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Digestate Management Options for Northern Ireland

Prepared for Action Renewables, Phoenix Energy, Firmus Energy & Evolve

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NNFCC is a leading international consultancy with expertise on the conversion of biomass to bioenergy, biofuels and biobased products.

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Definitions

AD	Anaerobic digestion
ADQP	Anaerobic Digestion Quality Protocol
BCS	Biofertiliser Certification Scheme
BtG	Biomethane to grid
CAPEX	Capital expenditure
CfE	Call for evidence
CH_4	Methane
CHP	Combined heat and power
CNG	Compressed natural gas
CO_2	Carbon dioxide
CoGAP	Codes of Good Agricultural Practice
DAERA	Department of Agriculture, Environment and Rural Affairs
DNO	Distribution Network Operator
DS	Dry solids
EA	UK's Environment Agency
EoW	End of waste
EU	European Union
GB	Great Britain
GGSS	Green Gas Support Scheme
GHG	Greenhouse gas
JRC	Joint Research Centre
LNG	Liquid Natural Gas
NAAC	National Association of Agricultural Contractors
NAP	Northern Ireland Nutrient Action programme
NI	Northern Ireland
NPK	Nitrogen, phosphorous & potassium
NVZ	Nitrate vulnerable zone
OPEX	Operating expenditure
PAS 110	Publicly Available Standard 110
RfI	Request for Information
RHI	Renewable Heat Incentive
RTFO	Renewable Transport Fuel Obligation
SBRI	Small Business Research Initiative
TWh	Terawatt hours
UK	United Kingdom
WFD	Waste Framework Directive

1. Executive Summary

This report outlines the key elements that should be considered in order to effectively manage and valorise digestate in Northern Ireland ahead of an expected period of growth in biomethane capacity.

Digestate exhibits high concentrations of nutrients, meaning that it is typically used as a fertiliser – most commonly applied to agricultural land as an alternative to synthetic fertilisers to aid crop production. However, it is well reported across Northern Ireland that the region faces significant challenges in relation to nutrient pollution, a problem caused primarily by excess nutrients from agricultural activity and wastewater treatment, combined with climate change and associated weather patterns, according to the Department of Agriculture, Environment and Rural Affairs (DAERA). With this in mind, it is evident that the most common industrial use of digestate, as an agricultural fertiliser, is not necessarily well suited to a region like Northern Ireland. It is therefore necessary to explore other possible uses of this material in order to ensure that it is consumed in the most effective and responsible way, according to where and how it is generated, as well as understanding its interaction with the existing slurry and manure volumes being generated and spread to land. Potential applications of digestate, other than for use in agriculture, include: horticulture, landscaping, mushroom growing media, forestry, construction materials, cellulosic ethanol production, fuel pellet production and biochar production. These alternative applications offer a positive and timely opportunity for Northern Ireland, to enable the removal of excess nutrients from the agricultural system, whilst at the same time offering low carbon, renewable gas and additional economic and social benefits. Growth of biomethane capacity should therefore be seen favourably, with potential to deliver a multitude of benefits and stimulate investment in nutrient management which would otherwise not happen.

Some of the primary challenges identified with regards to the management and use of digestates in general stem from regulations relating to waste and the spreading of fertilisers to land, as well as challenges concerning the perceived quality and potential of this material on the market. Digestate is typically used as a biofertiliser because it is rich in nitrogen, phosphorous and potassium (NPK), and it also improves soil quality by replenishing soil carbon stocks over time. However, when excess nitrogen and phosphorous are applied to land they can cause a host of environmental issues such as plant loss, soil imbalance, water contamination, and algal growth for example. This is particularly true in Northern Ireland, and the entirety of the region falls within a Nitrate Vulnerable Zone (NVZ), as designated by the EU under the Nitrates Directive. This means there are limits on the loading of such nutrients on land, to minimise risks and environmental impact. It also means that during a window spanning the autumn and winter months fertiliser spreading is not permitted; this creates a notable challenge for producers, as digestate is generated year-round, but can only be used at certain times of the year and nutrient loading must be avoided. Therefore, in instances where it is decided that digestate will be spread to agricultural land (if other applications are not viable) the storage of digestate during these closed spreading periods is absolutely critical. However, the infrastructure required to meet specific storage demands can be costly, both to establish and to maintain.

A solution to this is to consider a general hierarchy of use, with land spreading being the lowest value and least preferable option where additional volumes are generated, and digestate processing being considered more favorably, where nutrients are captured, transferred from agriculture to other sectors, exported from NI to other countries facing a nutrient deficit or even locked up in end products. Investment in processing infrastructure would increase the value of the product, reduce the environmental impact elsewhere and eliminate the need for additional storage capacity either at the point of production or in remote satellite locations. It should be noted that the hierarchy could evolve over time, as technology and market opportunities mature, presenting a greater opportunity for transfer and export than currently prevails at present.

Where digestate is derived from waste materials it should aim to meet end of waste (EoW) criteria in order to avoid controls placed on it by waste regulations (by means of the EU's Waste Framework Directive). Such criteria for digestates generated across the UK fall within the PAS 110 standard and the accompanying Anaerobic Digestion Quality Protocol (ADQP). Meeting EoW criteria demonstrates to end users that digestate is of an accepted quality, providing confidence to end users that the digestate meets a well-known industry standard. While this offers a potential solution to challenges associated with the market acceptance of this material, if potential users are not well informed on its benefits, it can cause critical issues in regard to the marketable nature of this co-product. Therefore, demonstration of quality means that producers can generate confidence amongst landowners and other end-users. However, there remains a very real need for effective end-to-end communication regarding the benefits of digestates to the wider market – not just to users, but to producers, handlers and regulators who may still not recognise its value.

Notable opportunities for digestate come with the fact that it is a biofertiliser generated in a process for which the primary purpose is often the production of biogas. It offers comparable nutrient benefits to synthetic fertilisers but with a considerably greener selling point, as it is not derived from fossil resources and the emissions associated with its production are much lower than for traditional fertilisers. Taking the production of grass silage as an example, it is estimated that the use of digestate instead of synthetic fertiliser results in the generation of roughly two thirds of the emissions per tonne of grass silage produced. This benefit will become more prominent and valuable over time, as the agricultural sector strives to decarbonise, the food industry looks to procure produce with a lower carbon footprint, and consumers become more environmentally conscious in their purchasing decisions. As a result, getting terminology, messaging and the value proposition for digestate right from the outset is key to establishing a strong and powerful market, through which material can be sold, generating additional revenue for producers whilst at the same time decarbonising the industry.

Up to 2 million tonnes of digestate could be produced in Northern Ireland annually by 2030, according to NNFCC estimates, assuming 1.5TWh of biomethane capacity is established over the same timeframe. This demonstrates that a considerable amount of synthetic fertiliser could be displaced in the future and other markets could benefit, beyond the agricultural sector. Whilst liquid digestate can be spread easily to growing crops, the separated fibre can be used fresh as a soil conditioner or, after further aerobic composting to stabilise it, as material suitable for transforming into a compost product potentially targeting higher-value markets outside of agriculture, such as horticulture and landscaping. Alternatively, it can be dried to ease handling and storage requirements, and subsequently used as a potentially higher value fertiliser or soil improver, or for use in energetic applications via combustion or as a fuel, and even converted to biochar, locking up carbon and nutrients in the process. These opportunities are highlighted by the vast array of digestate processing technologies that are currently available to the market. While digestate processing is not widely carried out beyond traditional mechanical separation processes at present, activity in the wider processing technology space demonstrates industry interest in the upgrading of digestate for higher value applications. Activity specific to Northern Ireland in this area is currently being showcased by projects funded under the Small Business Research Initiative (SBRI).

Under the SBRI, six companies were awarded a total of £600,000 to develop practical and environmentally friendly solutions for livestock slurry. The key aim being to reduce surplus phosphorus and to ensure the efficient recycling of organic nutrients within Northern Ireland whilst contributing to climate targets. SBRI funding was provided by the NI Department for the Economy and DAERA's Green Growth Fund. The funding is being used to create practical and economically viable models where livestock slurry can be separated with minimal nitrogen and methane losses, ideally to produce feedstocks which can be used to produce biogas or biomethane via anaerobic digestion (AD). Nutrients remaining in digestates post energy production will also be suitably processed to provide a replacement for artificial fertiliser for use in Northern Ireland or for export. These projects highlight the promising research taking place across the region, in order to effectively manage livestock slurries and digestates generated in the region.

To guide the most effective management and use of digestate, and to prevent nutrient issues being exacerbated as capacity increases, the hierarchy of use should be followed and appropriate production and use pathways considered. Only digestate derived from livestock wastes should be returned to land if necessary, with other pathways pursuing other processing options. Where digestate is produced from slurry and manure, the nutrient loading issue will be improved marginally and in the short-term, as the placement of digestate and the uptake of nutrients by soils is improved compared to unprocessed manures. However, where digestates are produced from other materials, such as food waste, crops and residues, where inherent nutrients would not have otherwise been returned to land, the issue of nutrient loading would be exacerbated if these digestates are spread to land. Therefore, careful management of digestate is necessary, to improve the situation in NI and to reduce the loading of nutrients on land wherever possible.

Further processing presents a significant opportunity in NI, to capture, convert and divert nutrients from agriculture, to address overloading issues on land. As a result, despite land spreading being the most common application across the AD industry more generally, other options should be considered and pursued as a priority in line with the hierarchy of use. Notable opportunities for NI include the processing of digestate into pellet or prilled form, allowing for physical export to other countries currently facing a nutrient deficit, or the processing of digestate into biochar, allowing for the capture and removal of nutrients and carbon from the system. Appropriate technologies exist to allow these pathways to be pursued, but typically, such processing would occur at larger-scale, hence a focus on centralised AD facilities is prudent, where both the AD system and subsequent digestate processing steps benefit from economies of scale, and the back-end system, subsequent marketing and logistics can be managed centrally.

Due to issues with nutrient loading, increasing the production of digestate should be considered an opportunity for improved nutrient management, as opposed to being viewed as a risk of exacerbating the issue. With positive framing of the opportunities posed by a growth in biomethane capacity, and support across the Executive Departments, existing concerns can be addressed, and current issues partially mitigated. With sufficient foresight and early consideration of the management options for digestate, new developments can avoid many of the challenges experienced elsewhere in the UK and reap additional economic and environmental benefits from the production of a valuable co-product.

Table 1: Summary of key recommendations.

Management	**Hierarchy of use**	A **hierarchy of use** should be considered at the outset of any future growth, and digestate only used for land spreading where nutrient management practices are neutral or improved. Where livestock wastes are digested that would otherwise be spread to land, the resultant digestate can be **spread to land** with careful management, monitoring and placement of nutrients, to ensure effective plant uptake, and in compliance with the necessary regulations. Where other feedstocks are used, such as food waste, crops and residues, which would otherwise not result in nutrient return to land, alternative digestate processing and use pathways should be prioritised, to **reduce additional nutrient burden**. Where alternative production pathways still result in a nutrient-rich product, **export** from NI agriculture to alternative markets or more preferably to countries experiencing a nutrient deficit should be pursued.
	Generating an effective digestate management plan	A dedicated **digestate management resource** should be committed at an early stage to plan, execute and deliver a strategy for the production, storage and distribution of digestate at site, local and national level. It is recommended that such a resource is shared across facilities, and the strategy managed centrally by a dedicated digestate management business.
	Managing a variety of outlets for digestate	Digestate producers should consider targeting **higher-value markets** outside of agriculture. It is recommended that a combination of bulk, lower-value markets and more niche, higher-value markets are considered, in order to minimise risk and maximise returns. This would also enable investment in more complex equipment, allowing nutrients to be processed into a form to allow for export, to reduce the nutrient impact domestically, offering wider benefits to the local environment and economy.
Market	**Using better language when discussing digestate and communicate benefits.**	Consumer perception of digestate in Northern Ireland is poor given the widespread problems associated with nutrient pollution in the region. In order to promote market uptake of this product, the **benefits of this material should be communicated** widely (e.g., lower GHG emissions when used to cultivate crops compared synthetic fertilisers) and niche markets considered.
	Ensuring market demand for digestate and creating consumer confidence	Through the SBRI projects, Northern Ireland is developing solutions to specific problems associated with nutrient pollution in the region. These projects have the potential to generate and provide access to new markets for digestate in the future (e.g. biochar production) and are helping to **build consumer confidence** in the region with regard to future production and use.
Regulatory	**Compliance with waste management regulations**	Regardless of the end use of digestate, if it is derived from a waste it should **comply with waste management regulations** in order to ensure that it can be used in value-added applications downstream.
	Getting certified under PAS 110 and the BCS	A key step towards demonstrating end of waste criteria is getting certified under the **PAS 110 standard**, that demonstrates the production of a quality product, and if it is to be used as a fertiliser, compliance with the **BCS** is also recommended.
	Compliance with land spreading regulations	Given that the entirety of Northern Ireland falls within an NVZ, if digestate is to be used as a fertiliser, then **compliance with land spreading regulations** is essential. It is recommended that digestate management plans in NI should consider the appropriateness of land spreading as a priority, and where nutrient loading problems would be increased as a result, alternative processing and use pathways should be pursued.

2. Introduction

Northern Ireland (NI) is aiming to reach net-zero emissions by 2050, and a key means of achieving this will be through the development and implementation of renewable energy technologies across the energy network.

Northern Ireland's "Energy Strategy – Path to Net-Zero Energy",[1] published in December 2021, sets out a pathway for energy to 2030 that will mobilise the skills, technologies and behaviours needed in order to take NI towards their vision of net-zero carbon and affordable energy by 2050. The resulting annual Action Plans, published in 2022 and reissued in 2023, focus on the delivery of five key principles of the overarching Energy Strategy: 1) placing the consumer at the heart of the energy future; 2) growing the green economy; 3) doing more with less (energy efficiency); 4) replacing fossil fuels with renewable energy; and 5) creating a flexible, resilient and integrated energy system to deliver power, heat and transport needs. These Action Plans outline NI's intention to deliver a 56% reduction in energy-related emissions by 2030, relative to 1990 levels, with anaerobic digestion (AD) highlighted as key to meeting these emissions targets through the generation of renewable biomethane at scale.

