thermophilic, aim at a residence time of at least 20 to 30 days for feedstock in the digester. During this time, about 80-90% of the potential biogas is expected to be produced. Doubling the reactor size may only increase the biogas yield by a further 5-10% and may not be worth the cost of the larger reactor. The mix of feedstocks should be selected to control the expected biogas production rate of the facility, with due regard to the capacity of the biogas utilisation equipment, because burning excess biogas in the emergency flare is a waste of resources and should be avoided.

In a **small anaerobic digester**, the feedstock typically has a lower residence time, hence feedstock should be of a higher rate of biogas production, although the maximum biogas potential of the feedstock may not be realised. In that case, the digestate from such a facility may then produce significant biogas in the digestate storage tank, which can also be collected.

However, for an on-farm AD system where the digestate needs to be stored for some time over the closed spreading season, the digestate store needs to be virtually empty at the start of this closed period. In this circumstance, digestate generated just before the closed season might be spread to land without any storage time. If there is a single digester then some of the input feedstock, once completely mixed with the digester contents, will be immediately removed in the digestate, having spent no time in the digester. Therefore, the digestate is not fully degraded and can still have significant biogas producing potential, which might be wasted. This waste can be avoided if two digesters operate in a series, so that most degradation and biogas production occurs in the first digester, and the second digester provides additional time for further degradation of the feedstock to take place. With this system, the digestate from the second digester, even if applied to land without storage, would have a low and acceptable residual biogas producing potential.

In a **large anaerobic digester**, the residence time is typically higher, and a greater proportion of the feedstock's total biogas potential can be realised. This would partly overcome issues of residual digestate biogas producing activity if digestate was applied to land without a storage time. However, the additional cost of the larger digester needs to be considered against the increased biogas yield and waste management benefits and compared with the option using two smaller tanks in series.

Figure 4.3: Typical biogas production rates over time in laboratory tests from different feedstocks



4.2.4.3 Typical biogas yields

Often AD facility designers refer to tables of typical biogas yields from feedstocks. Example sources for such data are shown below.

Example sources of feedstock biogas yield data:

- National Non-Food Crops Centre
  http://www.biogas-info.co.uk/about/feedstocks/
- Anaerobic Digestion Biosources Association: The Practical Guide to AD
  http://adbioresources.org/library/purchase-the-practical-guide-to-ad/
- BiG>East: Biogas Handbook
  https://www.lemvigbiogas.com/BiogasHandbook.pdf
- International Energy Agency Bioenergy: Biogas from Crop Digestion
  http://task37.ieabioenergy.com/files/daten-redaktion/download/energycrop_def_Low_Res.pdf
- Environmental Protection Agency Climate Change Research Programme 2007–2013: The Potential for Grass Biomethane as a Biofuel
  http://www.epa.ie/pubs/reports/research/climate/ccrp11-thepotentialforgrassbiomethaneasabiofuel.html
- FNR: Guide to biogas – From production to use
  https://mediathek.fnr.de/guide-to-biogas-from-production-to-use.html
- Online European Feedstock Atlas
  https://daten.ktbl.de/euagrobiogasbasis/startSeite.do

The data provided by independent data sources may vary in terms of the absolute values and the units used. Such data should therefore be treated as indicative, and laboratory testing of the feedstock sources intended for the AD facility is strongly recommended. *Table 5* presents data for some typical feedstocks for farm-based AD facilities, showing the range of biogas yields reported. We recommend seeking independent advice to interpret data for the purposes of design as well as economic and financial feasibility.

As a note of caution, AD equipment suppliers may provide data that indicates a biogas yield at the high end of such ranges to promote their technology. The above data should be used to check their claims and financial assessments should examine the impact of a range of yields on the business case.

Table 5: Typical biogas yields from different feedstocks

Feedstock	% dry solids Typical (range)	% organic matter of dry solids Typical (range)	Biogas m^3/t organic matter Typical (range)	Biogas m^3/t wet matter Typical (range)
Cattle manure	25	80	300 (110-406)	60
Cattle slurry	6 (2-10)	80	320	(15-25)
Pig slurry	4 (2-6)	80	320 (175-551)	(11.5-25)
Chicken manure	(35-60)	75	420 (210-584)	(30-100)
Grass silage	25	85	550 (341-572)	(117-200)
Food waste	20	85	(700-876)	119
Waste Potatoes	25	92	(680-758)	(156-400)
Cereal grains	85	95	(650-752)	(384-525)
Dairy whey	5	90	750	33.8

Manures generally have low biogas yields. This is because (particularly for ruminant manures) the feedstock has already passed through the ruminant gut, which, as an efficient anaerobic digester, will have removed much of the digestible organic matter. An AD facility based solely on animal manures as feedstock may not be feasible unless supplemented with more highly biodegradable feedstocks.

4.2.4.4 Methane content of biogas

The proportion of methane (CH_4) present in biogas determines its energy content. Typically, biogas is about 55% CH_4 but higher proportions are possible. There is an incentive for suppliers selling AD units to choose CH_4 content values that are higher than this. These need to be checked carefully to ensure they align with the feedstock mix available and the operating conditions of an individual AD facility.

The CH_4 content of biogas depends to some extent on the feedstocks used. In principle, the lower the oxygen content in the feedstock, the higher the CH_4 content of the biogas. Feedstocks with a high fat content, for example, vegetable oils, should in general give higher CH_4 yields than low-fat feedstocks.

The CH_4 content of biogas can also be influenced by the degree to which the carbon dioxide (CO_2) formed dissolves into the digestate rather than entering the biogas. CO_2 is about 20 times more soluble in water than CH_4 (especially at neutral to alkaline pH). This means that a lot of the CO_2 in biogas may dissolve in the digestate, increasing the proportion of CH_4 in the biogas. Other factors that affect the CH_4 content of biogas are:

- **The anaerobic digester operating pressure**
  More CO_2 will dissolve into the digestate (liquid) at higher pressures, therefore increasing the proportion of CH_4 in the biogas.

- **The process water strategy**
  If there is very little recycling of process water, the input water will be relatively free of dissolved CO_2, enabling more CO_2 to dissolve into the digestate (liquid).

Control of the CH_4 content through feedstock selection and anaerobic digester conditions may have advantages when upgrading to biomethane, as it will reduce the amount of CO_2 that needs to be removed from the biogas and thus reduce the cost of upgrading.

4.2.4.5 Estimating biogas production and energy yield

Estimating the biogas, CH_4 and energy yield that can be expected from the selected feedstocks based on their characteristics, is key to the design. The box below is a worked example of how to estimate the energy content of biogas. This calculation first estimates the total volume of biogas expected from the feedstock based on the tonnage of feedstock and its dry solids, organic matter and biogas production per tonne of organic matter. The next steps are to estimate the volume of CH_4 produced (Step 2) and then the energy present in the CH_4 (Step 3).

If the AD is to receive several different feedstocks co-digested together, then the Step 1 calculation can be made for each feedstock and the resultant total biogas estimated from the sum of each feedstock. Note that there are claims that co-digestion of feedstocks, especially mixtures with animal manure, can enhance the biogas yields above the sum expected from the individual feedstock characteristics.[6,7] The calculation method should be considered as providing an indicative estimate only, and further appropriate design expertise should be sought for each project.

Estimating energy yield from feedstock

1. Estimate volume (m^3) biogas from feedstock as:
   t feedstock x % dry solids/100 x % organic matter /100 m^3 x biogas m^3/t organic matter
   OR: t feedstock x biogas m^3/t wet weight

2. Estimate volume (m^3) CH_4 from feedstock as:
   m^3 biogas x % CH_4 in biogas
   (If % CH_4 in biogas is unknown, then a default value of 55% CH_4 can be used.)

3. Estimate energy content of the CH_4 produced as:
   m^3 CH_4 x energy content of CH_4
   (A suitable default value for the energy content of CH_4 is 9.8 kWh/Nm^3 CH_4.)

Note that the energy content of CH_4 is often described as between 50 and 55 MJ/kg, which equates to between about 9.8 and 11 kWh/Nm^3. Not all the energy in the CH_4 is captured as usable energy; this depends on the biogas utilisation technology. For example, in a typical combined heat and power (CHP) unit around 35% of the energy might be recovered as electrical energy and a further 30-45% as usable heat. The financial feasibility may depend on the efficiency of energy recovery from the CH_4.

Table 6 shows a hypothetical example of the calculation of the energy yield expected for a farm AD facility using cow slurry and grass silage as feedstocks (with characteristics as in *Table 5*). In the first scenario the biogas is sent to a CHP plant for heat and electricity on-farm demand, in the second scenario to a biogas boiler which only produces heat to meet on-farm heat demand.

---

[6] https://www.nature.com/articles/s41598-017-15784-w

[7] https://www.epa.gov/sites/production/files/2014-12/documents/codigestion.pdf

There are two setups explored, the first set up requires pasteurisation to comply with Animal By-product regulations, with more than 2 farms supplying slurry to the AD plant. In the second setup pasteurisation is not required as there are only two farms supplying slurry and the total slurry quantity is less than 5,000 tonnes/annum.

- Setup 1: Pasteurisation required:
    - 4 farms totalling 720 dairy cattle each producing about 0.33 m^3/week ofslurry[8] when housed for 40% of the year, giving a total of 4,942 t/a of slurry;
    - 73 hectares (181 acres) of grassland with a yield of 45 t/ha (wet weight), producing an estimated 3,291 t/a of wet silage (equivalent to 11.3 t DS/ha.a and 823 t DS in total, based on the silage characteristics of 25% DS content, *Table 5*).
    - An additional heat demand for post-digestion pasteurisation is required in this setup.

- Setup 2: Pasteurisation not required:
    - 2 farms supply the same quantity of slurry (4,942t/a) and grass silage (3,291t/a) between them.

In these setups, it is assumed that 10% of the electricity generated is needed for operating the AD facility in the CHP scenario and the same amount is required from the grid (or other sources) for the biogas boiler scenario. This reduces the amount of electricity available for use on the farm for the CHP scenario. It is assumed that some of the heat generated by the CHP or boiler is used in the AD process, for heating the digesters as a mesophilic process. All the figures are for illustrative purposes only.