At present, NI boasts the highest stocking density within the UK for the three main farmed animal species (cattle, pigs, and poultry), all of which produce wastes that are highly suitable as AD feedstocks. This means that NI has an abundance of animal-derived manure feedstocks compared to the rest of the UK, but it also means that emissions derived from agriculture are comparatively high in the region. As such, this has led to considerable interest in the deployment of AD facilities across NI, as a means of decarbonising both the energy and agricultural sectors, whilst also helping to reduce or more effectively manage the impact associated with nutrient loading in livestock-dense areas. Research led by Queen's University in 2022 found that NI has the potential to deliver 6 TWh of biomethane per annum (roughly 80% of the region's gas distribution network demand) – equivalent to heating over half a million homes each year.[2]

There are currently around 80 AD facilities operating in NI, the majority of which are based on farms and use farm wastes as feedstocks. The biogas produced at these AD facilities is generally used to generate heat and electricity (via CHP) for use on site, with surplus electricity being exported to the power grid. The biogas produced at these facilities may also be upgraded to generate biomethane for use as a renewable transport fuel or for injection into the gas grid. However, biogas upgrading is not widespread across NI as of yet, with only one site currently upgrading for injection into the gas grid at present. It is anticipated that activity will grow in this area over the coming years however, as industry becomes better aligned with the UK's heat and transport decarbonisation policy frameworks.

Alongside biogas, a nutrient-rich co-product is also generated as part of the AD process, typically named digestate. This co-product is most often used as an organic fertiliser and applied to agricultural land. However, with pressure increasing on Northern Ireland's agricultural sector to reduce its environmental impact, improve water quality, and increase overall productivity, the application of nutrients *via* fertilisers (including digestate) requires careful consideration and planning. As such, guaranteeing the offtake and use of digestate within NI may prove challenging over time, as a result of these concerns surrounding the loading of nutrients to land. Therefore, there is a real and timely need to consider how to transform digestate into a higher value product that is easier for operators and recipients to handle, use, and potentially export, reducing such risks, and generating an alternative revenue stream for producers going forward.

A period of rapid growth across NI's biomethane sector is anticipated in the near-term. However, prior to this growth taking place, it is prudent to appraise and address any concerns, and to understand the opportunities, risks and challenges likely to be posed by increasing the production and use of digestate in the region. A Call for Evidence (CfE) on biomethane in Northern Ireland is expected in the near-term, with digestate management anticipated to be one of three key pillars – the aim being to mitigate negative reactions to digestate at the local, regional and national scale through proper management and planning. To inform the response and to consolidate wider industry thinking around the necessary actions, Action Renewables and Northern Ireland's three gas Distribution Network Operators (DNOs), Phoenix Energy, Firmus Energy and Evolve, commissioned NNFCC to appraise the situation, in order to better understand three key areas:

- The quantification and composition of digestate in NI, now and in the future.
- Optimal production, processing & use pathways.
- Market awareness & acceptance, to understand the preferred models for effective digestate management.

NNFCC have been active in the AD market in the UK for the past 20 years, and have dealt with issues, concerns and innovations in relation to digestate regulation, management and use over the same time period. This report outlines the key elements and specific learnings from Great Britain that should be considered in order to develop an effective digestate management plan for Northern Ireland going forward.

3. The Anaerobic Digestion Process

The anaerobic digestion (AD) process starts when bioresources (feedstocks) such as food waste, manure, crops and crop wastes are fed into an anaerobic digester. Often a pre-treatment step is needed, either to remove packaging materials (e.g., from supermarket food waste) or to make materials more available for biological breakdown.

The core of the process consists of a tank (digester) or a series of tanks, into which suitable feedstocks are fed regularly and mixed into the microorganism-rich liquid or slurry already present inside the digester. Microorganisms break down the materials in a series of biological reactions, releasing biogas, a combination of methane (CH_4) and carbon dioxide (CO_2), with a typical methane content of 50-70% depending on the feedstock used.

There are three common conversion routes for biogas:

- **CHP**: biogas is combusted in a combined heat and power (CHP) unit to generate electricity and heat.
- **Heat**: biogas is combusted in a gas boiler to generate only heat (e.g., for the distilling process).
- **Biogas upgrading**: biogas is upgraded to biomethane, which can then be injected into the gas grid, and/or used for heating, transport or chemical processing.

Some AD plants use only one of these conversion routes, while others use a combination, generating energy for on-site use as well as for export. CHP and heat-only outputs are considered lower efficiency, and they require on-site or local demand to better utilise the biogas, which can be difficult to find in the absence of large populations (e.g., large villages, towns, and cities). Biogas upgrading to biomethane however, achieves higher efficiencies due to the fact that less energy is lost during conversion, and it is also not reliant on local energy users, simply requiring grid access for distribution.

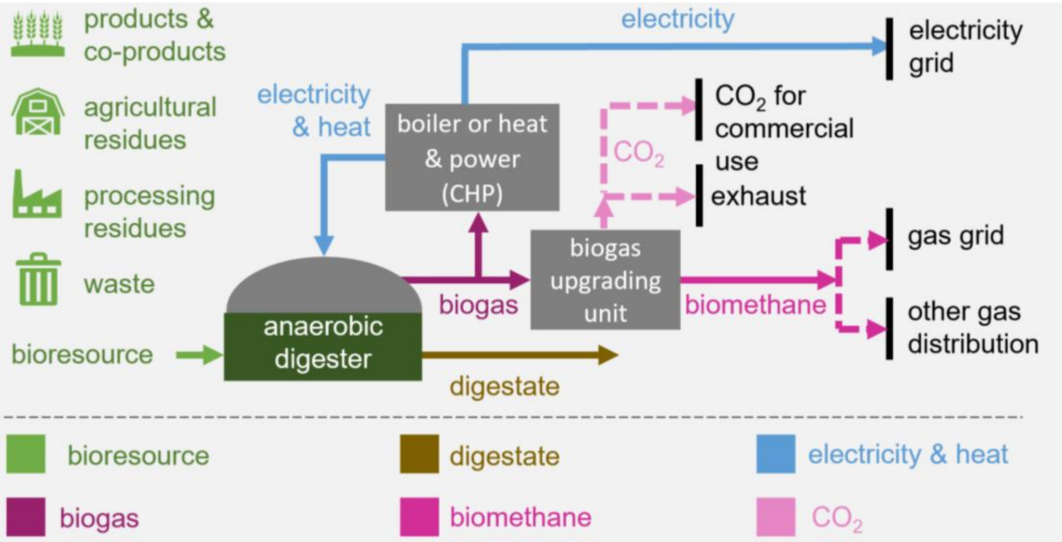


Figure 1: Overview of the AD process, showing options for inputs and outputs.[3]

Biogas is upgraded to biomethane by removing the carbon dioxide and other contaminants (e.g., water vapour, hydrogen sulphide and ammonia). Several technologies exist for this, with the most common being membrane separation, pressure swing adsorption (PSA), amine scrubbing and water scrubbing. These technologies upgrade the biogas to around 95-99% biomethane. For injection into a local gas grid, biomethane is typically odourised and supplemented with propane to ensure the calorific value of the gas meets the grid standard, so as to not disadvantage any local gas users.

The carbon dioxide that is removed during the upgrading process is traditionally vented to the atmosphere. This does not count towards biomethane's carbon footprint because it is biogenic carbon. However, there is increasing interest in capturing this carbon dioxide, both because of supply constraints and its increased market value (e.g., for use in the fizzy-drinks industry, the horticulture industry, as an e-fuel or chemical feedstock, and in livestock slaughter), and because it can potentially lead to a negative carbon footprint for the biomethane generated, further enhancing its decarbonisation potential. The latter is only true if the CO_2 is stored long term however, or if it can be demonstrated that the use of AD-derived CO_2 displaces fossil-derived CO_2.

Of the material that is fed into the front end of an anaerobic digester, only a fraction (roughly 10-20%) is converted into biogas. The remainder leaves the digester as a compost-like sludge, commonly termed digestate. There are two primary reasons for the generation of digestate. Firstly, only carbon, hydrogen and oxygen are used to make biogas, therefore other elements such as nitrogen, phosphorous and potassium remain in the digestate. Secondly, there are components of the original feedstocks that are not easily digestible (e.g., because they contain high amounts of lignin), and will not totally breakdown. As such, the generation of digestate as a co-product alongside renewable biogas is an inevitable and unavoidable part of the AD process. This digestate is recognised as being highly valuable when produced and used in appropriate applications, as is explained in the subsequent sections of this report.

4. Digestate Production, Benefits & Uses

Digestate is a co-product of the AD process. It is nutrient-rich and commonly used as a fertiliser and/or soil amendment, and as such, it is widely considered a valuable "biofertiliser". Digestate volumes generated by AD are typically around 80-90% of the original feedstock volume fed into the digester. All of the nutrients (including nitrogen (N), phosphorous (P) and potassium (K)) present in the starting feedstocks remain in digestate post-digestion. However, when used as a fertiliser, these nutrients are typically more available to plants compared to the original feed materials, due to the breakdown of accompanying structural components during the digestion process.

Digestate exits the AD process with a sludge-like consistency and can either be used whole, or mechanically separated into liquid and fibre fractions with different nutrient contents. Typically, digestate liquor contains high concentrations of N, while digestate solids retain high levels of P and K. Liquid digestate can be spread easily to growing crops, whilst the separated fibre can be used fresh as a soil conditioner or, after further aerobic composting to stabilise it, as a material suitable for conversion into compost or other products. Solid digestate can be further dried to ease storage and handling requirements, and again used in fertiliser or soil improver applications. Alternatively, dried digestate can also be used in less conventional, but emerging market applications, such as in fuel pellet production or in construction material manufacturing for example.

4.1 The Benefits of Digestate

Due to the inherent nutrient properties of digestate, this material is widely considered a valuable biofertiliser. It contains all the nutrients and micronutrients required for modern farming, and since no nutrients are lost during the AD process, it allows for the recycling of vital minerals contained within the original feedstocks. Furthermore, the percentage of readily available nitrogen present within digestate is understood to be much higher than in the initial starting materials, due to the breakdown of encompassing structural compounds during AD. Thus, increasing the fertilising value of AD feedstocks.

AD can also help to significantly reduce, or in most cases, eradicate, any plant or animal pathogens that may be present within organic starting materials, due to the technical and thermal pretreatment of feedstocks, and the microbial conditions inside the digester. AD can also help to minimise the spread of invasive weeds by neutralising any seeds that may be present within feedstocks. As such, digestate is generally considered a much safer material to handle and utilise in applications downstream, compared to unprocessed organic feedstocks.

Where manures and slurries are used as feedstocks for AD, not only is the resultant digestate considered safer than the original starting materials (for the reasons outlined above), but unpleasant odours and gaseous emissions are also considerably reduced as they are captured during the AD process. This is important, as the use of AD offers these benefits alongside the generation of a highly valuable biogas and a digestate with enhanced fertilising properties compared to the original input materials.

Compared to synthetic fertilisers, organic fertilisers like digestate are understood to have a "softer" impact on the environment.[4] Conventional mineral fertilisers typically have much higher levels of available N, P and K, and are therefore at greater risk of polluting surrounding water bodies through nutrient leaching to the environment. Digestate on the other hand, releases N, P and K much more gradually as it breaks down naturally over time, providing nutrients to soils up to three years after land spreading. Furthermore, the organic matter available within digestate can also help to improve the humus content of soils, which is essential for good soil fertility, water retention, CEC (cation exchange capacity), nutrient availability, and overall soil health. This is a key feature absent in traditional synthetic fertilisers, highlighting the range of potential benefits that digestate use can deliver.

Perhaps the most notable benefit of digestate however, is the markedly lower GHG emissions associated with the production of this material over traditional mineral fertilisers. To illustrate this, Figure 2 shows the comparative emissions associated with the production of 1 tonne of grass silage, using only synthetic fertiliser compared to using only digestate. The use of digestate results in roughly 20 kg less $CO_{2\,(eq)}$ for each tonne of grass silage produced, compared to the use of a typical synthetic fertiliser for the same quantity of grass. This benefit will be better appreciated over time, as the agricultural sector strives to decarbonise, the food industry looks to procure produce with a lower carbon footprint, and consumers become more environmentally conscious in their purchasing decisions.

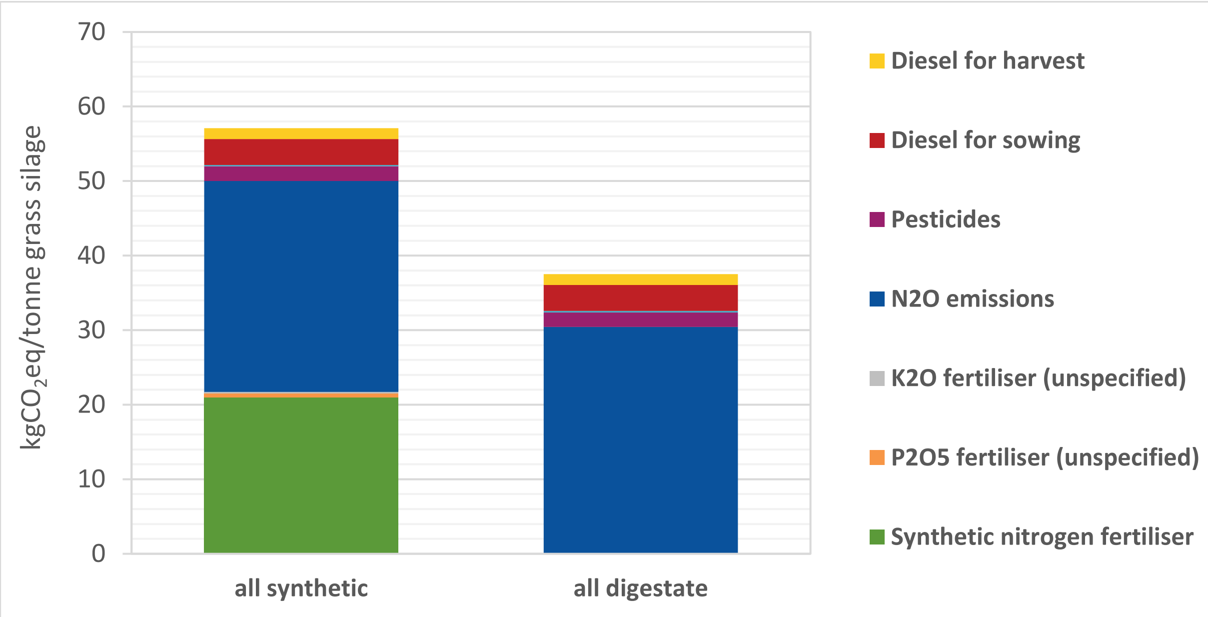


Figure 2: The GHG emissions associated with the production of 1 tonne of grass silage, on a fresh weigh basis, depending on whether synthetic fertiliser or digestate is used (NNFCC analysis).

The majority of synthetic nitrogen produced around the world is manufactured using the Haber-Bosch process, and accounts for roughly 1-2% of global energy consumption, and 3-5% of global natural gas consumption.[5] In Europe, for every tonne of mineral fertiliser manufactured, an average of 9.7 tonnes of CO_2 equivalent is emitted,[6] which not only harms the wider environment but also promotes energy dependence from imported natural gas.[7] By replacing synthetic fertilisers with organic products like digestate, these emissions have the potential to drastically decrease. It is estimated that the replacement of 1 tonne of artificial fertiliser with digestate will save up to 1 tonne of oil, 108 tonnes of water, and 7 tonnes of $CO_{2\,(eq)}$ emissions.[8]

4.2 Digestate Applications

Due to the high nutrient content of digestate, whether whole or separated into fractions, this material is typically used as a fertiliser – most commonly applied to agricultural land as an alternative to synthetic fertilisers for the growth of crops. Given the range of benefits that digestate can provide to agriculture, its use in this area should be considered over mineral fertilisers and manures/slurries where appropriate.

However, it is well reported across NI that the region faces significant challenges in relation to nutrient pollution, a problem caused primarily by excess nutrients from agricultural activity and wastewater treatment, combined with climate change and associated weather patterns. A prominent example of these issues came to light in the summer of 2023, when the largest lake in NI, Lough Neagh, which supplies 40% of the region's drinking water, was hit by record levels of potentially toxic blue-green algae. In response, NI's Public Health Agency was prompted to warn the public against swimming and eating fish from the areas affected by algal blooms.

With this in mind, it is evident that the most common use of digestate, as an agricultural fertiliser, is not necessarily best suited to a region like NI. Furthermore, converting slurry and manure to digestate via AD could pose a genuine and timely opportunity for NI, providing a mechanism to capture, convert and export nutrients from agriculture to other sectors or to other countries experiencing a nutrient deficit. It is therefore necessary to consider other possible uses of this material in order to ensure that it is utilised in the most effective and responsible way, according to where it is generated. Potential applications of digestate, other than for use in agriculture, include:[9]

- **Horticulture** – Given the favourable fertilising properties of digestate, a key opportunity for this material can be found in applications in field-grown horticulture (e.g., for the production of ornamental plants, shrubs and trees etc.). Furthermore, if solid digestate undergoes further aerobic composting to stabilise it, it can then be converted into a valuable compost product and used throughout the commercial horticultural industry, as well as in home gardening. This market is established and higher value than agriculture, but presents many of the same challenges as use in agriculture, in relation to nutrient placement, loading and control.
- **Landscaping** – Given the high organic content of solid digestate, it can be used to provide fibre to soils in landscaping and land restoration applications. This can help to improve the humus content within soils, which is essential for good soil fertility, water retention, CEC (cation exchange capacity), nutrient availability, and overall soil health. However, to prevent excess nutrient loading and to avoid further exacerbating existing issues within NI, careful placement would be essential.
- **Mushroom Growth Substrate** - Any organic material can be used as a substrate for the growth of mushrooms. While straw, cardboard and sawdust are commonly used for this purpose, digestate could also be utilised here. Given this activity is typically carried out in a controlled environment, this use would address some of the nutrient loading issues currently experienced on a short-term bases, but at end of life, the growth substrate would typically be spread to land, so nutrient placement would again become an issue.
- **Forestry** – Digestate can find uses in urban forestry or in tree planting for landscape and amenity purposes, notably on brownfield sites.[10] It can be used for its fertiliser properties or as mulch (a material used to save water, suppress weeds, and to improve the soils around trees and plants). The volume demanded by this application is likely to be low, and therefore a relatively niche opportunity.

- **Construction Materials** – Dried digestate has the potential to be incorporated into construction materials, with research demonstrating that medium density fibreboards (MDF) and fibre reinforced plastics (FRP) can be manufactured from the fibrous fraction of digestate.[11] This application would be beneficial in NI, as nutrients would be locked up in materials for a number of years, addressing the issue of overloading and subsequent leaching of nutrients from land.
- **Cellulosic Ethanol Production** – Cellulosic materials can be utilised as feedstocks for the production of bioethanol, with crop residues, wood residues and dedicated energy crops recognised as being suitable feedstocks for this application. Given that digestate fibre is also considered as being highly cellulosic, there could be potential for this material to be used as a bioethanol feedstock in the future.[12] Although this application would permanently remove nutrients from the system in NI, digestate is not currently used as a feedstock, so it would more likely be a longer-term opportunity, which would also require export given that there are no cellulosic ethanol production facilities within the UK.
- **Fuel Pellet Production** - Dried digestate fibre when pelletised can also be used as a solid fuel for the production of bioenergy. The useful heat generated at an AD plant, unless required for utilisation elsewhere, could be used here as a means of drying digestate sufficiently in line with this potential application. This application has been adopted commercially in the UK, notably when the Renewable Heat Incentive (RHI) permitted the use of heat from AD for digestate drying. Commercial production facilities exist elsewhere in Europe, and it could be a good application for NI to consider, given it would be possible at relatively small-scale and would remove nutrients from the agricultural system.
- **Biochar Production** – Biochar is defined as the solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment i.e. pyrolysis. It is a highly stable solid that is rich in pyrogenic carbon and can persist in soils for thousands of years, making it an excellent carbon sink when used as a soil amendment. Other uses include applications in water retention, in livestock feed, and as a concrete additive for example. Biochar can be produced from digestate, offering benefits to NI in terms of both nutrient and carbon removal.
- **Fertiliser Pellet Production** – Dried solid digestate when pelletised is much easier to transport than undried digestate. Therefore, there could be an opportunity here to transfer this material to regions outside of NI, which would benefit from the high nutrient content of digestate, in addition to the range of other advantages that it offers over synthetic fertilisers (discussed in the previous section). Notably, solid digestate retains high levels of P and K (while liquid digestate retains high levels of N). Global reserves of phosphate are declining at an alarming pace and further depletion would be disastrous for worldwide food production as it is an indispensable nutrient for plant growth. Areas accessible to NI which would benefit considerably from digestate pellet exports, in order to improve the levels of P within soils, include the majority of Spain, Portugal and Southern France (Figure 3). Furthermore, the organic matter contained within digestate can also help to build up the humus content in soils which is particularly crucial for arid and semi-arid lands with low carbon contents. Further processing of digestate to produce pellets or prills would allow more efficient transport, storage and distribution of the material, as well as improved product valorisation and use.

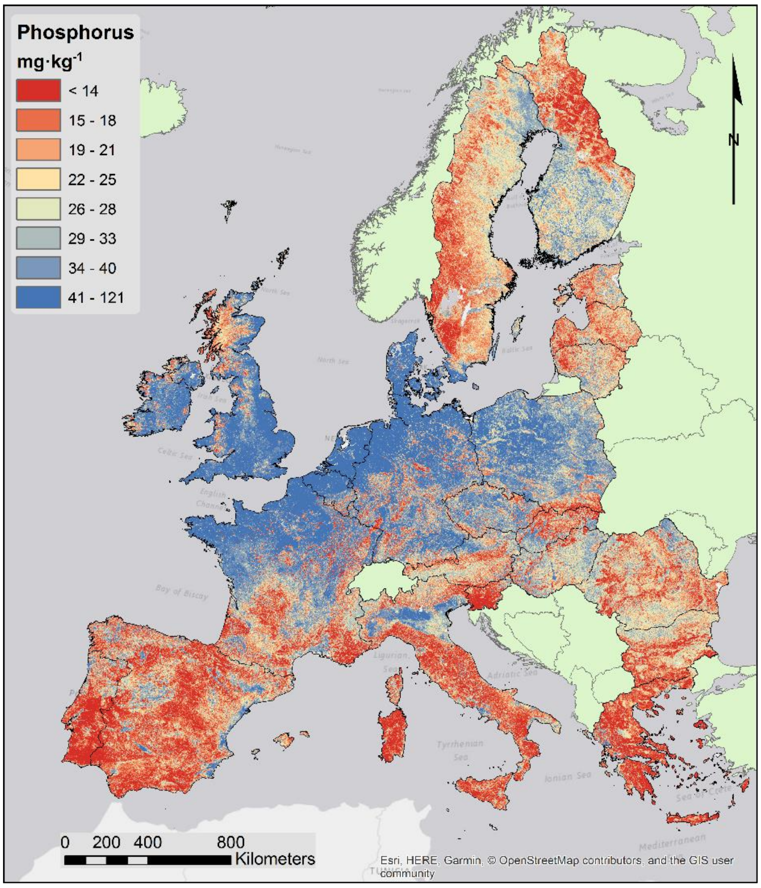


Figure 3: Map of phosphorous content within soils across Europe.

As a result of the pre-existing nutrient issues in NI and the wealth of processing and use pathways available, it is prudent to consider the most appropriate use of the material, based on how and where it is produced, from what feedstock and under what conditions. The hierarchy of use diagram below considers the appropriateness, value and ability of the different processing and use pathways to address the nutrient loading issues experienced in NI by 2030, given current technology and market maturity.

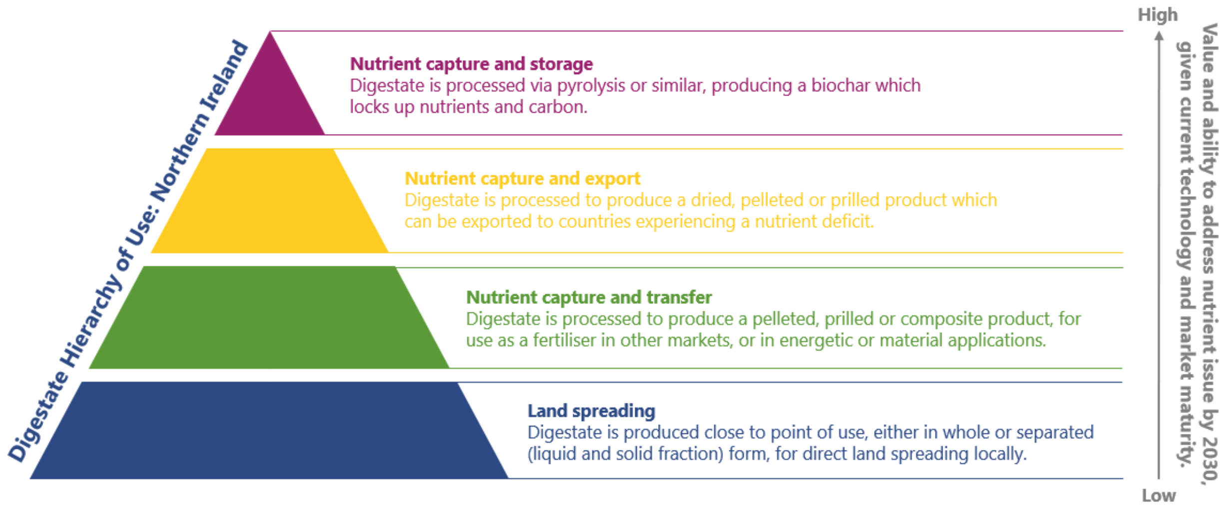


Figure 4: Digestate hierarchy of use, based on different processing and use pathways.

It should be noted that although nutrient capture and storage sits at the top of the hierarchy, this is based on the view to 2030 and the current level of maturity of technology and alternative markets. As is evident from Figure 3, the phosphorous deficit seen in other parts of the world could present a more advantageous and longer-term opportunity for the transfer and export of specific nutrients; however, the technology for separation of specific components and processing into an appropriate form for such transfer is not as established, and the markets and regulations require further advancement to fully exploit this opportunity. Therefore, it must be acknowledged that the hierarchy of use should be subject to regular review, considering advancements in technology, markets and regulations, to allow best use for future developments to be adjusted accordingly. The hierarchy and any future changes should not apply retrospectively to operational plant capacity, only to newly commissioned sites. A suitable time period for systematic review would be every 5 years, given the current and expected rate of technical advancements.

4.3 Digestate Composition

The composition of digestate outputs can vary significantly depending on the initial input materials used. Therefore, it is important to fully understand the properties and inherent value of different digestates before determining the most appropriate treatment route and eventual end-use of these products. This section outlines the compositional determinants of digestates, providing examples of 'typical' outputs in order to generate insight into the likely properties of these materials. Through regular testing of outputs, AD operators are able to accurately share the compositional analysis of digestates with end users, to allow for the effective management and placement of nutrients when land spreading, and to prevent the over-loading of specific compounds in high-risk areas. Many AD facilities have on-site test facilities, to routinely monitor outputs; and where off-site testing is required, access to suitable test-facilities is essential, to ensure that analysis is available in a timely manner.

AD feedstocks are typically rich in plant nutrients (i.e., macro and micro-nutrients), and may occasionally contain heavy metals and persistent organic compounds in varying amounts. Macronutrients typically include nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S) – elements that are essential for all life (plants, animals, and bacteria). Micronutrients commonly include boron (B), cobalt (Co), copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), and Zinc (Zn). Whilst heavy metals may include lead (Pb), chromium (Cr), cadmium (Cd), and mercury (Hg); however, these components are most prominent in food-waste AD.

When consumed by animals, the macronutrients outlined above are often used inefficiently, and high proportions are subsequently excreted. For example, research indicates that between 55-95% of the nitrogen available in animal diets is excreted through faeces and urine.[13] High proportions of phosphorus and potassium are also commonly expelled. Animal manures and slurries are therefore rich in plant nutrients and as a result, digestates derived from these feedstocks contain high macronutrient levels and thus, act as valuable biofertilisers. It should be noted that converting slurry and manure to digestate does not reduce nutrient availability and therefore AD should not be considered as a means of addressing nutrient supply issues without further processing steps being incorporated.

The composition of manure typically depends on the digestive system of the animal in question (i.e., ruminant, omnivore etc.) and on the diet of said animal. Other factors effecting manure compositions include: the species, sex and age of animals; as well as geographical and climatic conditions. Subsequent digestates generated from the AD of manures and slurries are therefore likely to be variable in terms of their composition. Typical compositions of different manures are set out in Table 2.