[8] Statutory Instrument No. 605 of 2017, Good Agricultural Practice for Protection of Waters

Table 6: Example of calculation predicting electrical energy production from an AD facility

	Parameter	Equations	Setup 1: Pasteurisation required			Setup 2: Pasteurisation not required		
			Cattle Slurry	Grass Silage	Total	Cattle Slurry	Grass Silage	Total
Generation	Input tonnage (wet t/a)	A	4,942	3,291	8,233	4,942	3,291	8,233
	Dry solids content (%)	B	6	25	-	6	25	-
	Biogas (Nm³/ wet t)	C	20	140	-	20	140	-
	Biogas produced (Nm³/a)	D = A x C	98,842	460,719	559,561	98,842	460,719	559,561
	CH_4 produced (Nm³/a) (55% of biogas)	E = D x 0.55	54,363	253,395	307,758	54,363	253,395	307,758
	Energy content kWh (9.81 kWh/Nm³)	F =E x 9.81	533,300	2,485,809	3,019,109	533,300	2,485,809	3,019,109
Parasitic (Process) heat demand(s)	Digester heat demand (kWh) (35 kWh/t feedstock)	G = A x 35	172,973	115,180	288,153	172,973	115,180	288,153
	Post-digestion pasteurisation heat demand (kWh) (45 kWh/t feedstock)	H = A x 45	222,394	148,088	370,482	0	0	0
Scenario 1: CHP - Heat and Electricity	Electricity Generation @ 35% efficiency (kWh)	I = F x 0.35 (35%)	186,655	870,033	1,056,688	186,655	870,033	1,056,688
	Electricity parasitic demand @10% (kWh)	J = I x 0.1	18,665	87,003	105,669	18,665	87,003	105,669
	Net Electricity (kWh)	K = I + J	167,989	783,030	951,019	167,989	783,030	951,019
	Heat Generation @ 40% efficiency (kWh)	L = F x 0.4	213,320	994,324	1,207,644	213,320	994,324	1,207,644
	Heat parasitic demand (kWh)	M = G + H	395,366	263,268	658,634	172,973	115,180	288,153
	Available Heat (kWh)	N = L - M	-182,046[9]	731,056	549,009	40,347	879,144	919,491
	Total CHP Output (kWh)	O = N + K			**1,500,029**			**1,870,510**
Scenario 2: Boiler - Heat Only	Heat Generation - Boiler @ 80% efficiency (kWh)	P = F x 0.8	426,640	1,988,647	2,415,287	426,640	1,988,647	2,415,287
	Electricity Parasitic Demand (kWh) from Grid	J	18,665	87,003	105,669	18,665	87,003	105,669
	Total Boiler Output (kWh)	Q = O - (G + H + J)	12,608	1,638,376	**1,650,984**	235,002	1,786,464	**2,021,466**

[9] Slurry will require more heat to pasteurised than it will generate in the CHP scenario for setup 1 (182MWh)

This example illustrates how cattle slurry, although around 60% of the feedstock by wet weight, only accounts for about 18% of the total biogas production. The total electricity generation of 1,323,408 kWh makes this around a 165 kWe sized facility based on the size determined by the electrical energy production.

Setup 1 has an additional heat requirement (370MWh) for pasteurisation because of this. The slurry in this setup is help meet the sustainability threshold of 70% (Section 4.6.1). This setup is also more flexible as it can take in additional farm's slurries and in a greater quantity, more than 5000t/a.

- CHP scenario for setup 1 will generate a net electricity amount of 951,019 kWh and 549,009kWh of net heat. This means that the CHP unit should be sized approximately 130kWe determined by the electrical energy production.
- Boiler scenario for setup 1, the boiler will generate 1,651 MWh of heat meaning the boiler size will be approximately 300 kW.

Setup 2 doesn't require pasteurisation therefore has more heat available for both the CHP and boiler scenarios. In the CHP scenario the slurry feedstock produces more heat than is required to process it. It is assumed the electricity parasitic demand is the same as the CHP scenario but will need to be provide from the grid or another source.

4.2.5 Feedstock delivery and storage

If receiving externally sourced waste feedstocks, operators require a permit from the local authority or an Environmental Protection Agency licence (the Overview Guide, Section 6, summarises these requirements). No further consents are required for animal-derived wastes, such as manure, generated on the operator's site. If animal-derived waste, including food waste, is being imported, the farm operator will need certification according to the Animal by-products Regulation before being permitted to deploy the digestate on the land.

There are some types of wastes which can only be imported using specific storage infrastructure (tanks for liquid wastes and bunkers for solid wastes). Storage approaches are described in Section 3.2 of the Technology Guide. Feedstock storage facilities need to minimise emissions of odours or contaminated leachate and not attract vermin (refer to Section 2.2 of the Operation and Maintenance Guide).

Imported feedstocks might need to be laboratory tested for quality and composition to identify dry solids, volatile solids, nutrients, acceptable contaminant levels and potential biogas production, and ensure that the correct loading rate for the AD process is maintained. Acceptance criteria for the feedstocks should be agreed with suppliers. This should include specific limits on the quality, including potential contaminants.

A key feature of AD operation is that the micro-organisms carrying out the degradation of the organic matter are sensitive to rapid changes in feedstock type. Switching from one feedstock to another risks compromising the operation of the anaerobic digester and is not advisable. Any new feedstock should be introduced gradually, so that the microbial community has time to adapt to it.

4.2.6 Feedstock costs and revenues

The feedstock costs, feedstock and digestate transport costs and specific pre-processing costs are key for ensuring commercial viability. Generally, for a farm-based AD process, the feedstock costs are associated with farming costs. Manures and slurries are likely be produced on a livestock farm. Additional costs may occur if collection and storage requirements change, or manures are imported from other farms.

Farm crops grown specifically as feedstock, such as grass silage, entail production costs. Waste crops, such as root crops unsuitable for sale to supermarkets, might be bought in, although there may be local competition for purchase. Some wastes, however, may command a gate fee if the disposal at the AD site is cheaper for the waste producer than the alternatives (for example, landfill).

Other feedstock costs to consider are the requirements of additional water and trace nutrients to optimise the process. AD often benefits from the addition of specific trace elements that help to keep the microbial community in optimal conditions. Whilst most feedstocks contain trace elements, AD requires some rare ones such as selenium and tungsten and insufficient natural levels of these in the feedstocks can cause problems. It is advisable to factor in costs for monitoring for and for adding trace elements.

Additionally, some feedstocks may require external processing to optimise their biogas yield (for example, it may be cost-effective to have seed grains milled by external contractors, if the biogas yield benefits are favourable).

4.3 Biogas utilisation outlets

When developing an AD facility, it is important to consider how the biogas produced will be used, and the associated equipment and agreements needed for the chosen option. As the CH_4 in biogas is a powerful greenhouse gas (with a global warming potential some 25 times higher than that of CO_2), it is important that the biogas is collected and used effectively. Biogas can be combusted in a flare stack to convert the CH_4 to CO_2 and water, but this does not effectively harness the potential of biogas to provide useful energy.

Biogas may be used directly (after some clean-up, as described in Section 5.1 of the Technology Guide) in boilers or CHP units to provide heat, electrical energy, or both. Alternatively, the biogas can be upgraded to remove the CO_2 and other trace impurities to produce biomethane. Feedstocks can be selected to limit contaminants in the biogas, prior to subsequent gas clean-up. This can include, for example, purchasing feedstocks containing low nitrogen (N) and low sulphur (S), which results in lower ammonia (NH_3) and hydrogen sulphide (H_2S) levels in the biogas. Agreeing specifications for imported feedstocks such as retail packaged food waste will also help.

Heat and electrical energy or biomethane fuel can be used in a variety of ways, on and off site. The main energy and fuel uses are summarised below.

Energy:

- Using heat or electricity on site to reduce imported energy and save energy costs;
- Providing heat or electricity to nearby users to generate energy sale revenues; or
- Exporting electricity to the electricity grid to generate sale revenues.

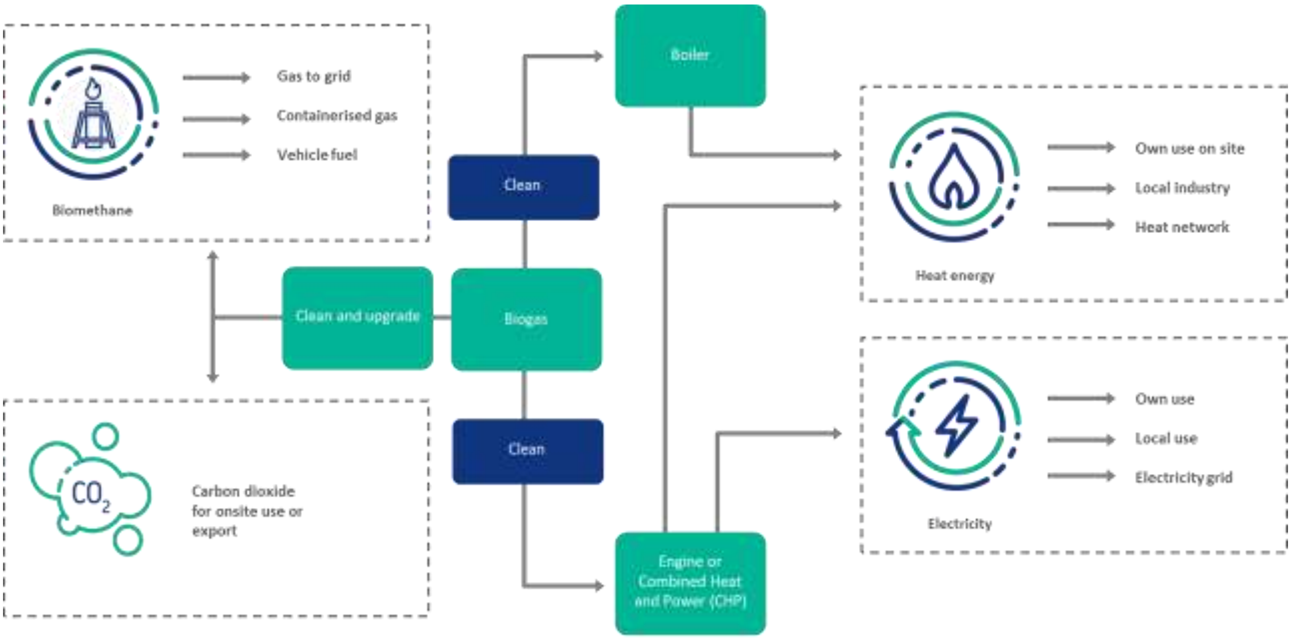
Fuel:

- Exporting biomethane fuel to the gas grid;
- Using biomethane as a fuel in portable gas containers and as fuel for vehicles; or
- Recovering CO_2 removed from the biogas stream can be recovered and used in industry (for example, in food production).

An active area of research is the potential to use other chemical compounds produced during the AD process as replacements for fossil fuel derived chemicals. For example, acetic acid can be isolated and used as a replacement for more carbon-intensive chemicals in industrial processes. Over time, demand for these bio-based products can add to the revenue streams from AD.

The above options are summarised in *Figure 4.4*. For an overview of biogas utilisation equipment, see the Technology Guide, Section 5.

Figure 4.4: Options for biogas use



Consider the potential local and national markets for the different forms of energy, and the feasibility of implementation (for example, the existence of the necessary infrastructure to provide the energy to the user).

The AD facility requires electricity to operate. It usually requires heat too, especially if the system includes a thermophilic anaerobic digester and/or includes pasteurisation processes for Animal by-product Regulations compliance. This energy is typically derived from some of the biogas being used in a CHP plant and is frequently referred to as parasitic energy. Even a facility designed to upgrade biogas to biomethane will therefore often still have a CHP plant on site to meet these parasitic loads.

4.3.1 Energy outputs from biogas

4.3.1.1 Heat energy

Methane (CH_4) contains a high chemical energy content that is released as heat when combusted. The following questions need to be addressed when considering the potential to use heat from biogas combustion.