Table 2: Typical nutrient concentrations of manures generated in the UK (kg/t fresh weight).[14]

Feedstock	TS%	Total N	NH_4-N	P	K	S	Mg
Dairy Cow Slurry	6	3.0	2.0	0.5	2.9	0.4	0.4
Cattle Manure	25	6.0	0.6	1.5	6.7	0.7	0.4
Pig Slurry	4	4.0	2.5	0.9	2.1	0.4	0.2
Pig Manure	25	7.0	0.7	3.1	4.2	0.7	0.4
Poultry Layer Manure	30	16.0	3.2	5.7	7.5	1.5	1.3

When used alone as feedstocks for AD, manures and slurries typically generate relatively low biogas yields per unit of fresh weight, and as a result, they are frequently mixed and co-digested with other feedstocks that are known to produce higher biogas yields.[15] Common substrates include residues from food processing, residues from crop production, and even purpose grown energy crops. In practice however, AD feedstock selection will largely depend on what is readily available locally. Examples of the macro-nutrient concentrations within common co-digestion feedstocks are highlighted in Table 3.

Table 3: Approximate nutrient content of common AD feedstocks (kg/t fresh weight).[16]

Feedstock	TS%	Total N	NH_4-N	Total P	Total K
Grass Silage	25-28	3.5-6.9	6.9-19.8	0.4-0.8	-
Maize Silage	20-35	1.1-2.0	0.15-0.3	0.2-0.3	4.2
Dairy Waste	3.7	1.0	0.1	0.4	0.2
Food leftovers	9-18	0.8-3.0	2.0-4.0	0.7	-

AD feedstocks, and subsequent digestates, can also contain trace quantities of micronutrients and heavy metals, as well as persistent organic compounds that are not biodegradable. The majority of heavy metals contained within manures are originally introduced *via* the animal's diet. When digestate is recycled back to land as a biofertiliser, most of these micronutrients are fully utilised as they are essential for plant and microbial growth. However, heavy metals and persistent contaminants can cause problems, and thus, must be carefully monitored. Table 4 presents information on typical trace element and heavy metal content in common AD feedstocks.

Table 4: Typical trace element and heavy metal content in common AD feedstocks (mg/kg DM).[17]

Feedstock	Zn	Cu	Ni	Pb	Cr	Cd	Hg
Animals							
Dairy Slurry	176	51.0	5.5	4.97	5.13	0.20	-
Pig Slurry	403	364	7.8	<1.0	2.44	0.30	-
Poultry Manure	423	65.6	6.1	9.77	4.79	1.03	-
Crops							
Grass Silage	38-53	8.1-9.5	2.1	3.0	-	0.2	-
Maize Silage	35-56	4.5-5.0	5.0	2.0	0.5	0.2	-
Agri-food Products							
Dairy Waste	3.7	1.4	<1.0	<1.0	<1.0	<0.25	<0.01
Brewing Wastes	3.8	3.7	<1.0	0.25	<1.0	<0.25	<0.01

During AD, bio-chemical changes take place that alter the organic structure in which the nutrients are present, enhancing their availability to crops. Since only organic compounds are targeted in this process, the quantity of nutrients contained within digestates is therefore the same as in the original starting materials. Therefore, the values presented in these tables are good indicative values of the nutrient values that can be expected in subsequent digestates.[i]

Digestate is the result of a living process that relies on the use of microorganisms to breakdown organic matter in feedstocks. Outputs will therefore have variable properties depending on the specific digester systems used and will even vary between batches from the same digester. It is important to recognise that digestate is, therefore, highly variable and as such, it is difficult to comment on specific compositions in the absence of any lab-based testing. A review of literature in this area, however, has allowed for generic digestate compositions to be estimated from three of the most common AD feedstocks used by industry (Table 5). Note, due to the variable nature of digestates in general, data ranges can be wide, and certain values can be difficult to determine (hence, some values are missing from the table).

Table 5: Estimated composition of digestates generated from three of the most common AD feedstocks.

Composition	Manure/Slurry [18, 19, 20, 21]	Crops [22, 23]	Food Waste [24, 25]
Dry Matter (DM)	3 – 8%	10%	2 – 6%
Organic dry matter	63 – 84.3% of DM	90 - 94% of DM	58% of DM
Ash content	15.7% of DM	6 – 10% of DM	42% of DM
C:N ratio	18:1 – 25:1	40:1	8:1
N	2 - 8% of DM	1.6 - 1.8 % of DM	4 – 5 mg/g of DM
Phosphate	0.6 – 4 mg/g	50 – 62 mg/L	0.5 – 0.7 mg/g
Potash K_20	2.5 - 3 mg/g	-	2 mg/g
Ca	0.46 – 1.42 mg/g	-	-

Given that the majority of AD sites currently operational in NI are farm-fed facilities, it is expected that the composition of digestates generated across the region will be largely reflective of manure/slurry and crop feedstocks (as shown above). In such cases, the digestate is likely to be used instead of the untreated wastes, and as a result, the nutrient position will be neutral or slightly improved, given that nutrients will be more readily available to soils, and thus, uptake will be more efficient. However, it is important to reiterate the issue of nutrient overloading across the existing agricultural system in NI. Therefore, although the use of manure-derived digestate will not necessarily make the situation worse, it will not drastically improve the situation either. And so, it is recommended that digestate use is considered carefully before being applied to land, so as not to exacerbate these existing problems.

Although less prevalent, there are also a number of sites across NI that are understood to be waste-fed, and so a proportion of digestate generated in the region will also exhibit properties comparable to those seen in food waste feedstocks. These materials will add additional nutrients to the system, and as such, these raw materials should not otherwise be land spread. Therefore, their production, processing and

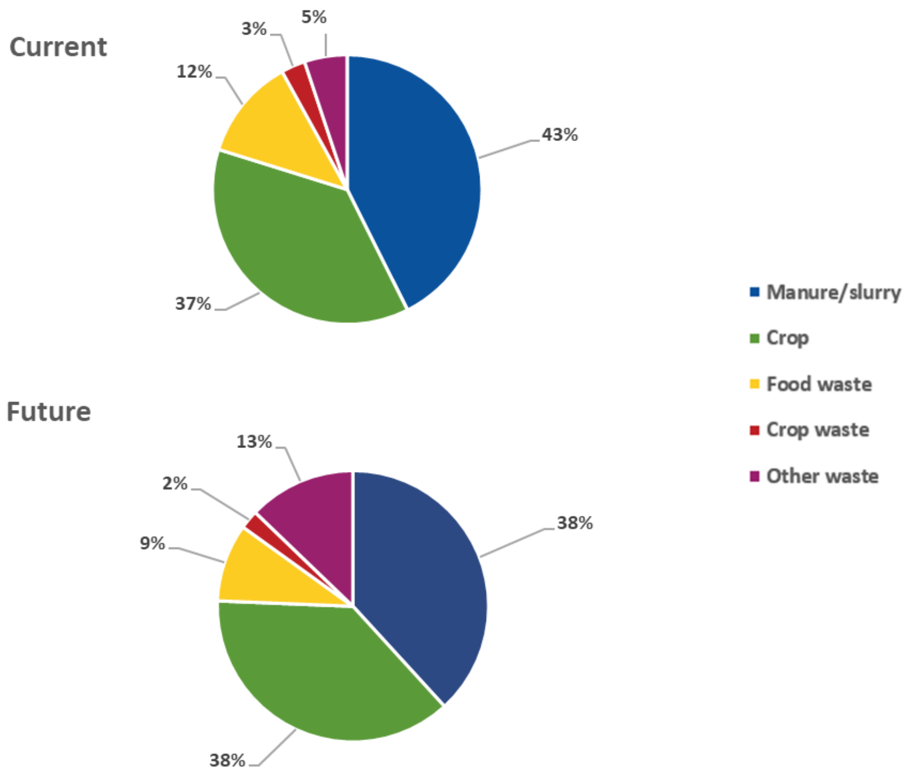
[i] Note that some organic nitrogen supplied within the feedstock will be converted to ammonium (although the total nitrogen content in the digestate will remain the same as in the original feedstock).

use needs to be considered more carefully, so as not to exacerbate existing problems with nutrient loading and leaching from agricultural land.

Regardless of the feedstock, all digestates generated by AD will contain valuable N, P and K nutrients making them useful biofertiliser materials (e.g., for use in agriculture, but also in horticulture and home gardening applications), but digestates that exhibit higher nutrient concentrations will be better suited to said uses. Similarly, regardless of the feedstock, all digestates generated by AD contain organic dry matter making them useful for the production of composts for landscaping, as mushroom growing substrates, as mulches, for the production of construction materials, or as bioenergy feedstocks for example. Digestates that exhibit higher organic dry matter concentrations may be better suited here.

In order to understand the composition of digestates now and in the future, feedstocks processed across NI were analysed, based on those reportedly used by operational and planned facilities in the region (Figure 5).

Figure 5. Feedstocks used for the production of digestate in Northern Ireland at present (top) and potentially in the future (bottom) (NNFCC analysis).



The largest source of digestate in NI currently comes from the processing of manure and slurries; (e.g., cattle manure and chicken litter) with crops being the second largest source of digestate (e.g., grass silage and energy crops). These trends are found both at present day and in the pipeline of projects being considered for future development (according to NNFCC's AD Deployment in the UK database). Food waste and "other wastes" then follow suit, with "other wastes" expected to surpass food waste in terms of the volume of feedstock used in the coming years. Included within the "other waste" feedstock category are industrial wastes from dairy and potato processing and bakery wastes for example.

Note that the percentages shown in Figure 5 should not be taken as exact values, given that the pipeline of planned (consented) AD projects in the region is subject to change as financial support mechanisms have changed over time. There are, however, a number of projects coming forward in the near future that are planning to be almost 100% manure-based AD facilities. As such, digestates generated at these sites will exhibit similar compositions as those highlighted for manure-derived digestates in the tables presented previously.

5. Regulatory Considerations

Some of the primary challenges associated with the management and eventual use of digestates stem from regulations relating to waste and the spreading of fertilisers to land. It is important to be aware of these regulations from an EU, UK and NI standpoint, in order to understand the restrictions and controls that producers and users of digestates in NI may face, and to allow for effective plans to be put into place in order to mitigate any potential difficulties associated with the valorisation of digestate. This section will outline key legislation and policies of relevance to the handling, storage, transport and eventual use of digestates, and outline critical actions that should be taken in order to minimise the potential impacts of these regulations.

5.1 Waste Regulations

Although the feedstocks used for AD are typically wastes, digestate can be used freely as a product provided that it meets end-of-waste (EoW) criteria. EoW is a concept originally introduced into legislation across Europe by means of the EU's **Waste Frame Directive (WFD)**. EoW criteria outline the set of rules that a given waste stream has to fulfil in order to cease being considered a waste. The importance of this is that when a material ceases to be a waste, it no longer needs to be treated and handled as such, generally becoming less costly and prohibitive to deal with.

Given that for AD, many input materials are waste feedstocks, EoW criteria is significant here to ensure that the resulting digestate is not considered a waste so that it can be used in higher value applications downstream. Waste streams that are candidates for EoW status must undergo a recovery operation and comply with a set of specific criteria. For digestates, these criteria are laid out in the 2014 JRC Report "*End of Waste Criteria for Biodegradable Waste Subjected to Biological Treatment*". The end of waste criteria specific to digestates are highlighted in Annex I of this report, and the types of input materials that are permitted by EoW criteria are included in the table below. It is important to note here that manure and slurry derived digestates are exempt from EoW controls, and thus, these digestates are not considered as being waste derived i.e., they do not require waste management controls during subsequent handling and use.

Table 6: Example input materials for producing digestate. These fall within the proposed scope for EU EoW criteria on digestates.

Input material sources	Examples
Amenity areas - parks, gardens, cemeteries and other green spaces	Leaves, grass, fruit, flowers, plants and plant parts
Households	Biowaste from households: incl. fruit and vegetable remainders, coffee and tea remainders, food remainders, plants and soil attached to plant parts. Bags for source-separated household waste shall be biodegradable (paper or biodegradable plastics according to EN 13432 or EN 14995).
Caterers and restaurants	Fruit and vegetable remainders, coffee and tea remainders, food remainders

Food and beverage related retail premises	Biowaste from markets, food preparation waste and food remainders
Food and beverage processing plants	Food waste, food washing waste, sludge from food and feed processing plants not containing pollutants
Horticulture	Leaves, grass, fruit, flowers, plants, plant parts, weeds, mushrooms, soil attached to plant parts and peat
Forestry	Bark, wood, wood chips, sawdust *(although not well suited to digestion)*
Agriculture	Straw, harvest remainders, silage, plant material, energy crops and catch crops, manure (as defined in ABP Regulation (EC) No 1069/2009)
Fishery and aquaculture	Slaughter waste and fodder residues from traditional fisheries and aquaculture industry, crustacean shells and similar residues, seaweed
Animal by-products Category 2 and 3	See the ABP Regulation (EC) No 1069/2009 and implementing Regulation (EU) 142/2011 for allowable input materials – various across livestock management, meat processing, food preparation, service, retail and consumption sectors.

Although not a requirement by EU law, standards and specifications for digestate have been developed in a number of EU Member States, including in the UK. The **Publicly Available Specification 110 (PAS 110)** and the **AD Quality Protocol (ADQP)** are the two main examples of where guidance is available to ensure that quality digestate is produced and recognised in the UK.[ii]

If waste derived digestate meets the conditions laid out in both the PAS 110 and the ADQP, it can be certified under the **Biofertiliser Certification Scheme (BCS)** when destined for use in fertiliser applications.[26] This applies to England, Wales and Northern Ireland (a separate scheme covers Scotland). The BCS provides assurance that the digestate produced from AD is safe for human, animal and plant health when spread to land. If a digestate generated from a waste meets these criteria, it is no longer considered a waste, waste controls are no longer applicable, and it is considered a higher value product with a wider range of possible applications downstream. This can make it easier for operators to establish a market and secure value for their digestate as a co-product from the AD process. However, securing BCS Certification is not easy; currently there are 108 active producers certified on the scheme,[27] and just three certification bodies authorised to audit and accredit producers.[28] There is extensive Guidance available for potential participants, and a 38-page checklist available online[iii] which sets out key requirements, centred around the following themes:

- Quality management systems (QMS)
- Operator training and competence
- Processes and procedures
- HACCP systems
- Input materials, regulation and monitoring
- Separation, storage and sampling
- Labelling, marking and use

[ii] Note that manure and slurry derived digestates are exempt from EoW controls, and so do not need to comply with PAS 110, ADQP & the BCS in order to be used freely in applications downstream.
[iii] Checklist available from https://www.biofertiliser.org.uk/upload/bcs_checklist_apr2021_final_june.pdf

BCS registered producers are able to use a certification mark (logo) which depicts the quality of the output, confirming that it can be supplied, stored and used as a "product" in England, Wales and Northern Ireland.