- **In what form and at what temperature is the heat required?**
Heat will most often be conveyed as hot water or steam. Hot water is suitable for many demands (for example, heating and domestic hot water) but some specialist applications may require heat as steam (for example, sterilisation, and distillation). Biogas-fired hot water and steam boilers are available; however, heat is more commonly derived (as hot water) from biogas-fired CHP units. Appliances producing hot water tend to be more thermally efficient, cheaper and less complicated to operate than steam appliances.

- **How near are the heat users to the facility?**
Hot water or steam is transmitted through insulated pipework. Modern pre-insulated pipework allows hot water to be transmitted over hundreds of metres with only modest falls in temperatures. Steam tends not to be transmitted over such long distances due to technical complexities. The distance between the facility and a prospective user will be a key consideration in the cost of distribution.

- **How consistent is the demand for heat?**
Many uses of heat are seasonal (winter heating demand). If demand is seasonal, alternative uses for the biogas need to be found for when demand is low. Options for managing seasonal variation include a portfolio of users

with complementary heat demands. For example, heat can be used in absorption chillers (which use heat to drive a refrigeration cycle), to meet demand for cooling during times when heating demand is low.

4.3.1.2 Electrical energy

By combusting the biogas in a reciprocating gas engine which drives a generator, it is possible to produce electricity as well as heat (combined heat and power).

Electricity generated can be used on site (including for AD parasitic loads) and the remainder exported to the electricity grid.

Where operators intend the AD facility to be connected to the electricity network (either to export excess power to the grid, or to import power to support the facility), they need to apply for an embedded generator connection from the network operator. For connections at a voltage at 38kV or less (distribution connections) the operator is ESB Networks. For higher-voltage (transmission) connections, the operator is EirGrid. Most operators expect to be connecting at voltages requiring a distribution connection. Generators intended to be connected to the electricity network are required to have an Authorisation to Construct and a Licence to Generate granted by the Commission for Regulation of Utilities (CRU)[10]. Generators with an installed capacity not exceeding 1 MWe, are automatically considered to be authorised and licenced under Statutory Instruments Nos. 383 of 2008 and 384 of 2008 of the Electricity Regulation Act.

When applying for a connection, the operator must advise what their maximum export capacity will be. This is the peak capacity (in kW_e) that the operator will wish to export to the grid at any time. The application fees and connection costs will be influenced by the maximum export capacity. If a connection application is accepted, this will result in the provision of a connection offer from the system operator, setting out the work associated with installing the connection and the cost of these works.

Connection works will often be divided into two elements:

- **Contestable works**
  These are works that can be done by parties other than the system operator (for example, a contractor appointed by the project developer), meaning competitive quotes can be sought. This may cover some works on the facility side.

- **Non-contestable works**
  These works can only be done by the system operator. They cover works on grid assets (for example, substations) and commissioning and energising the connection.

Once the facility is connected to the electrical grid and is operational, the operator will need to operate in accordance with the requirements of either The Distribution Code (for distribution connections)[11] or The Grid Code (for transmission connections)[12]. These codes place obligations on operators in matters such as metering, telemetry and communications with the system operator. The extent of the obligations will depend on the capacity of the connection. For example, generators smaller than 2 MW_e must meet different requirements than those of a higher power.

Finally, the operator will need to have a power purchase agreement in place with an energy supplier who will pay for power exported to the grid. The terms and conditions will typically be negotiated directly with the supplier.

4.3.2 Biomethane production

Biomethane is a high purity gas (typically 96% CH_4) derived from biogenic material. The production of biomethane from biogas therefore involves removing most of the CO2 and other gases from the biogas to leave the CH_4. Biomethane fuel can be fed into the national gas grid (normally enriched with a small amount of propane to raise the calorific value to a level consistent with gas grid specifications) or used for transport as compressed biomethane fuel.

[10] https://www.cru.ie/professional/licensing/atc-gl-licensing-2/
[11] https://www.esbnetworks.ie/who-we-are/distribution-code
[12] http://www.eirgridgroup.com/site-files/library/EirGrid/Grid-Code.pdf

For injection of biomethane into the national gas grid, the proximity of a suitable point for direct connection needs to be determined. If the gas grid is too far away for a direct connection, it may be that an injection point is available or under development that can accept tankers of compressed biomethane produced from the AD plant and transported by road to the injection point. This may be an option in circumstances where there are several AD plants in the area. When calculating the sustainability of this biogas usage, greenhouse gas emissions from the transport of the compressed biogas must be considered.

The operator must have in place a gas purchase agreement with a gas supplier or shipper, to pay for gas injected to the grid. The operator must apply to the gas network operator for permission to inject biomethane into the network and initial and ongoing charges for connection may apply. Gas Networks Ireland (GNI) operates Ireland's national gas grid and should be the first point of contact for any queries regarding injection projects.

4.4 Biogas quality

The raw biogas from the digester may contain levels of contamination that mean it is unsuitable for direct use in biogas utilisation equipment. It should not be assumed that if the feedstocks are limited to animal manures and farm grown crops that there would be no such contamination. Some contaminants, such as siloxanes, pose a risk of damaging the biogas utilisation equipment, affecting the efficiency and longevity of the equipment. Other contaminants such as hydrogen sulphide (H_2S) and ammonia (NH_3) are oxidised to sulphur dioxide (SO_2) and nitrogen oxides (NO_x) respectively when combusted. Emissions to atmosphere of SO_2 and NO_x from equipment combusting biogas, such as boilers or CHP plants, are likely to be limited as part of the environmental permit or other control measures. It therefore is very likely that appropriate biogas clean-up equipment would need to be incorporated into the facility design.

Some potential biogas contaminants and their removal from biogas are briefly discussed below. Some effort can be applied to the selection of feedstocks that limit the production of biogas with lower contaminants (for example selecting feedstocks low in nitrogen and sulphur, in order to limit NH_3 and H_2S levels in the biogas) and specifying limits for other contaminants such as siloxanes in feedstock supply agreements. The biogas clean-up technology required should therefore be considered within the process design (see also the Technology Guide, Section 5.1, for details).

4.4.1 Moisture content

Biogas is produced in an enclosed humid environment and contains a significant proportion of moisture. It is standard practice to remove the moisture by condensation using coolers or other means.

4.4.2 Air contamination

Air or oxygen may be deliberately introduced into the biogas as a control measure to remove H_2S (see Technology Guide, Section 5.1). However, air should not be unintentionally introduced into the biogas flow.

4.4.3 Hydrogen sulphide

AD generally converts sulphur present in the organic matter (mainly sulphur in proteins) and in inorganic sulphate to H_2S. H_2S is undesirable as it is very odorous and toxic. If introduced into combustion plants, it will be converted to sulphur dioxide (SO_2), which is an air pollutant and as such likely to be limited in any biogas combustion plant exhaust permit. AD operations at risk should have measures to limit H_2S levels in the biogas.

4.4.4 Ammonia

Contamination of the biogas with NH_3 is inevitable as this is produced from the decomposition of organic matter such as proteins. NH_3 is an issue for combustion as it can be converted to polluting nitrogen oxides (NO_x) and emitted in the exhaust gases. Some control can be achieved by selecting feedstock with of low nitrogen content, and by controlling the pH of the digester, as NH_3 is more volatile at high pH values.

4.4.5 Siloxanes

Siloxanes are volatile ('oily') silicon compounds that that are often associated with certain food materials and can be found in biogas. If they enter combustion engines they are oxidised to silica, and essentially converted to a hard form of sand, which can cause significant damage to the engines.

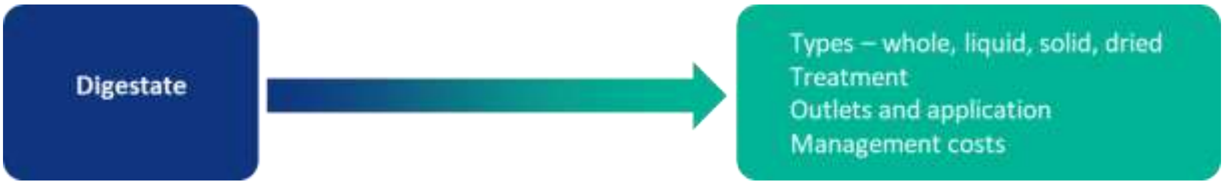
4.5 Digestate

The digestate from an AD facility is a principal output and will still continue to produce CH_4 after it has left the anaerobic digesters and entered storage tanks, especially if it is not fully biodegraded (as is inevitable due to the continuous mixing of AD digesters where some small portions of undegraded feed leave the digester almost immediately after addition). Therefore, digestate needs careful management. Best practice dictates that digestate is stored in covered tanks where any residual biogas produced can be recovered.

This section focuses on the application of the digestate to agricultural land as a fertiliser (also discussed in Section 5.4 of the Operations and Maintenance Guide). Other uses are possible, such as in horticulture (although further composting may be required), but as these are peripheral markets to the farm they are not considered further here. When digestate is applied to land, temporary storage time in small tanks at the field site should be minimised, as this may be a source of emissions of CH_4.

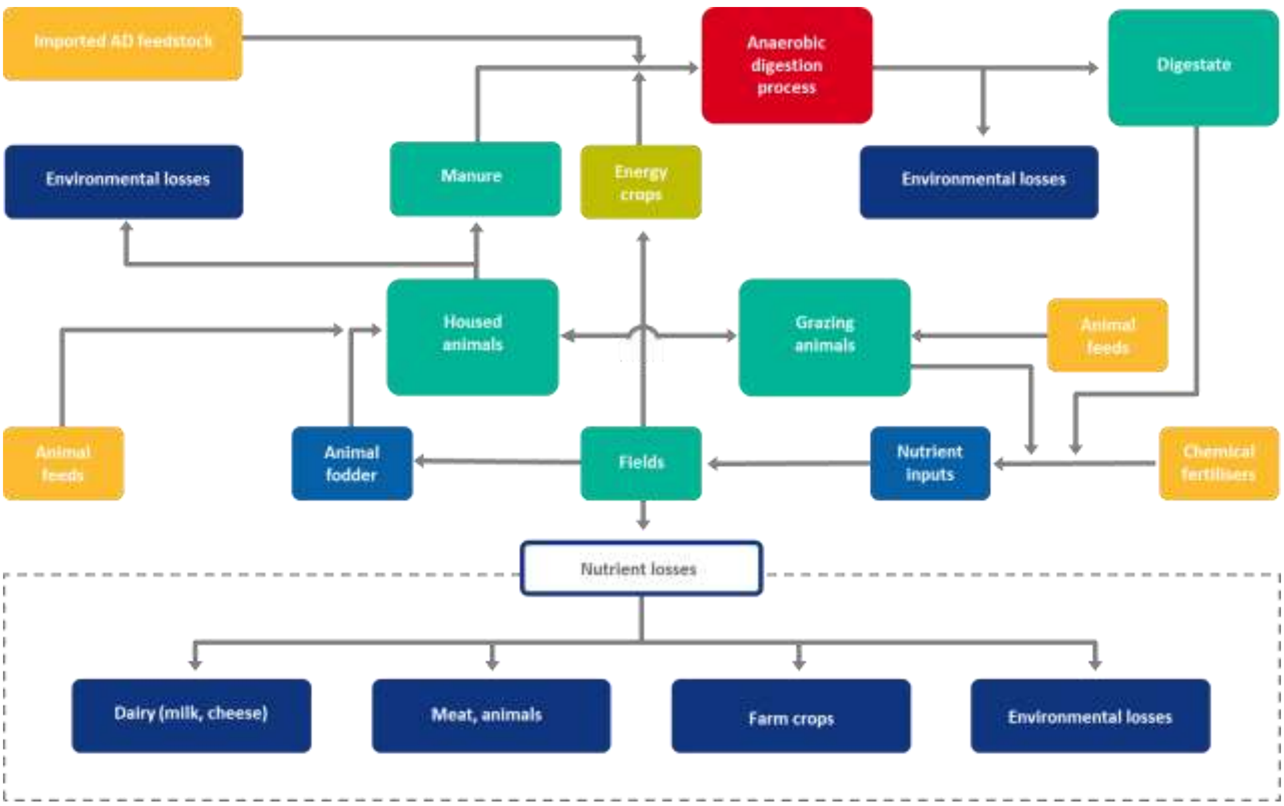
Key aspects of digestate and its management are summarised in *Figure 4.5*.