5.2 Land Spreading Regulations

While agricultural land spreading is not necessarily seen as being the preferred end use for digestates generated in NI, due to issues with nutrient pollution in the region, it is nevertheless expected that a notable portion will still be used in this area given the long-established use of digestates as effective biofertilisers in agriculture. Where digestates are produced from slurry and manure that would otherwise be land spread, the expectation would be that the majority of the end product would be returned to land, replacing the unprocessed livestock wastes, offering improved nutrient availability and management opportunities, whilst not exacerbating nutrient loading. Additional uses (discussed in the previous chapter of this report) will be favourable for digestates produced from other feedstocks, such as food wastes, crops and residues. Due to the prominence of land-spreading still, it is important to be aware of the key regulations concerning the spreading of fertilisers to land.

As mentioned in the previous chapter of this report, digestate is recognized as being a valuable biofertiliser as it is rich in nitrogen, phosphorous and potassium (NPK). Nitrogen is the most important of these, as plants absorb this element more than any other nutrient. However, when excess nitrogen is applied to land it can cause a whole host of environmental issues such as:

- **Plant loss:** N aids plant growth, but weeds and non-native plants often grow more readily in the presence of excess N. Other plants with lower N requirements end up dying, causing a decline in native species.
- **Soil imbalance**: too much N also creates an imbalance of other nutrients that are important for plant growth.
- **Water contamination**: Soil bacteria convert N into water soluble nitrates which can runoff soils and pollute nearby water sources (e.g., rivers, streams, oceans, wells, and ground water etc.). If humans ingest water with high levels of N, they can develop gastrointestinal swelling and irritation, diarrhea, and protein digestion problems.
- **Algal growth**: N aids in plant growth, so if it washes into rivers and streams it can result in algal blooms. As algae dies and decomposes, the volume of organic matter in the water increases – a process that uses up oxygen, causing levels to drop. Without oxygen, fish, crabs and other aquatic life die.

Other plant nutrients can also cause similar issues if applied to land in excess. However, N is the most widely used by plants, and therefore it tends to cause the most notable problems in general. In NI similar issues also arise as a result of phosphorus build-up, and so the effective management of all macronutrients is essential in this region in order to minimise negative impacts and to prevent further issues from occurring as digestate production volumes rise.

Due to issues associated with nitrogen pollution in agriculture, the EU's **Nitrates Directive** was published in 1991. This Directive aims to protect waters against nitrate pollution from agricultural sources. In particular, it is concerned with promoting the better management of animal manures, chemical nitrogen fertilisers and other nitrogen-containing materials (such as digestates) when spread to land. The EU's Nitrates Directive is the main legislation concerned with the use of digestate as a biofertiliser across the EU and the UK. The main aims are to: 1) identify polluted water sources, or those at risk of pollution; 2) designate **"nitrate vulnerable zones" (NVZs)**; 3) establish Codes of Good Agricultural Practice (CoGAP) to be implemented by farmers on a voluntary basis; 4) establish Action Programmes to be implemented by farmers within NVZs on a compulsory basis; 5) limit the application of nitrogen from manure (170 kg/ha/yr in areas covered by the Action Programmes); 6) conduct national monitoring and reporting.

NPK limits are dependent on a range of factors such as:

- The types of fertilisers being used (e.g., chemical or manure etc.).
- The types of crops being grown.
- The types of soils being applied to.
- The geography of the land (i.e., land gradient, close to rivers etc.).

There is no specific upper limit for the use of NPK, except when spreading in an NVZ. As highlighted in Figure 6, all of Northern Ireland is designated as an NVZ. Within an NVZ the Directive sets out 170 kg/ha per annum as the maximum amount of N from livestock manure that can be applied to land. Even within an NVZ, the amount of N permitted from other fertiliser sources can vary depending on the specific application (i.e., different limits for different crops being grown).

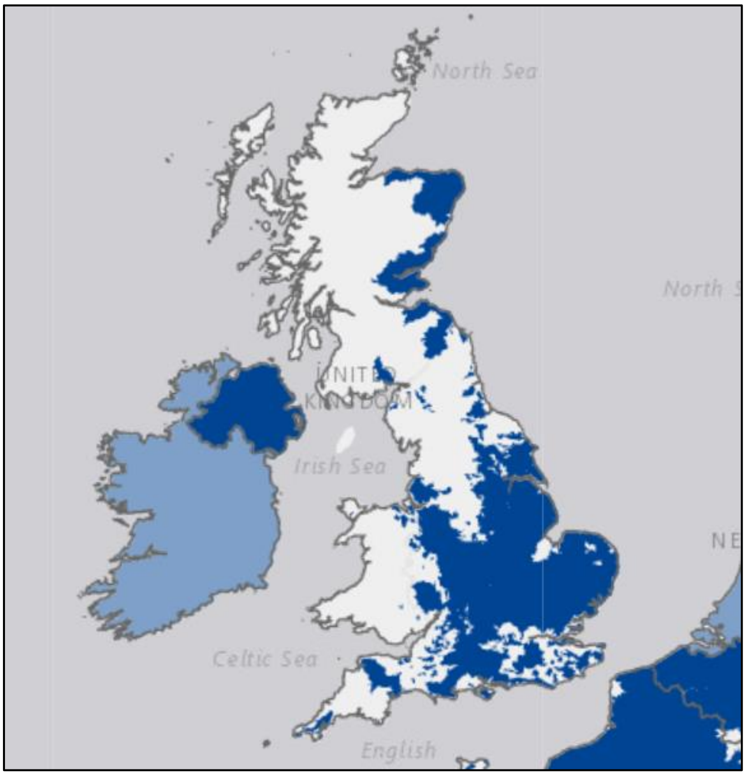


Figure 6: Illustration of the reality that all of Northern Ireland is designated a nitrate vulnerable zone.[29]

In general, farmers should comply with Codes of Good Agricultural Practice (CoGAP) to ensure that they are using only what is needed for their specific land's requirements. CoGAPs are published by individual nations of the EU, therefore content can vary depending on region. They are practical guides to help farmers, growers and land managers protect the environment in which they operate. Compliance with CoGAP is important if farmers are receiving payments under the EU's Common Agricultural Policy and subsequent support frameworks. This is therefore the key motivation when looking to use NPK fertilisers responsibly, to comply with legislation in order to receive relevant payments.

As a result of the Nitrates Directive, it is required by law to apply digestate to land seasonally within an NVZ. Furthermore, in order to ensure the optimal effectiveness of fertilisers (i.e., at times when nitrogen is better absorbed), application should be carried out during periods of active crop growth. Digestate spreading in NVZs therefore occurs from late winter though to the end of summer i.e., avoiding application during autumn and the early winter months, when nitrogen availability is not required by crops (thus, not absorbed as effectively), and there is a significant risk of run-off to surface water or leaching to groundwaters.[iv]

Table 8 highlights the seasonal spreading closed periods for NVZs in the UK. These specific dates are only fixed for areas within an NVZ i.e., the entirety of Northern Ireland.

Table 7: Seasonal spreading closed periods in the UK for organic manure spreading in NVZs.[30]

Start Date	End Date	Land Use	Soil Type
1st August	31st December	Tillage Land	Shallow/Sandy
1st September	31st December	Grassland	Shallow/Sandy
1st October	31st January	Tillage Land	All Other Soils
15th October	31st January	Grassland	All Other Soils

This seasonal requirement for spreading can create logistical issues for AD plant operators as there is not always sufficient demand for digestate. Digestate is created all year round, but due to these spreading restrictions, it can only be used at specific times of the year. This means that the storage of digestate is highly important if it is to be used for land spreading, especially in Northern Ireland. As such, AD operators and digestate offtakers in NI must plan effectively to ensure that there is always sufficient storage capacity for digestates at times when it cannot be spread, or alternative uses must otherwise be found (e.g., in horticulture, landscaping, construction materials or energy applications). Such alternative uses further mitigate investment and operational risk, should spreading not be practicable during the open window for unforeseen reasons, such as poor weather, waterlogged soils, or mechanical issues.

Investment in sufficient digestate storage, either on-site at the point of production, or remotely close to the point of distribution, is critical at the outset of any AD development. Storage can be a significant capital cost and must be included accurately in business plans and financial forecasts, to ensure that management is not compromised once production commences. As digestate has historically been viewed as a by-product of AD rather than a co-product, investment in related infrastructure has been low and the development of appropriate storage a secondary consideration. However, digestate

[iv] Due to the water-soluble nature of nitrates and the greater risk of fertiliser runoff, neither synthetic nor organic fertilizers should be applied to land when soil is waterlogged, flooded, frozen or snow-covered.

management can be more costly at the outset and for the duration of the project if it is not effectively planned in the early stages.

5.3 Northern Ireland Nutrient Action Programme (NAP)

The EU's Nitrates Directive is transposed into Northern Irish Law by means of the 2019 **NI Nutrient Action Programme (NAP)**.[31] This regulation outlines rules surrounding the storage and spreading of fertilisers in Northern Ireland and provides extensive instruction and reference tables to allow farmers and landowners to safely use digestates as fertilisers for their crops.

The Action Programme provides direction to protect water bodies from contamination and nutrient overloading. This Programme was originally aimed at wastewater treatment plants, in order to inform the required treatments necessary before drainage. However, it has since been rolled out more widely in order to protect from other forms of nutrient contamination. Figure 7 illustrates the extent of sensitive water bodies in NI and identifies those at risk of eutrophication and a threat to ecosystems in the region. As of the December 2015 review of areas, 86% of water bodies across NI were considered very sensitive.

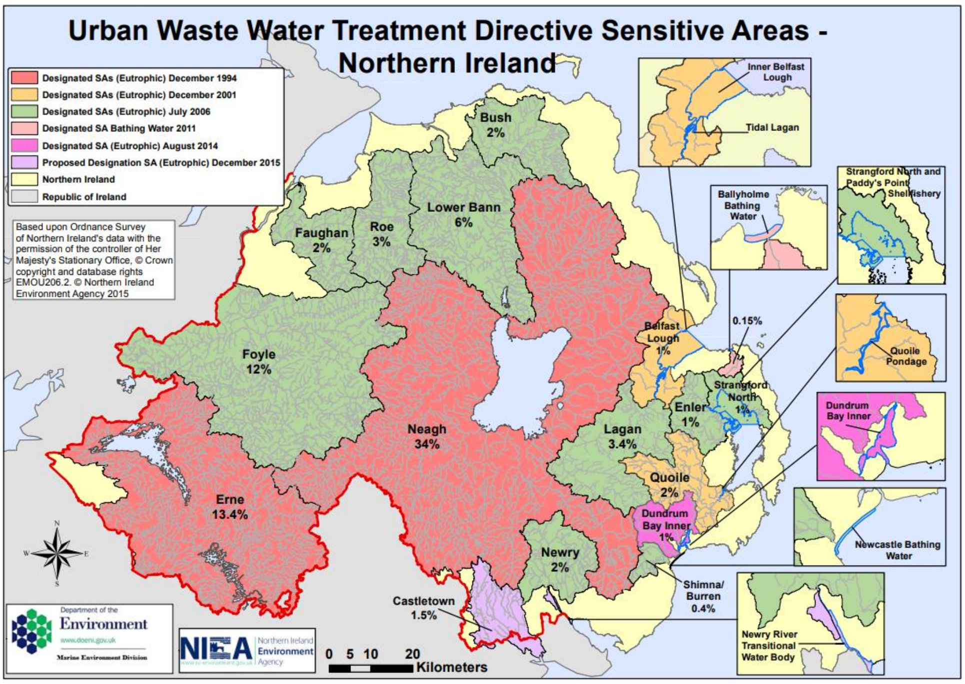


Figure 7. Areas sensitive to eutrophication.[32]

According to the NAP, digestates and manures must be stored and covered with impermeable covers within 24 hours of collection or production. Furthermore, digestate heaps should not be stored near bodies of water (i.e. streams, lakes, rivers) and public water sources. This is to avoid nutrient leaching which could cause contamination and eutrophication down the line. When stored on fields, heaps should not be placed on waterlogged, frozen or flooded land, or on land that is likely to get flooded in the near future. Storage should be carefully planned at the outset of a project, to ensure compliance with guidance and to minimise risk to land, water and human health.

Prior to digestate application to land, detailed chemical content analyses of both the digestate and the soil must be performed. This is to ascertain and quantify the need for fertiliser application to the soil (or lack thereof), and to evaluate the nutrient content in the digestate. This data can then be used to calculate how much digestate can be safely applied to the land (if needed at all). The Nutrient Action Programme includes detailed reference tables listing nutrient requirements for a range of crops. The document also gives instructions on digestate spreading quantities depending on the soil nutrient content and different soil types. Finally, it provides a standardised way for farmers and landowners (or digestate producers in general) to calculate the N content of digestates.

In order to prevent nutrient loss and environmental contamination, digestate must be spread close to the ground. The Action Programme lists a number of approved methods: hand spreading, dribble bar, trailing hose, trailing shoe, soil incorporation and direct soil injection. Furthermore, similarly to digestate storage, digestate should not be spread on waterlogged or flooded ground, or on ground that is likely to flood in the near future. Specific buffer zones between water bodies and digestate spreading areas must also be maintained. Once again, this is to mitigate nutrient leaching and the contamination of water bodies and public water sources. Finally, the application of digestate resulting from the anaerobic digestion of livestock manure is capped at a maximum of 170 kg N/ha/yr, as per the overarching EU Nitrates Directive. This is a measure aimed at preventing nitrogen build up in soils, and can be subject to amendments in cases where soils already contain high levels of N.

Farmers and landowners using digestate to fertilise their land are required to maintain detailed records of use. These records should cover the previous 5 years and incorporate data relating to: land area, soil nutrient content (N and P in particular), the crops planted, the chemical properties and origin of the digestate used, spreading rates and quantities, and any information about livestock grazing and movements on the land. Full traceability of the value chain is important in order to be able to communicate the benefits of digestate fertilisers through to the end consumer.

In the future, it is believed that the use of digestates as agricultural fertilisers will be looked upon favourably in terms of carbon accounting considerations, as farmers and landowners will need to become more accountable for their emissions going forward. Cases where low emissions storage and spreading practices are adopted will be favoured, with such conduct already being encouraged in Great Britain, under the current policy framework.