Figure 4.5: Key aspects of digestate to consider



Use of the digestate as an organic fertiliser should be considered in terms of the whole farm nutrient balance (*Figure 4.6*). This might include nutrients imported with externally sourced AD feedstocks as well as their more traditional introduction through chemical fertilisers and animal feeds, and the losses of nutrients in farm products exported from the farm (for example, milk and meat).

Figure 4.6: Farm nutrient balance and role of digestate



4.5.1 Types of digestate

The digestate from the anaerobic digester may be further processed to give several possible types of digestate as described below. This has consequences for the choice of facility design (see Section 6 of the Technology Guide).

Digestate can still produce biogas, so the facility design should incorporate measures to capture this and avoid fugitive CH_4 emissions from the stored biogas. Digestate will also have high ammonia (NH_3) content and mitigating fugitive emissions of NH_3 should be allowed for in the design.

4.5.1.1 Whole digestate

Whole digestate from a wet AD system is typically a liquid slurry with a low content of dry solids. It comprises the whole of the AD digester output that has had no further processing, and is consequently of significant volume, and requires storage in suitable tanks.

In a wet AD system with whole digestate production, there is a single pass of feedstock through the digester, and little or no recycling of digestate or process water. This simplifies the AD design considerably. It also raises three key questions:

- **What size and design of digestate storage tank is required?**
  Considerable storage capacity is required for a whole digestate producing facility. Material must be stored for long periods in winter during times when land spreading is not permitted.
- **Where does the water to dilute the incoming feedstocks come from?**
  If there is no recycled process water, high moisture feedstock should be used if available. Otherwise clean process water (from the mains) can be used.
- **Are there suitable local outlets for the large volume of liquid digestate?**
  It is essential to know what local outlets are available, and when. The cost and environmental impact of transporting whole digestate over long distances (in most cases greater than 8 km) may be significant.

4.5.1.2 Solid and liquid digestate

Whole digestate slurry may be treated by dewatering, either using filter presses, or centrifuges (see the Technology Guide, Section 6, for details). Dewatering separates the undigested solid material from the water and will typically produce a 'stackable' digestate cake (fibre) with a dry solids content of about 15% to 20% and a liquid digestate (liquor). Both may be used as fertiliser. Producing solid cakes is a more economical choice if the digestate is being transported over longer distances.

Liquid digestate, if all applied to land as fertiliser, would also require large tanks for storage during the season when spreading is not allowed. It may also be recycled as process water. This reduces the requirement for finding water sources for feedstock preparation and decreases the volume of digestate to be temporarily stored and transported for application to land. Note that such recycling would tend to make the liquid digestate richer in nutrients and therefore a similar land bank would be needed for its use as a fertiliser. Too much recycling of digestate can also lead to an accumulation of materials that inhibit the micro-organisms in the digester.

A dewatering facility can also mitigate unforeseen plant disruption. For example, if the storage capacity for whole digestate is nearly full, the facility might be able to continue biogas production by employing a dewatering system and reducing required digestate storage volume.

The decision of whether to include dewatering in the design should therefore be based on the local situation. Dewatering can be beneficial if the input feedstocks are dry and need a lot of dilution with water, or if the land bank for digestate is a long way from the facility.

4.5.2 Digestate treatment

Under most circumstances, the quality of the digestate reflects the quality of the feedstock and the operation of the anaerobic digester. Ferrous chloride is sometimes added to digesters to control the amount of hydrogen sulphide (H_2S) in the biogas. This has the added benefit of reducing the odour of the digestate. Generally, post digestion treatment is limited to dewatering as discussed above.

If, however, the facility receives animal by-product feedstock, such as animal manure from another farm, then it may need to comply with the Animal by-products Regulation. This requires the digestate to have been sanitised to mitigate the risks from pathogenic micro-organisms. The most common method of sanitisation is to pasteurise the feedstock. The digestate must subsequently be stored under conditions that prevent it from being re-contaminated with untreated animal by-products.

Pasteurisation involves heating the prepared feed or digestate to a temperature of at least 70°C for an hour. This can be carried out at any stage of the AD process and the design should consider the best means of doing this. Typically, it would be done just before the feedstock enters the digester or just before the digestate enters the digestate storage tank. Careful consideration of the location of any pasteurisation unit is required within the design.

Thermophilic anaerobic digesters operating at temperatures of 50-60°C for the much longer digestion period of several days can also provide sanitation to comply with the Animal by-products Regulation. More details are provided in the Technology Guide, Section 4.12. The heat for the pasteurisation step or for operating at thermophilic temperatures is usually provided by the combustion of some of the biogas in a combined heat and power (CHP) unit.

Any digestate that has not met the Animal by-products Regulation requirements must be reprocessed or landfilled. If any digestate that does not meet the requirements has been stored on site, then the storage facilities may require cleaning, which would disrupt the facility operation.

4.5.3 Digestate outlet and application

Digestate outlets, which for farm-based AD almost exclusively means use as fertiliser on agricultural land, must be carefully secured so that there is enough land bank available to receive the expected volume of digestate.

Agricultural outlets should use the digestate in a controlled way so as not to cause pollution. There should be several outlets in case any become temporarily unavailable. Statutory Instrument No. 605 of 2017, Good Agricultural Practice for Protection of Waters[13] includes the rules which apply to the application of digestate to agricultural land. These limit the amount of digestate that may be applied according to:

- The nutrient content of the digestate;
- The nutrient content of the receiving field; and
- The nutrient requirements of the crop.

The rules limiting nitrogen and phosphorous are complex and depend on the crop grown. A fertiliser calculator is available from The Fertilizer Association of Ireland[14] and can be used to determine fertiliser applications. Specialist advice should be sought from a qualified farm advisor. An advisory service is also available from Teagasc.[15]

Additionally, digestate application is not permitted all year round and is prohibited for a lengthy period during winter months. For some areas of Ireland, this period extends from 15 October to 31 January (3.5 months). These limitations have an impact on the design of the AD facility (overall capacity of the facility and, especially, the size of digestate storage tanks).

Taking the same example as in Section 4.2.4.5 above, an agricultural AD plant processing 5,242 tonnes per year of cattle manure and 3,600 tonnes per year of grass silage (both with a dry solids content of about 25%), might generate about 10,000 tonnes per year of digestate at roughly the same volume (10,000 m^3), assuming the infeed is diluted with water to lower the infeed dry solids to 20% and about 10% of the mass is lost in the biogas. The digestate storage capacity therefore would need to be greater than 2,917 m^3 to manage the digestate over the period when no spreading can take place. This capacity is significantly larger than an anaerobic digester, which for a 30-day residence time in this size of plant, would need to be about 820 m^3.

4.5.4 Digestate quality

Control of the digestate quality in terms of its fertiliser nutrient content is limited. Therefore, regular monitoring of actual digestate quality is important for determining the fertiliser value of the digestate. This defines the application

[13] https://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/nitrates/2017/SINo605271217.pdf
[14] https://www.fertilizer-assoc.ie/p-k-calculator/calculator/
[15] https://www.teagasc.ie/about/farm-advisory/

rate that may be applied to each field as required by Good Agricultural Practice for Protection of Waters. These requirements need to be carefully considered as they differ depending on land use, crop type and existing soil quality.

For example, for grassland not used for grazing animals but for silage production only (as might be the case for a grass crop grown as an AD feedstock) the maximum annual available nitrogen application is 125 kg/ha for the first cut and 100 kg/ha for subsequent cuts. For the phosphorous (P) application, this depends on the existing P content of the soil (*Table 7*). For soils with a high existing P content (index 4) no further applications of P fertiliser, which would include digestate, may be applied.

Table 7: Maximum phosphorous fertiliser application rates (kg/ha) to grassland used just for silage production as amended by existing soil phosphorous content (P-index)

	P-index 1	P-index 2	P-index 3	P-index 4
1st cut	40	30	20	0
Subsequent cuts	10	10	10	0

Digestate quality may have to meet other specifications (for example, limits on microbial pathogens required for Animal by-products Regulation compliance).

The AD facility licence or permit may include additional requirements on digestate quality such as limits on the contents of contaminants: for example, heavy metals and materials such as plastics. Beyond this a landowner may wish to ensure that their land is not contaminated by these substances.

Other environmental issues may also affect aspects of the digestate quality, and the facility should, as far as possible, seek to anticipate these. For example, plastics and microplastics in the environment represent a risk and it is currently difficult to ensure that plastics are not present in digestate if the feedstock to the facility includes packaged retail food waste. Strict control of the feedstock quality is the main way to mitigate against the pollution of the digestate with plastic.

4.5.5 Digestate management costs

The costs of digestate management include capital and operating costs for:
- Digestate storage;
- Digestate treatment (pasteurisation, dewatering);
- Digestate quality monitoring;
- Outlet agricultural land quality monitoring;
- Digestate transport; and
- Digestate spreading.

Typically, although digestate is a valuable fertiliser and its use offsets the cost of buying fertilisers, it is usually an overall cost to manage.

4.6 Anaerobic digestion facility design

An outline concept for an AD facility is defined by considering the available feedstocks and their quality, storage and preparation, biogas production, quality and usage, and output digestate production and storage. This conceptual model should ideally be developed at as early a stage as possible to identify any key issues and see if there are any unsurmountable barriers that would mean the facility was not a feasible project.

4.6.1 Sustainability of the anaerobic digestion facility

It is important that the AD facility is designed to operate sustainably, maximising environmental benefits and minimising environmental impacts, at both the local and national level. Key aspects include:

- **Positive impact on greenhouse gas emissions**

AD can substantially mitigate current methane (CH_4) emissions from manure and other organic waste management. Extracting CH_4 from manure in an AD system and using it to produce renewable energy is far preferable in terms of greenhouse gas impacts than fugitive CH_4 emissions to atmosphere from the open storage of manures and slurries.

- **Contribution to national and local renewable energy**
  Biogas can increase renewable energy production: for example, the injection of biomethane to the national gas grid or its use as a vehicle fuel.

- **Benefits of recycling nutrients in organic wastes as fertiliser**
  Most of Ireland's agriculture is based on milk and beef production, which results in a net loss of nutrients from the soil as these are taken from the farm (that is, as meat and dairy products). Manures provide fertilisers for agricultural land, representing a saving on commercial fertilisers and partly offsetting the amount of nutrients taken off the farm. However, there is normally a net requirement for external chemical fertilisers. An AD system, if it imports additional feedstocks such as waste food materials onto the farm, will also import additional nutrients that can further offset the chemical fertiliser requirements.

- **Converting farmland from food production to energy crop production**
  Ireland aspires to increase agricultural output, particularly of milk and beef; together, these products account for about 70% of agriculture (Food Wise 2025[16]). To meet this goal, Ireland must ensure that the quality and fertility of soils is maintained. Digestate can play a significant role in this. On the other hand, the widespread conversion of farmland to produce energy crops would inevitably reduce the amount of land used for food production. These competing needs may need to be managed for a sustainable national approach.

These factors may be considered by the planning authority in assessing a planning application. Developing the project proposal to seek a positive sustainability outcome is therefore advised.

An important factor to consider is that producing crops such as grass silage as AD feedstocks involves significant greenhouse gas emissions from the fuels and agrochemical inputs used in their production, which is then mitigated to some extent by using the biogas to produce heat and electricity as a renewable energy source.

4.6.1.1 Complying with Sustainability Criteria

The revised Renewable Energy Directive (EU 2018/2001) sets a 70% threshold for greenhouse gas emissions savings from biomass fuels, which means gaseous and solid fuels produced from biomass.

Renewable Energy Directive II (EU 2018/2001)
The EU is committed to reducing greenhouse gas emissions by 2030 to 40% of 1990 levels as part of the 2015 Paris Agreement on Climate Change. As part of the strategy for meeting this target, the revised EU renewable energy directive (2018/2001/EU) aims at increasing the amount of renewable energy generated in the EU, setting a target for 32% of energy needs in the EU to be met by renewables by 2030. However, the EU recognises that renewable energy, particularly the production of biomass for bioenergy can create greenhouse gas emissions, both from fuels and agrochemical inputs used for cultivation and harvesting of the biomass and potentially from land use change triggered by cultivation of the biomass. The directive therefore specifies that new plants beginning operation after 2021 must achieve 70% greenhouse gas savings compared to heat and electricity produced conventionally using fossil fuels. This will rise to 80% from 2026. While these thresholds only apply to biogas systems above 2 MW capacity, Member States can choose to apply the criteria to smaller plants. In Ireland, the support scheme for renewable heat, for which biogas from AD is eligible, requires all biogas to meet these thresholds for sustainability.

[16] https://www.agriculture.gov.ie/foodwise2025/

SEAI's Sustainability Criteria Options and Impacts for Irish Bioenergy Resources,[17] as a best practice guide, advises that this threshold should be met for all on-farm AD facilities and how to calculate the greenhouse gas savings. The SEAI guide indicates that the cultivation and harvesting greenhouse gas emissions can be significant, especially if large volumes of synthetic fertilisers are used (and in particular nitrogen-rich fertilisers, since their application results in N_2O emissions from soil), which is 298 times more potent than CO_2 as a greenhouse gas). Greenhouse gas emission accounting for wastes as AD feedstocks start at the point where the feedstock is collected. Therefore, these supply chains can have very low emissions as there are no associated cultivation emissions.

Table 8 shows how this 70% threshold (see box above) can be met, for example, by a manure-based plant and a mixed feed plant using 40% silage and 60% wet manure (slurry), but not by a facility based only on grass silage. An AD system based solely on grass silage may generate a 43% and 30% greenhouse gas emission saving for heat and electrical energy respectively. This difference is largely because grass silage is a biomass crop where the significant greenhouse gas emissions from cultivation are included in the assessment. Manures are considered a waste and therefore register a positive contribution when emissions from the amounts of manure currently stored in slurry tanks are mitigated.

This threshold should then limit the extent that grassland is cultivated for the production of feedstock for on-farm AD facilities and encourage co-digestion with waste manures.

Table 8: Relative greenhouse gas savings from alternative AD feedstocks (extract from SEAI – Sustainability Criteria Options and Impacts for Irish Bioenergy Resources)

Feedstock	Biogas or biomethane?	Value (gCO_2eq/MJ)	Greenhouse gas emission saving (heat and electricity)	Key assumptions ('Central' scenario)
Grass silage	Biogas	60.5	43/30%	Yield of 89 t/ha (82% moisture content). 10 km transport from farm to digester. 8.129 MJ biogas/t dry input. 0.2 g CH_4/MJ biogas losses. Closed digestate system.
Wet manure	Biogas	-63.1	159/173%	90% moisture content. 10km transport from farm to digester. 6,477 MJ biogas/t dry input. 0.2 g CH_4/MJ biogas losses. Closed digestate system.
Grass silage and Wet manure	Biogas	25.4	76/71%	40:60 split (by weight). Closed digestate system.
Grass silage and Wet manure	Biomethane	19.2	71.8% – heat	40:60 split (by weight). Closed digestate system. Off-gas combustion (no CH_4 emitted from upgrading).

These values are a representation mixture, sites need to investigate their site-specific feedstocks and mixtures further.

4.6.2 Development of AD facility conceptual model

The scale of the facility should be informed by careful consideration of the sustainability aspects, feedstock sources and their characteristics, biogas use and quality, and digestate outlets and quality. The conceptual design should then be developed in more detail to define the size and type of equipment that would be part of a facility infrastructure that matches the outline scale.

[17] https://www.seai.ie/publications/Sustainability-Criteria-Options-and-Impacts-for-Irish-Bioenergy-Resources.pdf

Considerations include the size and design of the feedstock storage, feedstock preparation, type and size of tanks for the digesters and for digestate storage, the mixing method for the tank contents, emergency flare, biogas treatment and utilisation, and the site layout plan. This more detailed design concept should be made, refined and developed at the same time as other elements of the system, and become more defined during the feasibility study. The more detailed design concept also provides initial information on assessing the capital cost of the facility.

It is advisable that technical consultants are commissioned to undertake a more detailed design of the facility. AD facility suppliers may offer off-the-shelf designs that they have installed at several locations. These may however be of a particular set size and capacity that may not be suited to the particular site – if the design is too large, the facility is overdesigned; too small, and it will operate at throughputs beyond its design capacity.

AD facility design considerations:

- The generic AD type to be used (for example: wet or dry AD, mesophilic or thermophilic, 1-stage or 2-stage;
- The number, size, arrangement and detailed design of the anaerobic digesters and other associated tanks;
- The associated process units required for feedstock, delivery and storage, feedstock preparation, digestate treatment, pasteurisation and storage, and emergency flare requirements; and
- The infrastructure required for environmental protection and regulatory compliance.

Important aspects of the design include the number of anaerobic digesters and whether multiple tanks will be used in parallel or in series (see Section 4.1 of the Technology Guide). A smaller number of larger tanks may be cheaper but can reduce flexibility if a part of the AD facility is out of operation (for example, during maintenance). There are advantages to operating anaerobic digesters in series for farm-based AD facilities. It ensures the digestate is stabilised and has little residual biogas production during storage. However, this also means that the feedstock throughput rate may be less than if multiple tanks were used in parallel.

Most farm-based AD systems are based on wet AD. A dry AD system is only likely to be considered if the available feedstocks have particularly low moisture contents.

Farm-based AD systems are typically operated in either a continuous mode where feed is perpetually added to the digester, or a semi-continuous mode where fresh feed is added at set times during the day. A continuously fed system may include periodically filling a feed hopper system which then feeds the digesters continuously.

The decision to operate the digesters as either as a thermophilic or mesophilic system is key to the nature of the facility. Thermophilic AD systems (50-60°C) are often considered more productive (higher rates of biogas production) than mesophilic (30-40°C) systems but may be more prone to shocks to the microbial community. In practice, typical loading rates in terms of kilogram of loss of ignition per volume per day (LOI/m^3. d) are similar for either option and biogas production rates are therefore similar. Thermophilic systems kill off pathogens more effectively and can have the inherent ability to comply with the Animal by-products Regulation. Maintaining thermophilic conditions requires heat input from using some of the biogas produced as a fuel, for example in a combined heat and power (CHP) system. On the other hand, a mesophilic system does not usually require heating and can meet the Animal by-products Regulation if either the feed to the digesters or the digestate passes through a pasteurisation process. Therefore, similar heat input requirements may be needed for mesophilic processes to meet the Animal by-products Regulation.

The overall design concept should include measures that limit and control environmental emissions and visual amenity aspects. For example, capturing emissions from stored feedstocks, preventing leaks of liquids and gases (odours and biogas), bunding to contain leaks, noise from equipment and vehicles. These controls are important in ensuring that the sustainability target is met, and that the facility operates safely. Such controls may form part of the planning and permit consents for the facility.

Other design aspects also need to be conceptualised at this stage, including the overall site layout, preparatory groundworks, concrete footings, site drainage systems (including bunded areas), utility supplies, landscaping and access roads.

Detailed scale design drawings encompassing the whole site should be made as early as possible to give the envisaged layout, and its likely cost. In practice, it may be appropriate to consider more than one conceptual design, especially if there is still some uncertainty or multiple options in aspects such as feedstock availability and biogas usage.

4.6.3 Development of facility mass and energy balance model

Having considered the factors above, it should be possible to prepare a well-developed mass balance model for the AD facility. A mass balance model is a mathematical model of the process which considers and models the processing of the feedstocks through to biogas energy usage and digestate production. This should also include an energy balance covering the energy requirements of the facility and the energy generated from the biogas (including the parasitic energy requirements of the facility).

The mass and energy balance model should therefore consider:

- The mass of all the inputs and outputs of the facility;
- The processing of organic waste through the facility;
- The generation of biogas (for example, volume and energy content);
- The utilisation of the biogas, including types and amounts of energy generated, its usage within the facility and excess exported;
- The generation of digestate, its storage and transport for application to land; and
- De-packaging and other output waste streams, such as wastewaters, if generated.

The mass and energy balance model should model the path of the key feedstock parameters, such as dry solids, volatile solids, moisture, and major nutrients such as nitrogen and phosphorous through the whole process. The model predicts the volatile solids decomposition and conversion to biogas as a key prediction of the facility performance.

Initially a conservative estimate should be made of the facility's performance regarding biogas and energy yield from the proposed feedstock, and the sensitivity of the model to variances in feedstock quality (moisture, volatile solids, biodegradability and biogas yield) should be examined. It is also advisable to assess the limits and sensitivity of the financial feasibility of the conceptual facility design to variances in feedstock quality and the mass and energy balance model.

The factors discussed above should be reviewed, re-visited and refined in increasing detail to strengthen the mass balance and energy model.