6. Digestate Production in Northern Ireland

This section presents the current and future production potential of digestate in Northern Ireland, providing quantifiable insight into the scale of opportunity associated with the generation of this co-product from the established and growing AD industry in the region.

6.1 Current Digestate Production in Northern Ireland

As of September 2023, Northern Ireland was home to approximately 80 operational AD facilities, with a combined electrical capacity of 47.5 MWe_{eq}.[v] According to information extracted from the plants' original planning documents, along with more up-to-date information found in the press, these plants have the capacity to process up to 1.35 million tonnes of feedstock per annum. By assuming that 90% of processed feedstocks are typically retained as digestate, it is therefore estimated that the AD plants currently operating in the region will thus, have the capacity to generate in excess of **1.2 million tonnes** of digestate per annum.[vi]

Figure 8 shows the location of operational AD plants within NI, along with an indication of digestate production and distribution density around the sites, based on plant size. This provides a visual indication of the areas across the region which would be more likely to experience issues in terms of finding a suitable landbank for digestate, should it be used in conventional agricultural land spreading applications. In areas where digestate density is lower, land spreading could be considered a possible end-use, provided that relevant rules and regulations are complied with. However, in areas where digestate density is higher, or in areas close to bodies of water (i.e. streams, lakes, rivers) and public water sources, alternative end-uses of digestate should be prioritised to minimise risk of nutrient excess.

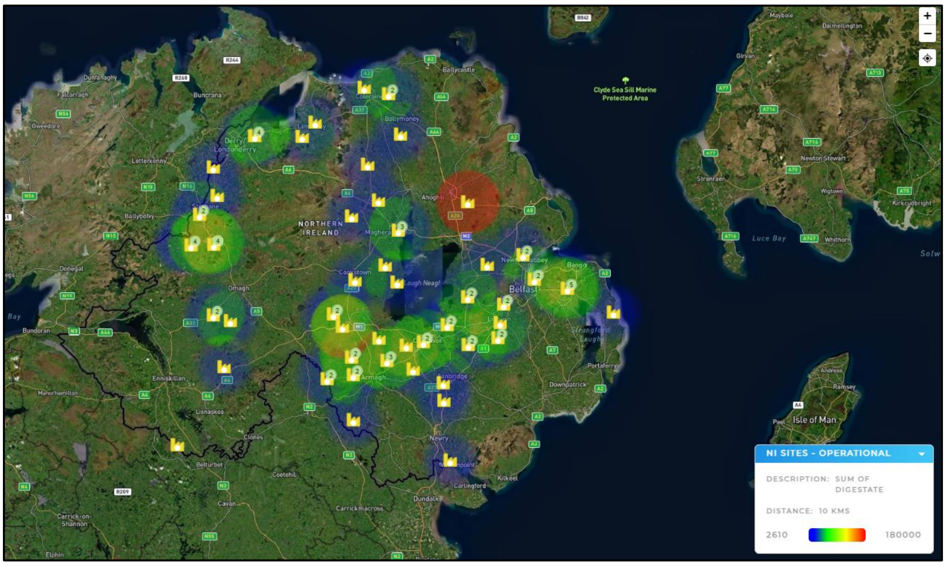


Figure 8. Location of operational AD plants in NI and corresponding digestate densities.

[v] Information extracted from NNFCC's AD Deployment Database (updated a monthly basis).
[vi] 6 out of the 80 operational plants in NNFCC's database do not have any feedstocks data, therefore, no digestate production estimates could be made for those plants. The estimate of 1.2 million tonnes per annum only covers the 74 other plants.

6.2 Future Digestate Production in Northern Ireland

There are currently 22 unbuilt AD projects with planning consent across NI. All of these projects were designed to be CHP facilities and have a cumulative electrical capacity of 14.5 MWe. Application documents indicate that just over 400,000 tonnes of feedstocks could be processed at these plants, leading to the production of roughly 360,000 tonnes of additional digestate per annum.

However, given recent changes to the policy framework across the UK, it is unlikely that many of these planned projects will proceed in their original guise. Where UK policy has previously supported the generation of electricity and heat from AD, support has now shifted to prioritise the generation of biomethane for use in transport, or for grid injection. The two main policies supporting AD project development in GB at present are the **Green Gas Support Scheme (GGSS)** and the **Renewable Transport Fuel Obligation (RTFO)**, with the latter extending to NI. Given that all of the 22 plants currently in the planning pipeline in NI are registered as being CHP (i.e., electricity and heat generating) facilities, it is anticipated that a considerable number of these will therefore not go ahead in their original form, due a lack of support for these types of AD facilities in the current climate. It is possible however, that some of these projects will instead amend their planning consents to become biomethane-to-grid (BtG) facilities, in order to benefit from future policy support. Despite the uncertainty, this data provides valuable insight into NI's AD development interests.

Furthermore, data reported by the DNOs in NI suggests that 24 projects have registered an interest to inject biomethane in the future. Further detail on these 24 projects will be obtained through a formal Request for Information (RfI), due to be issued in early 2024. By 2030, it is envisaged that 1.5TWh of biomethane could be injected into the NI Gas Network annually.[33]

Building on knowledge obtained for the plants previously consented, and extrapolating data points in line with DNO expectations, it is estimated that the AD sector in NI could produce up to 2 million tonnes of digestate per annum by 2030 (Figure 9), with new plants likely to commission from 2024 onwards.

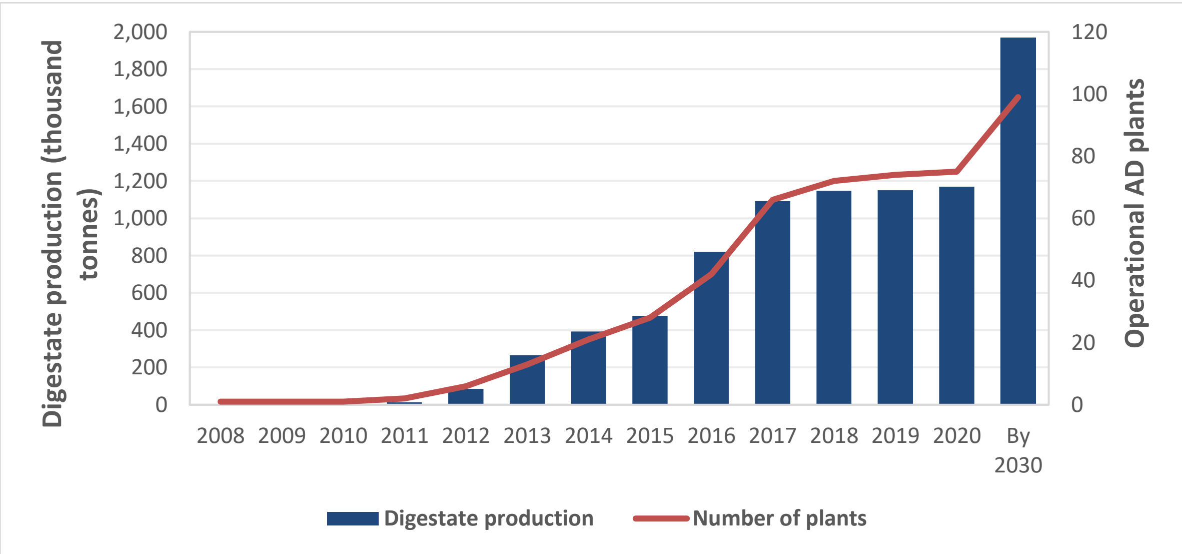


Figure 9. Cumulative digestate production capacity in Northern Ireland (NNFCC analysis).

Figure 10 shows the comparative distribution of existing and potential future plants, based on data gathered from available planning documents. The maps illustrate that if the consented projects were to go ahead, there would be a more significant increase in digestate production in the north of NI. However, it is important to note that, pending the RfI, specific locations may change. Although, as developments are typically based around areas of high feedstock availability, distribution is not expected to deviate too significantly from what is already proposed.

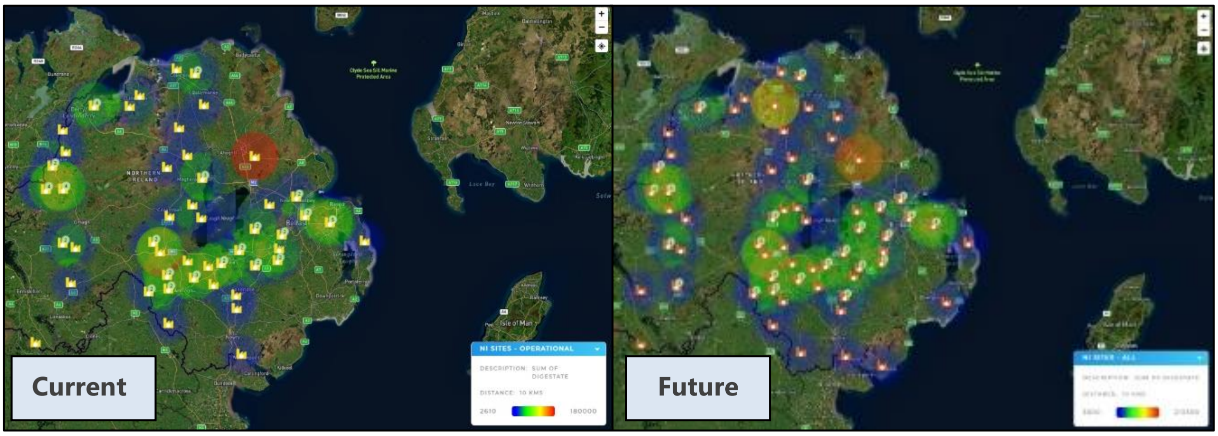


Figure 10. Potential location of AD plants in NI in the future and corresponding digestate densities.

In 2021, the Northern Irish government published their energy strategy: “The Path to Net-Zero Energy”. It highlights that there are a range of approaches that could be taken to deliver a net-zero carbon energy mix by 2050. To help illustrate potential pathways after 2030 two scenarios were presented, to show different net-zero carbon energy systems based on the adoption of different policies and technologies. These two scenarios explore future energy pathways and have been developed using a new publicly available and open-source Energy Transition Model built specifically for Northern Ireland.[34, 35] Neither are forecasts of the future, nor do they represent any statement of policy intent.

The two scenarios put forward in this document are referred to as the “Power Play” scenario and the “Flexible Fit” scenario. These are summarised in the table below.

Table 8. Description and characteristics of the Future Energy Scenarios in 2050, as set out in NI’s energy strategy: “The Path to Net-Zero Energy”.[36]

Scenario	Approach	Characteristics
Power Play	This scenario relies largely on the success of the renewable electricity sector. High levels of electrification take advantage of a substantially larger renewable electricity base. Increased generation capacity is met through a combination of solar photovoltaic, offshore wind, and marine technology. In addition, there is an expansion of onshore wind, aligned with improved demand-side management and flexibility measures.	• With high levels of electrification and energy efficiency, overall energy demand falls by 52%. • Electricity is the largest energy source across heat, power and transport: 50% of total demand. • Hydrogen (19%) plays a key role in transport and industry, and **biogas is an important energy source**. • Oil and gas continue to play a very small role due to ‘hard to electrify’ areas. • Coal is no longer in use.

Flexible Fit	This scenario takes greater account of regional differences in Northern Ireland and includes higher levels of both local involvement and local responses to the energy transition. Although electrification remains at the centre of the energy system across NI, there is greater use of alternative fuels like hydrogen and biofuels. Energy for heat and transport will likely have different solutions depending on location and geography, and for power it may require a more decentralised system.	• A diverse mix of technologies, greater decentralisation, and energy efficiency means that energy demand falls by 50%. • Electricity is the largest energy source: 38% of total demand. • **Biofuels account for 29% of total energy demand, due to biomethane use in the gas network and biofuels replacing some heating oil**. • Hydrogen contributes 24% across transport, heat and industry, whilst coal is no longer in use. • Oil accounts for 3% of final energy demand for transport.

In both cases, biogas and biomethane is set to play an important role in the net-zero carbon energy mix by 2050. Figure 11 illustrates the expected final energy demand anticipated in 2030 and onward to 2050, depending on the future energy scenario adopted.

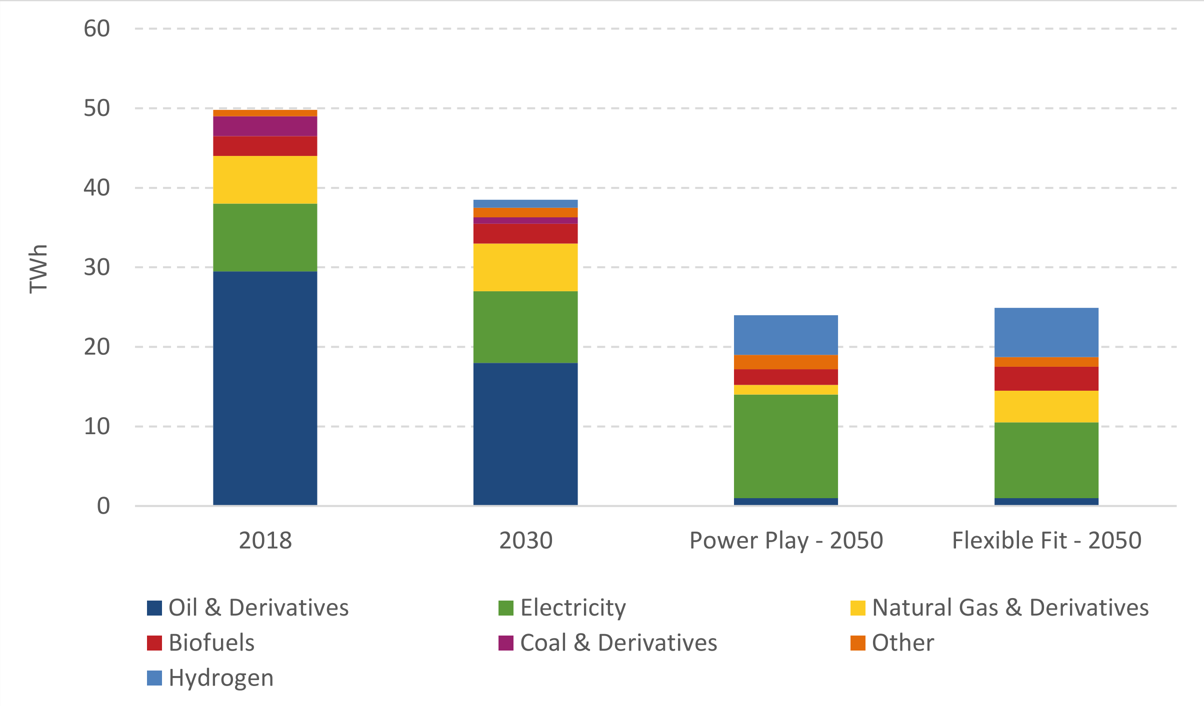


Figure 11: Final energy demand by scenario to 2050.[37]

Demand for energy is clearly driving growth across the AD sector, but as a valuable co-product it is essential that digestate is effectively managed and considered at the outset, to ensure that appropriate investment is allocated to fully maximise the potential of this material. Further detail on treatment options and investment requirements is set out in subsequent sections.