4.6.4 Planning permission, permits and other consents and regulations

4.6.4.1 Planning permission

The Department of Housing, Planning and Local Government is responsible for the national administration of the planning service, planning policy and legislation. The planning system in Ireland is operated by local planning authorities. Technical planning staff in each local authority prepare recommendations on planning applications. The City or County Manager has the executive power to make the final decision.

The legislation setting out Ireland's planning process is the Planning and Development Act and the detail is set out in the Planning and Development Regulations. These key pieces of legislation set out the following:

- Procedures for applying for and obtaining planning permission;
- Special requirements for protected structures;
- Conservation areas and areas of special planning control; and
- The development plan process, at local and regional levels.

This legislation also provides a structure to planning and development contribution fees, defines the types of development that are exempt from the planning process, and governs the operation of An Bord Pleanála, Ireland's planning appeals body.

Applications for strategic infrastructure, as defined by the Planning and Development (Strategic Infrastructure) Act 2006, can also be made directly to An Bord Pleanála. In such cases, the local planning authorities do not determine whether planning permission is granted, although they are consulted during the consent process.

Proposed developments for AD facilities require planning permission from the relevant local authority or, in cases where the development application relates to strategic infrastructure, directly from An Bord Pleanála.

Proposed developments exceeding certain thresholds, as set out in the amended Environmental Impact Assessment Directive (2014/52/EU), require an environmental impact assessment to be carried out as part of the planning process. In such cases, the assessment is passed to the Environmental Protection Agency (EPA) for consultation, as part of the application process.

In general, the requirement for environmental impact assessments applies to an AD facility with a capacity of 25,000 tonnes per annum or higher, but this should be confirmed with the local planning authority at the pre-planning or pre-application stages on a case-by-case basis, as other factors are also taken into account, such as meeting the 70% greenhouse gas emission saving sustainability criterion, existing activities on site, nearby (cumulative) activities or the sensitivity of the location of the proposed facility, in which cases the planning authority or the EPA may request a sub-threshold environmental impact assessment.

4.6.4.2 Anaerobic digestion facility permit requirements

In addition to planning permission, all AD facility operators require consent to operate in the form of either a permit from the local authority or a licence from the EPA. The capacity of the plant determines whether a permit or a licence is required.

- **Local Authority Waste Facility Permit**
  Under the Waste Management Act 1996 as amended, and the Waste Management (Facility Permit and Registration) Regulations, 2007,[18] as amended, a facility that accepts up to 10,000 tonnes per annum biowaste (and does not exceed 6,000 m^3 of biowaste or digestate in storage at any time) requires a Waste Facility Permit issued by the relevant local authority. Waste Facility Permits are generally issued for a period of five years. Permits may be renewed through the review process. A review may also be initiated by the permitting authority.

- **Environmental Protection Agency Industrial Emissions Licence**
  Any AD facility proposing to accept over 10,000 tonnes per annum of waste must apply to the EPA for an Industrial Emissions Licence. Licences are issued under the Environmental Protection Agency Act of 1992 and the Environmental Protection Agency (Industrial Emissions) (Licensing) Regulations, 2013.[19]

Early communication with local government and the EPA is required to identify concerns that need to be considered for obtaining planning or permitting consents as they may have significant impact on the design of the facility.

4.6.4.3 Animal by-products Regulation

The objective of the Animal by-products Regulation (EC 1069/2010)[20] is to ensure that all meat and other products of animal origin processed by waste treatment technologies such as AD, meet specific treatment standards for destroying potential pathogens, to reduce and eliminate, where possible, the risk of spreading disease. There are three categories of animal by-product, depending on the risk level for containing pathogens. Category 1 is the highest risk and category 3 the lowest.

[18] http://www.irishstatutebook.ie/eli/2007/si/821/made/en/print
[19] http://www.irishstatutebook.ie/eli/2013/si/137/made/en/print
[20] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009R1069

Typical Animal by-products Regulation categories for AD feedstocks

- Category 2 – Animal manures.
- Category 3 – Catering waste, domestic food waste, supermarket out-of-date meat, used cooking oil.
- Non-animal by-product – silage, plant crops, meat-free waste food (for example, food manufacturing waste streams such as waste dough or chocolate), wastewater treatment plant sludge (for example, sewage and dairy sludge).

Under the Animal by-products Regulation, AD plants processing animal by-products require approval from the Department of Agriculture, Food and the Marine.[21] The approval conditions for an on-farm AD facility depend on whether the facility feedstock comprises animal by-products produced on 'own farm', or not. The key guidance notes are:

- CN9 (conditions for approval and operation of on-farm biogas plants transforming own animal by-products – type 9 biogas plants);[22] and
- CN11 (approval and operation of biogas plants transforming animal by-products and derived products in Ireland).[23]

The approval of an animal by-product plant is a two-stage process. The first stage relates to the design of a plant, when the Department agrees in principle to the design. The second stage begins once the plant is constructed. The Department validates the plant once all the procedures and hazard and critical control points are in place. The timeframe for the process is on a case-by-case basis. However, to speed up the process the Department recommends that plant developers engage with them as early as possible.

Farm AD plants that use animal manures only and where the digestate is used on the same farm as the manure, may not require Animal by-products Regulation certification. If the facility accepts other animal by-product feedstocks, however, it does require certification. Several facility certification types are available and the correct one to apply for should be clearly understood. The Animal by-products Regulation influences the design of AD facilities, because the feedstock or digestate must have been processed by pasteurisation under the following conditions to be compliant:

- Have a maximum particle size of 12 mm before entering the pasteurisation unit; and
- Be treated at 70°C for a minimum of 60 minutes.

Additionally, the design must ensure that there is minimal risk of the treated and pasteurised digestate being re-contaminated with untreated feedstock. This requires separation of 'clean' and 'dirty' areas within the facility design. The Animal by-products Regulation restricts the use of the digestate: livestock grazing and cropping animal feedstuffs, such as hay or silage, cannot take place within 21 days of applying the digestate to the fields.

4.6.4.4 Movement of waste

Other waste management regulation also applies to any facility, in addition to those associated with the site licence or permit. The movement of waste is regulated and controlled by the Waste Management Act 1996, as amended, and related regulations. To transport waste point-to-point within Ireland, a waste collection permit is required from the National Waste Collection Permit Office.[24] The EPA does not regulate the movement of waste.

Waste Collection Permits are required by carriers bringing wastes to the facility (for example, if wastes such as out-of-date retail food waste are used as feedstock) and taking wastes away (for example, packaging waste from food waste de-packaging).

The movement of waste into and out of Ireland is regulated by the National Transfrontier Shipment of Waste Office[25] under the Waste Management (Shipment of Waste) Regulations 2007.

[21] https://www.agriculture.gov.ie/agri-foodindustry/animalbyproducts/
[22] https://www.agriculture.gov.ie/media/migration/foodindustrydevelopmenttrademarkets/animalby-products/applicationformsconditionsforabpprocessingoperations/conditionsforms/CN9160916.pdf
[23] https://www.agriculture.gov.ie/media/migration/foodindustrydevelopmenttrademarkets/animalby-products/applicationformsconditionsforabpprocessingoperations/conditionsforms/CN11ApprovalOperationBiogasPlants200617.pdf
[24] http://www.nwcpo.ie/
[25] http://www.dublincity.ie/main-menu-services-water-waste-and-environment-waste-and-recycling/national-tfs-office

4.6.4.5 Land use and soil protection

Statutory Instrument No. 605 of 2017, European Regulations, Good Agricultural Practice for Protection of Waters includes the rules that apply to the application of fertilisers, including digestate to agricultural land. These rules are in place to mitigate the risks of pollution from the use of fertilisers.

Some key points are listed below.

- Fertiliser application rates are made to match crop nutrient requirements so that no excess nutrients are applied that might overflow and cause pollution. This entails an understanding of the nutrient content of the digestate, the nutrient status of the intended outlet soil and the fertiliser requirements of the intended crop. The Agricultural and Food Development Authority has an online nutrient management planning software model for determining fertiliser application rates.[26]

- Rules for how, and under what conditions, the digestate may be applied to agricultural land. This includes avoiding applications on sloping fields, in adverse weather, and in the vicinity of potable water sources.

- Limits on the overall amount of nitrogen (N) and phosphorous (P) that may be applied from organic and inorganic fertilisers. As digestate contains N and P, care is required. Repeated applications of digestate for its N fertiliser value might raise soil P contents enough to limit further applications of digestate. If the digestate outlet land area or application rate was reduced, this might cause issues with the continued operation of an AD facility. The limits affect both digestate application rates and the land area required for the digestate produced. Reliance on a limited land area can result in having to reduce the AD throughput at times.

- The timing of the digestate applications are restricted so that applications are not permitted for about three months during the winter. This means that the design should provide enough digestate storage capacity for all the digestate produced during this period.

4.6.4.6 Emission controls to air

An AD facility is a source of air emissions. Facilities are likely to have air emission control requirements, plans for investigating and remediating air emissions, and monitoring and emission limits imposed as part of their licences or permits. These requirements also influence the design of the facility. For example, the licence or permit may require that air from facility buildings, displaced by the filling of tanks, is collected and treated prior to discharge to atmosphere. A key factor in achieving greenhouse gas reductions is to ensure that fugitive emissions of CH_4 from the facility are minimised.

Typical AD facility emissions to air:

- Biogas can give rise to fugitive Methane (CH_4) and ammonia (NH_3) emissions from leaks in the processing stages and from the open storage of digestate;
- Odours can be a nuisance to neighbours and a source of complaints; and
- SO_2, NO_x and unburnt CH_4 from the emergency flare and biogas combustion units, such as boilers and combined heat and power (CHP) plants.

4.6.4.7 Emission control of wastewater

An AD facility involves large quantities of digestate being stored in tanks and transferred in pipes. This poses a risk of significant spillages that need to be contained to avoid adverse environmental impacts, especially the pollution of surface and ground waters. The facility design may therefore feature appropriately sized, sealed bunded areas to house tanks that can contain any spillages. Such requirements may also be part of planning consent, permits or licences.

The site may also generate contaminated wastewaters that need to be treated before disposal, unless they are suitable for use as liquid fertiliser or can be recycled in the process as dilution water for incoming feedstock. Excess wastewaters may be discharged to sewers for treatment, transferred by tanker to a wastewater treatment works, or treated on site if they are to be discharged into surface water.

[26] www.teagasc.ie/environment/soil/nmp/

The AD facility design should therefore consider water volumes and water management as part of the design, especially regarding the moisture contents of feedstocks and digestate, and the potential excess wastewater.

Discharges of water from AD facilities are controlled as part of the licence or permit.

4.6.5 Health and safety

The main health and safety legislation (the Safety Health and Welfare at Work Act 2005[27]) imposes a key duty to provide a safe working environment. Health and safety considerations are described in detail in Section 2 of the AD Operations and Maintenance Guide.

Health and safety should be incorporated into the design of the facility, including design features that allow safe operating and maintenance of the plant (refer specifically to Section 2.3.1 of the Operations and Maintenance Guide).

Each project is required to appoint a project supervisor for the design process whose role includes identifying hazards arising from the design, ensuring they are mitigated, and managing health and safety during the construction of the facility.

4.7 Economic and financial assessment

A crucial aspect of AD facility design is to review the commercial feasibility of the project for each design option. An associated financial model, incorporating technical assumptions as they are developed, allows the financial assessment to keep track and become more precise as the project design develops.

Early cost estimates of key aspects should be determined, and these should consider the economics required over the expected whole project lifetime, where an AD facility is expected to operate over an extended time period with the facility main equipment lifetime, typically at least 20 years. This requires some prediction of the likely changes in costs and revenues over long periods and periodic major maintenance or replacement events. Ultimately, financial assurance is needed that the revenues will exceed the costs by the margin required by the investors.

Typical AD facility economic and financial considerations:

- Costs and of generating farm-derived feedstocks compared with costs and revenues of using the land for other farming options;
- Revenues from gate fees for processing imported wastes;
- Capital cost of the facility;
- Operating costs for each process unit including spare parts and major overhauls;
- Operating costs for ongoing external supports, such as specialist advisors and plant maintenance contractors;
- Revenues from the sale of biogas-related outputs such as heat, electricity and biomethane;
- Potential cost savings and revenues from the use of digestate;
- Costs of digestate management;
- Repayment of project finance;
- Capital or lease costs of land;
- Insurance payments; and
- Maintenance of consents and agreements, including legal costs.

4.7.1 Capital costs

It is important to establish likely capital costs on a conceptual design, covering all aspects, including groundworks, landscaping, buildings and roadways, as well as the process units themselves.

[27] http://www.irishstatutebook.ie/eli/2005/act/10/enacted/en/print

4.7.2 Advisor and testing costs

When considering costs, it is important to take into account the costs of any technical, financial and legal advisors required for the project, this may be throughout the project lifetime (for example, testing the biodegradability and applicability of new feedstocks, and maintaining agreements such as feedstock contracts).

4.7.3 Feedstock costs

The costs of many own-farm waste-based feedstocks, such as manure, should be negligible. There are costs to the farm of producing its own energy crops such as grass silage. The economic assessment needs to consider the cost of using the land to produce feedstock crops for an AD facility compared with other agricultural uses of the land, for example land rental. The production of AD feedstock crops may present an opportunity if the current land use is not making significant revenues or even operating at a loss.

It might be costly to import external wastes onto the farm, although the farm can charge a gate fee, especially if it offers a disposal route that costs less than where the waste is normally directed.

There may be additional costs associated with feedstock preparation, for example, if whole grain is milled and additional nutrients are used to enhance the microbial activity.

4.7.4 Operating and maintenance costs

The costs associated with the operation and maintenance of the whole facility should be defined. This includes manpower, fuel, water, electricity (if biogas is not used to produce this) and gas services, maintenance contracts, spare parts, and the purchase of consumables; and may be carried out through an operating and maintenance contract.

Some facilities require period shutdowns for major maintenance overhauls such as clearing settled grit from tanks and scheduled parts replacement. This may mean disruption to normal operations for several weeks.

Further information is provided in the Operation & Maintenance Guide.

4.7.5 Costs for managing the digestate

This may include transport and analysis costs and advisor costs for digestate users. If digestate is taken off site, the users may be responsible for transporting the digestate themselves, and there might even be an opportunity to generate revenue from the sale of digestate once the market, and the agricultural benefit, is established.

4.7.6 Avoided fuel costs and revenues from excess biogas utilisation

The production of biogas is an opportunity for the farm to generate its own renewable energy and avoid fuel costs for both farm operations and other uses, for example, electrical, gas, oil and maybe vehicle fuel costs.

The excess biogas may then be exported (in whatever energy form), providing an additional income stream for the farm. This revenue over the lifetime of the project is most likely a key factor in the financial assessment.

4.7.7 Renewable energy incentives

This assessment should cover any fiscal incentives to encourage renewable energy in Ireland. It is crucial to consider the duration of these incentives.

4.7.8 Loan servicing

If borrowing is required, then due consideration should be given to the repayment of the loan, based on the repayment period and the interest rate. This should ideally be made at a level that provides little risk to the farm of the loan not being serviced comfortably by the returns from the facility. Caution is therefore required when making assumptions about the facility performance, a key factor in determining what excess biogas may be generated and the resulting income from its sale. Borrowing may require the project's technical and financial model to be closely scrutinised by independent experts on behalf of the lenders.

4.7.9 Financial liability provision

A further financial consideration is a requirement for financial provision to cover the cost of potential liabilities. The amount of this provision must be agreed with the permitting authority and hence early communication on this subject is recommended.

Required Liability Provision

All operators of AD facilities, whether permitted or licensed, are required to have financial provision to cover the cost of the environmental liabilities that may arise as a result of the operation of the facility.

4.7.10 Pre-contractual agreements

Discussions with feedstock suppliers, energy users and digestate outputs should be made as clear as possible with pre-contractual supply agreements and agreed plans should be as firm as possible. These should indicate any quantities, specifications, and costs so that they can be used with some confidence within the feasibility assessment. Such pre-contractual agreements provide increased certainty on assumptions that feed into mass balance and energy models and into economic and financial models in regard to predictions about the facility performance, amounts of facility outputs and the rates of return likely from excess biogas and other on-farm savings, for example reductions in fertiliser costs.

Competition for resources may mean that, for example, assurance for external feedstock supply cannot be secured from potential suppliers and this insecurity should be accommodated within the design. The provision of pre-contractual agreements means that key aspects of the future facility are secured to the extent that the development can proceed at minimal risk.

5. Project development

5.1 Introduction

Once an agreement is reached about the project's technical and commercial feasibility, the project is ready to proceed, subject to due diligence by any interested parties such as investors. Plans for the project development should then be firmed up. The following describes an approach for the procurement and construction of the AD facility.

This should be read with Section 4 of the Operations and Maintenance Guide, which describes plant start-up, picking up from construction completion and addressing plant commissioning, acceptance testing, and ramp-up to full operations.

It is also important to maintain proactive communications during this period, keeping all stakeholders (local people, local authority, banks or other finance bodies and project partners) informed of the progress and activities occurring, especially when it comes to the construction phase.

5.2 Procurement

The selection of a lead contractor and the equipment suppliers is a key stage. These parties may have been pre-selected and have been part of the development team during the feasibility assessment and design process. However, to access the wide range of AD technologies and associated equipment available, maintaining independence from equipment suppliers up to this point is advisable. A competitive tendering process would then be undertaken, as described in the following sections.

5.2.1 Design and build

For example, you may consider a 'design-and-build' contract for your AD facility. Design-and-build arrangements come in various forms but typically the contractor takes responsibility for design and construction. There are several benefits to this, which include:

- Possible reduction in delivery time, as there can be an overlap of design and construction;
- The possibility of obtaining a guaranteed maximum price for the design and build of the facility, providing financial certainty;
- A single point of responsibility for the design and build, which can minimise communication channels;
- Ease of arranging changes in the design; and
- The transfer of contractual rights and obligations from one party to another by a novation agreement, (that is, the design team develops the design, which is then novated to the contractor who takes the design responsibility and then constructs the facility).

However, there are some potential disadvantages to the client (owner) in this process, which include:

- Some contractors can compromise on design (for example, use low quality components) to meet the budgeted price, therefore placing a greater responsibility on the owner to carefully detail all requirements, although not to the point of effectively providing the design; and
- Any design changes will have cost and time implications, reducing flexibility.

There are numerous variations around design-and-build contracts, including:

- Design-build-warranty, which combines a warranty provision with design-build; and
- Design-build-maintain which combines maintenance provisions with design-build.

If you do not use a formal competitive tendering approach, take note of the essentials of procurement, as there are elements that might be usefully applied. Note that when operating an AD facility, if you haven't procured a design-build-maintain contract you may require an alternative operations and maintenance contract, for which the principles of competitive procurement can also be followed.

5.2.2 Engineering, procurement and construction contracts

Engineering, procurement and construction, or 'turnkey' contracts, are similar to design-and-build contracts, in that there is a single contract for the design and construction of the project, but generally with an engineering, procurement and construction contract, you will have less influence over the design of the project and the contractor takes more risk.

The engineering, procurement and construction contractor will carry out the detailed engineering design of the project, procure all the equipment and materials necessary, and then construct and deliver a functioning facility. A turnkey contract is an agreement under which a contractor completes a project, then hands it over in fully operational form to the client, who needs to do nothing but 'turn a key' to start it working.

To ensure the facility performance is as expected when handed over; a programme of specific acceptance testing is advised.

5.2.3 Developer route

This may take some form of partnership between the farmer, a developer (who may also become the plant operator) and one or more investors (one of whom may be the farmer). It generally requires setting up a legal entity under company law, known as a special purpose vehicle. Depending on the details, the farmer may provide the land for the facility, most of the feedstocks, have a contract with the special purpose vehicle, and a shareholding in it. Typically, a memorandum of association, articles of association, and a shareholders' agreement will be required.

5.2.4 Competitive tendering

If involving competitive tendering, aim to get the best from the tendering process by:

- Treating suppliers fairly and using a transparent process and a level playing field (see, for examples, the RICS Guide);[28]
- Encouraging innovation to drive the market to meet targets and objectives, particularly in improvements for waste management, environmental performance and sustainability criteria;
- Ensuring that risks are managed by those most suited to do so, by transferring appropriate risk, for example, facility performance guarantees and risks from under-performance should rest firmly with the contractor;
- Balancing the bidders' price with the quality of bidders' proposed solution (the cheapest bid may not necessarily be the best technical proposal); and
- Ensuring sufficient system flexibility to meet current and future (long-term) requirements, complying with legislation and regulation over the life of the project, and minimising the risk of project failure from technical, financial and legal aspects.

Technical, financial and legal advisors can play an independent supporting role in preparing tender documents and selecting the appropriate technology supplier.

Before preparing or commissioning any contract documents, review and assess the more detailed requirements of the services you intend to tender. This will provide you with the information and data needed by potential bidders as well as enabling you to identify any gaps that need addressing.

5.2.5 Tender documents

Whether you are procuring a contract for a technology, a service, or maintenance supplier, it will typically include:

- Contract conditions
- Contract specification
- A service delivery plan (or method statements)
- A performance framework
- A payment mechanism.

The tender documents and instructions to bidders should then reflect these contractual elements so they can be incorporated into the contract with the successful bidder.

5.2.5.1 Contract conditions

The conditions of contract include 'general conditions' that are common to all types of contracts, and conditions that are specific to individual contracts (for example, contract change conditions, payment conditions, variation and

[28] https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/sector-standards/construction/black-book/tendering-strategies-1st-edition-rics.pdf

termination provisions). Legal advice should be sought to ensure that the conditions of the contract are tailored appropriately to what is being procured.

5.2.5.2 Specification

The contract specification defines the services required from the provider and sets the technical requirements, standards and performance of any facility or service for the term of the contract. This will have evolved from the conceptual modelling and feasibility studies.

The specification can be either input or output based, or a combination of the two.