7. Optimal Processing & Use Pathways

Following the review of digestate availability in NI and the expected growth in future years, it is prudent to consider processing options that are currently available to address logistical and technical challenges associated with its production, storage, distribution and use.

In WRAP's 2020 "AD and Composting Industry Market Survey", AD operators were interviewed regarding the extent of digestate processing at sites across England and Wales. Figure 12 shows the types of processing undertaken once the digestate was produced at these sites, indicating how digestate is currently processed by the existing AD industry in these areas of GB. A small proportion (12%) of those surveyed said that no processing of the digestate was undertaken. This compares to just over half (54%) of those surveyed in 2012.

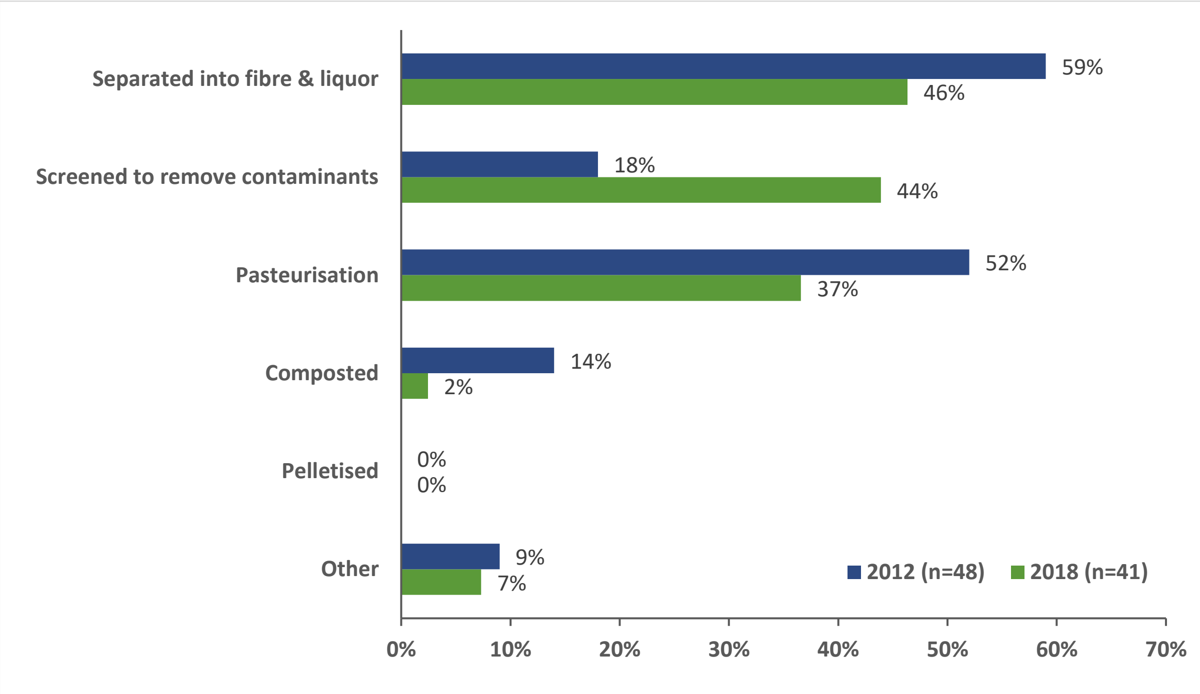


Figure 12: Digestate processing undertaken (% of sample).[38]

Furthermore, after separation, 24% of the surveyed sites said they undertook further processing compared. Four respondents specified that this involved: aerobic treatment (1 respondent); fibre centrifuged (1 respondent); drying off the liquor (1 respondent); ultra-filtration and reverse osmosis (1 respondent).

In practice around 50% of all digestate produced in England and Wales is used whole, whilst the remainder is mechanically separated into solid and liquid fractions, according to WRAP's 2020 "AD and Composting Industry Market Survey". Furthermore, in 2018/19 at commercial waste sites across the UK, operators paid users to remove almost all of the whole digestate produced at these facilities (99%) (Figure 13), whilst all of the whole digestate produced by farms was consumed by their own business. Sites were marked as commercial if they processed food waste (these could include some sites based on farms). Sites were marked as farm if their feedstock requirements consisted only of manure/slurry, purpose grown crops, or crop residues.

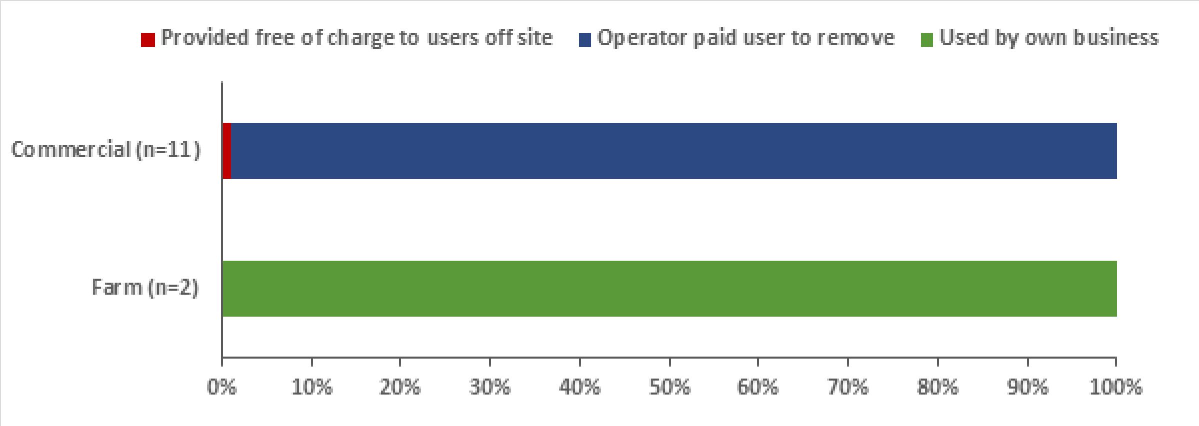


Figure 13: Whole digestate destinations, by site type (% of tonnes).[39]

The same survey results also showed that amongst commercial sites, half of separated fibre was used by their own business, whilst one quarter was sold off site, and another quarter removed by paying end users (Figure 14). At farm AD sites, the majority of separated fibre (68%) was provided free of charge to users off site. The remaining 32% of solid digestate was used by the farm's own business.

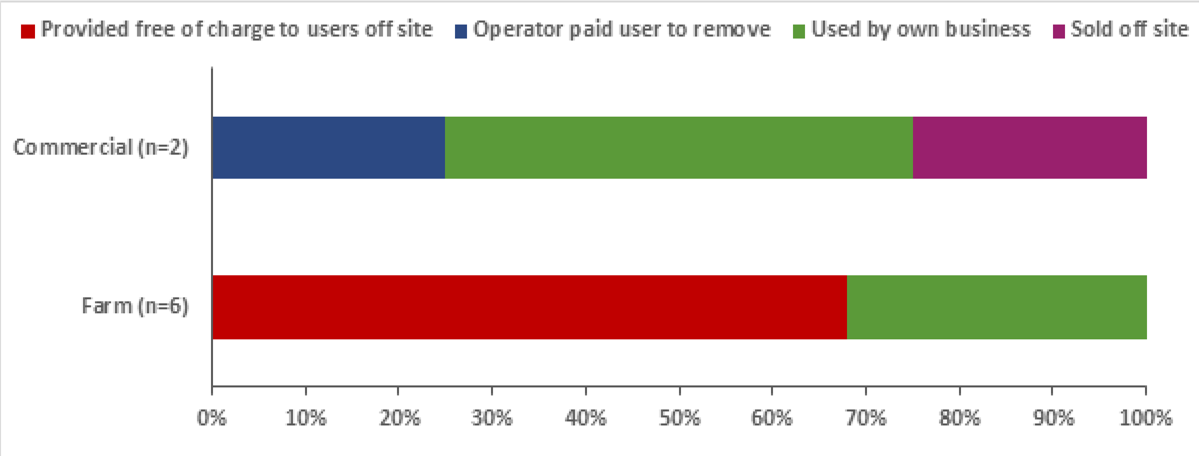


Figure 14: Separated fibre destinations, by site type (% of tonnes).[40]

From the commercial sites (other than one water company included in the analysis), 35% of liquid digestate was sold off site; this option would represent over 70% of the liquid digestate from commercial sites if the water treatment facility were excluded from the analysis. At farm AD facilities, around half of liquid digestate produced (46%) was provided free of charge to users off site and a similar proportion (45%) was used by their own business. The remaining 9% was paid for by operators to be removed by users (Figure 15).

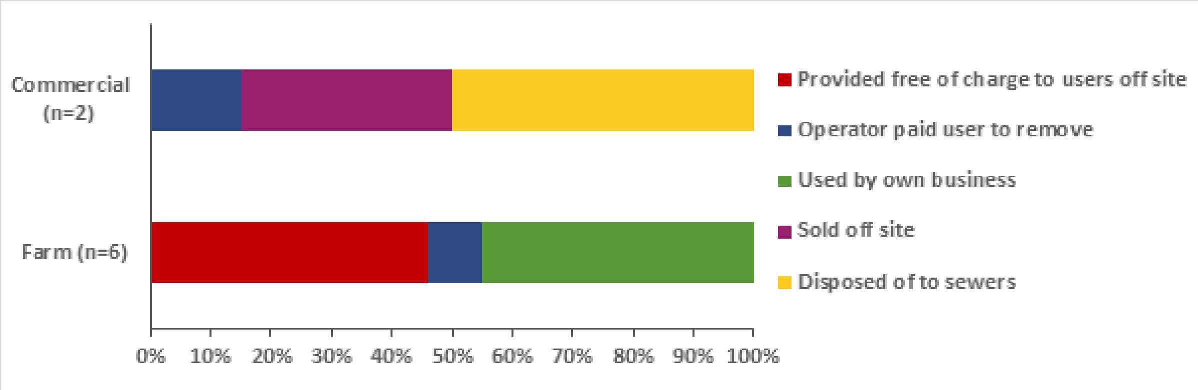


Figure 15: Liquid digestate destinations, by site type (% of tonnes).[41]

The survey results also highlighted that over 90% of digestate produced (whole, fibre and liquor) is used in agriculture at present (Figure 16). This is despite the range of possible applications of digestate presented earlier in this report, and highlights the likelihood that a considerable proportion of digestate would also be used by the agricultural industry in NI, unless investments are made to encourage greater use elsewhere.

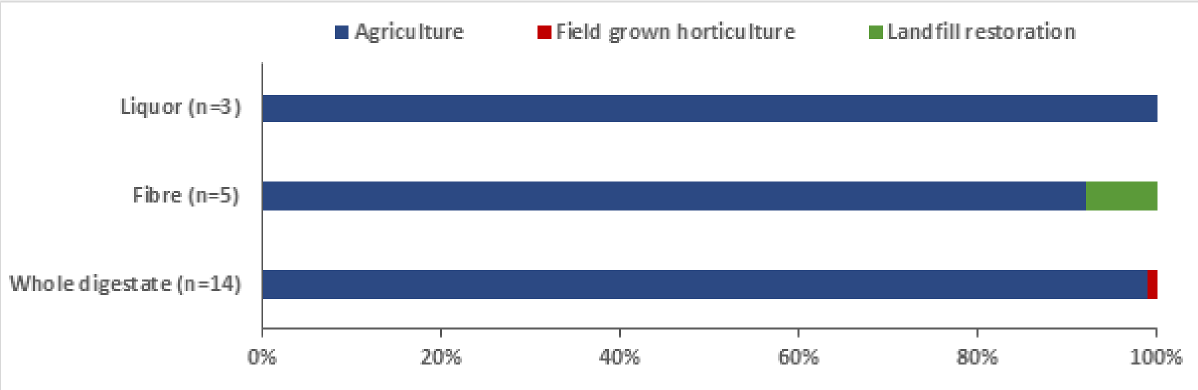


Figure 16: Application of whole digestate, fibre and liquor (% of tonnes).[42]

The survey data presented above indicates how digestate is currently processed in other areas of the UK. If NI is to follow suit, this analysis presents key options that producers of digestate should consider going forward, with the nature and extent of processing being dictated by the composition and volume available, by the seasonality of demand, and by any relevant regulatory restrictions. Processing is typically undertaken where the market has a preference for certain forms of digestate (e.g., fibre or liquor), where storage costs are otherwise prohibitive, or where an excess of supply is present in a local area, so wider geographic sale or distribution is necessary. The remainder of this section will discuss processing options in greater detail.

Digestate treatment methods can generally be divided into either partial or complete processing techniques. Partial processing typically uses relatively simple and cheap technologies, and is primarily used to describe methods of separating solid and liquid digestates. Mechanical technologies are often employed (e.g. screw press separators or decanter centrifuges) and methods of flocculation or precipitation may also be used to improve separation. Complete processing, however, refers to the total refining of digestate, down to the purification of generated process waters. For example, membrane technologies such as nano- and ultra-filtration, followed by reverse osmosis can be used for nutrient recovery. Membrane filtration gives two products, a nutrient concentrate and purified process water. Furthermore, stripping, ion exchange and struvite precipitation can be used to reduce the nitrogen content in the digestate, whilst advanced processes like pyrolysis can be used to lock up nutrients and carbon in biochar. Independent of the technologies used, complete processing requires high chemical and energy inputs. Treatment costs are usually high and there will be higher investment costs for appropriate equipment, so this option is only generally pursued if no local or alternative market exists for less refined products, or a specific challenge or market opportunity is identified for the outputs – it is also typically more favourable at scale, due to the higher capital and operating costs incurred.

7.1 Digestate Separation

In its raw state as a wet, bulky product, digestate can be costly to store, transport and spread. Furthermore, when combined with regulatory restrictions and growing seasons (which limit the window of opportunity for spreading) digestate is often difficult to valorise.