- An **input-based specification** involves the owner preparing the precise contractual requirements that detail how the service should be conducted. These transfer less risk to the contractor but require the owner to have a detailed understanding of how the services will be carried out.
- An **output-based specification** allows the contractor more flexibility to optimise proposals because it specifies the desired performance outputs without describing how the contractor should meet them. Where an output specification is used, risk transfer to the contractor is increased.

5.2.5.3 Service delivery plan

The service delivery plan describes how the bidder shall deliver the services in accordance with the contract and, in particular, the specification.

Typically, bidders are required to submit a comprehensive service delivery plan as part of their tender, which is used in part to evaluate their bid. Depending on the services sought, service delivery plans may include:

- Design
- Planning and permitting
- Construction
- Commissioning and testing
- Deliverability and continuity
- Mobilisation
- Reception and transfer
- Transportation and logistics
- Requirements for the facility
- Diversion, recycling and energy targets
- Service management
- Monitoring and reporting
- Markets and disposal
- Contingency
- Health, safety and welfare
- Sustainability and carbon management
- Liaison and external communications
- Expiry and termination.

The specification and the service delivery plan will be the baseline reference documents for ongoing contract management. Disputes are usually based on these and therefore they should be scrutinised for loopholes by the legal advisor.

5.2.5.4 Performance framework

The performance framework is set up to ensure that a contractor undertakes the service in accordance with its contractual obligations. It applies to the design, construction, commissioning and acceptance testing of the facility. If the operation of the facility is being contracted out rather than handed over to the owner to operate, it would also apply to the performance to be achieved by the contractor over the period of the contract and define how this would be measured.

5.2.5.5 Payment mechanism

The payment mechanism sets out how a contractor shall be paid for delivering the facility and services. The structure of the payment mechanism will be governed by the contract requirements and its complexity linked to the term of the contract.

5.2.6 Tender evaluation

The tender documents should indicate criteria that would be used to assess bids. A scoring matrix with different weightings and points for different aspects of the bid may be considered, although the scoring method should be made clear to bidders. A scoring matrix, however, may become over-complicated if it is not well constructed, and lead to a focus on scoring highly in selected aspects of the bid rather than a total solution.

5.3 Detailed sizing assessment and system design

Once selected, expect the commissioned installer and supplier to develop a detailed design based on the specification and service delivery plan. This should then be evaluated against a checklist of required features drawn from the conceptual design, the contractual specification, and the services delivery plan. Technical advisors may be best placed to comment on any departures from the conceptual design proposed at this stage by suppliers.

Care should be taken to ensure that any detailed design does not result in a loss of flexibility to the facility that might affect its future robustness in a changing working environment. During the detailed design stages, cost-saving incentives often lead to a simplification of the design. Any such cost savings should be assessed against the loss of options for plant operation in the future – for example ruling out the possibility of using certain feedstocks.

Particular aspects may require firming up, including those not covered in sufficient detail during the conceptual design and procurement submissions due to the lack of certainty in the development. These aspects may be associated with peripherals to the main AD facility. The buyer should ensure that, through the contractual provisions, they are protected from any escalation of capital costs from a more detailed design.

5.4 Detailed financial assessment

Alongside the detailed design it should be possible to provide a detailed financial assessment with predicted revenues. This would be updated as the feasibility study defines the project with increasing certainty.

5.5 Planning, environmental and other regulations

Steps should be taken early to obtain the appropriate planning and environment permits and consents. This should be done far enough in advance that any specific requirements imposed by the regulators can be introduced into the detailed facility design (that is, before the 'design freeze').

5.6 Development mobilisation plans

The lead contractor should be required to provide a contractually binding mobilisation plan for the installation, commissioning, acceptance testing and handover of the facility. This should include timescales that do not compromise the feasibility of the project.

Contractual penalties should be clear and indisputable, to avoid legal disputes if failings in the installation programme or performance occur.

5.7 Construction

5.7.1 Contracting suppliers

A further aspect to consider is the timescales for the development. Adequate time should be given, so that sufficient planning and a robust feasibility study may be carried out before commitment. However, timescales for delivering the project need to be factored in.

When developing a timeline for the project, all key stages, milestones and pinch points on which the timescale is dependent should be identified.

Once the design is established, the installers selected, and all necessary consents obtained, the project can proceed through construction to operation.

5.7.2 Construction

Installation is a key step that should be monitored on the buyer's behalf to ensure that the facility is being constructed according to the agreed design and that no mistakes are made. It is probably best that an independent certifier monitors the construction, to ensure aspects such as equipment and materials are used as specified. The independent certifier should also have the role of signing off the facility when it is ready to start processing feedstock (is ready to undergo commissioning and testing – refer to the accompanying Operations and Maintenance Guide, Section 5).

5.8 Commissioning and acceptance testing

Once built, the facility is commissioned. This is normally undertaken in three stages outlined in a commissioning plan. This plan is usually produced by the contractor and agreed with the owner. It defines what testing will be carried and to what timescale. It is advisable that commissioning be monitored by an independent certifier whose appointment is agreed by all parties and who would certify that commissioning tests have been passed.

5.8.1 Cold commissioning

This would normally include testing before the facility receives any waste. It includes ensuring all the equipment and infrastructure is as specified, and has been installed correctly and safely, and that it works. Typically, cold commissioning would culminate in a 'readiness certificate' showing that the facility is ready to receive actual feedstock and begin hot commissioning.

5.8.2 Hot commissioning

Hot commissioning then involve testing and optimising the facility with actual feedstock. The process usually takes several weeks or months after a cold commissioning and typically involves increasing the feedstock loading rate and fully testing all parts of the facility under operational conditions. During hot commissioning the objective should be to optimise the process so it can efficiently receive its specified input feed throughput and operate at the guaranteed performance. During this process the owner may have obligations for the supply of substrate, and, in the event of commissioning being delayed, should have protection in the contract for any costs associated with the production of feedstock that might not then be used. Hot commissioning should culminate in acceptance tests that demonstrate the facility performance is as required.

5.8.3 Acceptance testing

Hot commissioning should ideally culminate in acceptance tests wherein, over a defined period, the facility is operated as intended and its performance closely monitored and evaluated against agreed parameters. Usually the decision of when to take the tests rest with the contractor, although the contract should have contractual long-stop dates to prevent this being open ended.

The tests should not just be for AD performance, such as biogas production, but also demonstrate the reliability of the equipment and compliance with environmental requirements, for example, noise levels, digestate quality, odours and gaseous emissions. Passing these tests is ideally confirmed via an independent certifier who provides an acceptance test certificate. Once the test has been passed, the facility can be transferred to the owner.

5.9 Handover

As part of the final handover the owner should ensure they receive the required documentation so that they can independently operate the facility.

5.9.1 Operating manuals

A full set of operating manuals for the facility equipment should be provided, accompanied with 'as built' design drawings and process control philosophy documents. These documents should describe the principles of the process, the operation and maintenance of the plant, and how to respond when the performance is not as it should be.

5.9.2 Maintenance

A full set of maintenance plans should be provided, especially those required by equipment suppliers to maintain warranties. Maintenance may require specialist external maintenance sub-contracts to be made (for example, for combined heat and power (CHP) maintenance).

5.9.3 Warranties

Equipment should have suitable warranties and expected lifetimes provided by the suppliers. These are important for an operator to avoid costs associated with defects in the equipment arising within their expected lifetime. Such warranties, however, are often conditional on the maintenance being carried out by recognised contractors and in full accordance with the suppliers' maintenance manuals.

5.9.4 Training and post take-over support

In a design-and-build contract there should be a provision that states that the suppliers and commissioning parties provide suitable training to the ultimate operators of the facility. This should extend to providing support following take-over. This provision should be contractually binding.

5.10 Ongoing performance monitoring

Following take-over, the owner should undertake routine testing to ensure a satisfactory ongoing performance. Over time, the owner may need to adjust and amend operations, and should seek to develop a full understanding of the capabilities of their plant and what can be achieved without risking its smooth operation and performance. Some on-site testing might be carried out to provide rapid monitoring and a rapid response for corrective operational changes. The monitoring should include aspects of environmental performance as well as process performance.

Some aspects to monitor include, but are not limited to:

- Feedstock quality and tonnages stored and used;
- Feedstock storage conditions and associated emissions;
- Emergency alarms and usage of the emergency flare;
- Digester operation, including biogas pressures in the headspace;
- Composition and quality of the digestate;
- Performance records of any pasteurisation unit, if compliant with the Animal by-products Regulation;
- The structural integrity of all the equipment, especially of the tanks and pipelines;
- Performance of any biogas utilising equipment and its yield of energy;
- Integrity of the facility with respect to small biogas leaks from equipment and digestate storage;
- Soil quality and productivity of the fields receiving digestate; and
- Complaints from the public, for example, about noise, odours, or vehicle movement disruption.

6. References and other sources of information

- ADBA, 'Best Practice Checklists'.
  Available at: http://adbioresources.org/our-work/best-practice-scheme/best-practice-checklists/

- ADBA, 'Voluntary guidelines on best practice for crop feedstocks in anaerobic digestion'.
  Available at: http://adbioresources.org/library/crop-best-practice-document

- ADBA, The Practical Guide to AD (A comprehensive guide from the UK Anaerobic Digestion and Bioresource Association)
  Available at: http://adbioresources.org/library/purchase-the-practical-guide-to-ad/

- DAFM, 'Food Wise 2025: A ten year vision for the Irish agri-food industry'.
  Available at: https://www.agriculture.gov.ie/media/migration/foodindustrydevelopmenttrademarkets/agri-foodandtheeconomy/foodwise2025/report/FoodWise2025.pdf

- DCCAE, 'Draft Bioenergy Plan'.
  Available at: https://www.dccae.gov.ie/en-ie/energy/topics/Renewable-Energy/bio-energy/Pages/Bio-Energy.aspx

- IEA Bioenergy, 'Biogas from Energy Crop Digestion'.
  Available at: http://www.iea-biogas.net/files/datenredaktion/download/energycrop_def_Low_Res.pdf

- 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, '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, reactor) in which anaerobic digestion 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.
Biomethane	Methane product produced by separating methane from biogas.
Boiler	Equipment for heating hot water or producing steam.
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 usable 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)	The material remaining after drying (moisture removed) at about 100-105°C and typically expressed as a percentage of the wet weight. Sometimes also referred to as dry matter.
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 (that 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.
Gas engine	Reciprocating engine designed to run on a gaseous fuel, such as biogas or natural gas.
Loss on ignition (LOI)	See 'Organic matter'.
Organic matter (OM)	The carbonaceous matter typically expressed as percentage of the dry solids. Measured by weight loss of dry matter during heating in air at 450-550°C. Also sometimes referred to as volatile solids and loss on ignition.
Volatile solids (VS)	See 'Organic matter'.

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Rialtas na hÉireann
Government of Ireland

Sustainable Energy Authority of Ireland
Three Park Place
Hatch Street Upper
Dublin 2
Ireland
D02 FX65

e info@seai.ie
w www.seai.ie
t +353 1 808 2100

@seai_ie