According to WRAPs latest industry survey, in 2018/19 around 50% of digestate was used whole, whilst the remainder was separated, typically into solid and liquid fractions, to ease storage and distribution pressures.[43] 'Dewatering' is a term used to describe the separation of digestate into: solid fibre (typically 25-35% dry matter) which can be used as a soil improver; and a liquor (typically ≤ 6% DM) that can be used as a liquid fertiliser. Dewatering can be achieved using:

- **Mechanical dewatering** - for solid-liquid fraction separation using screw presses, belt presses, or centrifuges.
- **Biological dewatering** - utilising the heat produced by the exothermic reactions in aerobic decomposition (composting) of stacked digestate (while capturing any runoff).
- **Thermal drying** – utilising the waste heat from CHP engines (typically after dewatering) to increase dry solids content to >90%.

Figure 17 highlights the main pathways for digestate processing and use. Table 9 provides a comparison of commonly used equipment.

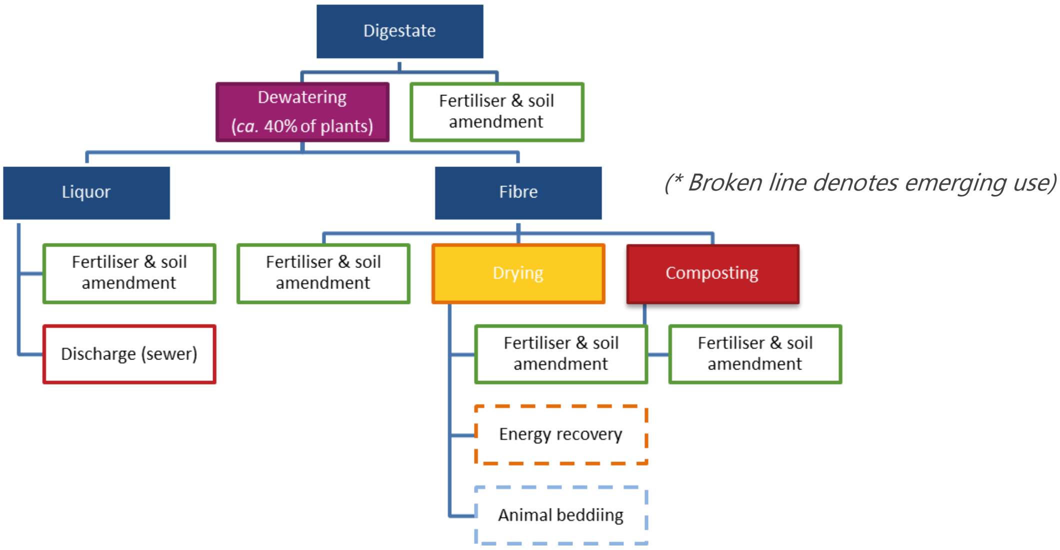


Figure 17: Pathways for Digestate processing and use.

Table 9: Overview of common digestate processing equipment.[44]

Step 1: Thickening/ dewatering	Step 2: Separation/drying	Step 3: Concentration of separated liquid	Energy consumption	Throughput	Capex	Opex	Comment (DS=dry solids)
Belt Press			Low (1.5-2 kWh/m^3)	Large range of unit sizes	Low-Medium: £100K+	Low	• For treating digestate >0.5% DS • Produces a cake of 18-25% DS Higher efficiency of solids capture than screw press
Centrifuge			Low (3 – 5 kWh/m^3)	13-20 m^3/h +	Low-Medium: £105K for 10,000 tpa capacity[45]	No info	• For treating digestate >1% DS • Produces a cake of 18-35% DS (highly efficient solids capture (>95%)) and liquor of <0.3%DS
Screw Press			Low (0.4-0.5 kWh/m^3)[46]		Low: £15,000 for 500 kW$_e$ plant	Low	• Delivers up to 30-38%DS • Simple systems but efficiency of solids capture is low (10-40%)
	Rotary Drying (Direct heat)		1 MWth per tonne water removed		Medium	High	• For treating digestate >18%DS • Produces up to 95%DS
	Belt Drying (Direct heat)		1MWth per tonne water removed	(250kg ->1 tonne/hr)	Medium-High: £270-£295K for 0.5MW$_{th}$ unit (£70-100K for drier alone)	High	• For treating digestate >18%DS • Produces up to 90%DS
Press Evaporator and vacuum (J-Vap)		**0.3-0.35 MWth per tonne of water removed**		High	High	For treating digestate >1% DS Produces up to 99%DS	• For treating digestate >1% DS • Produces up to 99%DS
		Evaporator (Indirect heat)	Moderate (0.35MWh$_{th}$/ton evaporated)	10,800 kg/hr examples	High (£1.3m)	High	• For treating liquor at 1-2% DS • Produces up 20%DS. Requires ammonia trapping
		Reverse osmosis (membrane purification)	High (less than vacuum evaporation) (0.016-0.025MWh/m^3)		High	Much lower than evaporation	• For treating liquor <1% DS • Produces concentrated liquid fertiliser (30% of output) and purified water (70%). Complicated and requires ammonia trapping. Reserved for large facilities with water discharge issues.

7.1.1 Mechanical treatment

Mechanical treatment removes excess water from digestate, to increase dry matter content of the solid fraction. This also yields a nitrogen rich liquor which can be used for more targeted land spreading or use in higher value applications.

- **Dewatering** is a term used for processes achieving greater than 18% dry solids; though more typically 25-35% DS, which stabilises digestate for storage and spreading.
- **Thickening** is a term used for processes producing digestate of 5-10% dry solids and separate nutrient-rich liquor.

Mechanical treatment is often employed as a first step in the processing of digestate, typically generating a semi-solid “cake” which is easier to store and use in other applications, alongside a nutrient-rich liquor which is still best suited to land spreading. Reduced material volume resulting from such a process greatly simplifies handling and reduces subsequent transport costs. Common mechanical treatment options include:

- Dewatering press (material is pumped through filtering screen plates)
- Screw press (rotating screw of reducing pitch linked to screened outlets)
- Belt press (digestate held between cloth belts and repeatedly pressed between rollers)
- Rotary press (rotating drums with screen walls, water separated using centrifugal force)

These mechanical approaches are relatively low in cost (CAPEX and OPEX) and energy use compared to more energy intensive thermal drying methods. Many sites will incorporate simple mechanical separation immediately post-digestion, to ease storage pressures and reduce capacity. The solid fraction will be stacked on hard-standing and liquid stored in tanks or covered lagoons.

7.1.2 Biological treatment

Biological treatment involves a post-AD aerobic composting step, where dewatered digestate is stacked, then regularly turned and agitated to increase exposure to aerobic conditions which generates heat and helps to dry out the residual digestate naturally. Disadvantages of this approach include the treatment area needed, labour requirements for physical moving and turning of material, and the extended treatment time. Runoff also needs to be captured, adding to infrastructure costs, which results in higher relative CAPEX and OPEX than dewatering alone.

7.1.3 Thermal treatment

Following mechanical treatment (to reduce process energy demand), thermal treatment (drying) can be used to remove water and further increase dry solids content. Digestate is typically dried to over 90% dry matter to stabilise it and facilitate long term storage in silos (or bags) without the risk of fermentation breakdown.

Drying typically occurs in two forms:[47]

1) Direct: hot air (300-600˚C) flows through the vessel containing digestate;

2) Indirect: digestate is separated from the source of heat by metal walls where heat is passed to digestate by conduction. Temperatures are typically lower than with direct systems e.g. using steam at 135-215°C or thermal oil at 200-250°C.

Digestate drying can make use of what would otherwise be considered 'waste' heat from biogas CHP systems, which is often difficult to use elsewhere, particularly in rural areas or at large plants, where supply can sometimes outweigh demand from suitable existing or potential new heat users. By utilising this 'waste' resource from biogas CHP facilities, costs and GHG impacts can be reduced elsewhere in the supply chain (e.g. storage; transport; spreading; improving overall sustainability and the viability of such plants).

In the case of solar drying no pre-treatment is required, although it may be beneficial. Digestate is fed into a ventilated greenhouse or drying facility where water is evaporated by thermal energy from the sun, it is then turned continuously to ensure consistent product quality. If an integrated system is developed here, waste heat from a combined heat and power (CHP) system can also be utilised to supplement solar energy *via* underfloor heating.

At the elevated temperatures used by thermal drying processes, ammonia is commonly released. It should be captured by evaporated fractions, and condensed to form a condensate (high strength liquor) which will require further treatment prior to discharge. If required, dried products can also be pelletised to ease subsequent storage, transportation and use. Dried digestates have a number of potential uses but they are normally applied to land as organic fertilisers, or alternatively used as fuel for energy production.

7.2 Commercial Processing Technologies

At present, as discussed above, digestate is predominantly applied to land unprocessed. However, industry, regulators and policy makers are growing increasingly aware of issues associated with operation, management and digestate quality i.e., issues that could compromise the market potential of this material going forward. For example, plastic contamination, typically from food packaging, and the possibility of high levels of ammonia emissions are problematic when digestate is spread to land. Therefore, there is a real need to be able to transform digestate into a higher value product that is easier for operators and farmers to handle and use. As such, there are already a number of commercial technologies currently available for optimising the value of digestate. WRAP's review of "Technologies to optimise the value of digestate (2020)" outlines such systems.[48] Commercially available technologies that are of greatest relevance to the interests of NI are included in the table in Annex II. There also a considerable number of pre-commercial processing technologies that are currently under development for the optimisation of digestate value according to this same review by WRAP.

Some of the most notable digestate processing technologies available and under development at present are discussed further below:

- **Neo Energy** - The Neo Energy system uses excess heat together with electricity from CHP to dry digestate to a granular form. The process has been commercialised in the US with granules being sold to golf courses as high value fertilisers. Digestate pelleting lines have been set up by organisations across the UK (e.g. PRM Waste Systems UK, Kesir Pellet Mills UK, Dorset Green

Machines) but despite this technology being available at larger scales, there is little evidence of wider upscaling to date.[49]

- **Hydrothermal Carbonisation (HTC)** - Hydrothermal carbonisation takes wet/dry biomass and applies heat and pressure to convert it into a dry, black powder (biocoal/biochar). This reduces the weight of the digestate and adds value to both the digestate and the feedstock. Organisations understood to offer such a technology include Antaco and TerraNova Energy. The Incover EU project also aimed at validating and demonstrating HTC for the production of bio-coal. The project determined that this process has a technology readiness level (TRL) of 9, indicating that it is now ready for use on the market.[50]

- **Boerger Bioselect Separator** - With this technology, digestate flows through the Bioselect vessel through a sealed slotted screen, which separates the outer vessel from an auger chamber. The liquid then filters through the screen to the outer vessel. The liquid phase can then be discharged, whereas solid particles remain on the filter where they are conveyed by a rotating auger unit to a postpress channel. This process has been applied to digestates containing 6-15% dry solids and achieving up to 35% dewatered fibre. This is a fully commercial process that is already being utilised at full-scale.[51, 52]

- **Weltec Kumac Digestate Processing** - In a multi-stage process, the Kumac processing system separates solid matter from water. The result generates roughly 50% clear water, approximately 25% solid matter and about 25% liquid nutrient concentrate. This technology has already been in continuous use for several years and is successfully installed at 15 locations with intensive livestock breeding or close to large biogas plants. One of the key benefits of this solution – which is already well established in the Netherlands and Belgium – is the scalable modular nature of this system which can be used to process roughly 70,000 tonnes of digestate per year.[53] It is anticipated that this technology could be widely deployed in NI, with the solids (containing P & K) having the potential to be exported to nutrient deficient regions outside of NI.

- **Digestate Pyrolysis** – Research in this area indicates that digestate pyrolysis can generate biochar, biooil and syngas, whereby syngas can be used as an energy source for the process. Research indicates that AD combined with pyrolysis, could produce roughly 6100 GWh of biomethane, in addition to 200,000 tonnes of biochar, per year. This biochar is capable of retaining 64% of phosphorus (addressing a notable problem across NI), in addition to delivering a CO_2 removal rate of 563 kg CO_2 eq per capita in NI.[54] This technology is being developed by researchers in NI as a means of addressing the widespread nutrient pollution problem in the region.

7.3 Processing & Use Pathways for Northern Ireland

Considering the current situation with nutrient loading in NI and the planned growth of the biomethane industry, the above review is helpful in understanding how and where digestate is best produced, processed and used within the region for greatest benefit.

Evidently, livestock wastes are typically best digested close to the point of source, and at a relatively small-scale, in on-site AD facilities. Where this is the case, the resultant digestate will directly replace the untreated livestock wastes that were otherwise spread to land, presenting a neutral or favourable position with regard to nutrient loading on agricultural land, given that nutrients in digestate would be more available for plant uptake and less susceptible to run-off and leaching. In such instances, a simple mechanical press may be prudent, to separate digestate into solid and liquid and solid fractions, for ease of storage, logistics and distribution. Once separated, if other local processing facilities are established at larger sites, the solid fraction could be transported there, to be further processed into higher value products or materials that feature higher up the hierarchy of use (as described in Figure 4).

Where crops are co-digested with livestock wastes, typically at a slightly larger-scale, combining inputs from multiple sources, a fraction of the resultant digestate could be land spread, to substitute the untreated wastes, and the remainder would need to be captured and processed, then transferred to alternative land-based markets, such as horticulture, landscaping or forestry. By diverting a fraction of the output from such facilities away from agriculture, the nutrient issues would remain neutral or improved, given crop feedstocks would take up nutrients which would not then return directly to land.

Where other, non-agricultural feedstocks such as processing residues and food wastes are used as feedstocks, these should be processed centrally in larger-scale facilities, benefitting from economies of scale and allowing a more sophisticated and costly approach to digestate management to be adopted. In such cases, although capital and operational costs would be further increased by the requirement for more complex digestate processing equipment, the value of the resultant output would be improved, in line with the hierarchy of use (Figure 4). Where large volumes of digestate are produced centrally, digestate should be processed to allow for the nutrients to be captured, and subsequently either transferred to other land-based markets, exported away from the land-based sector, to either energetic or material-based applications, or exported away from NI to other countries currently facing a nutrient deficit. Furthermore, in such situations, the highest value application with the greatest ability to address the nutrient issue could be targeted, producing biochar via pyrolysis for use in agriculture, AD (as a feedstock additive or slurry treatment) or in construction for example.

The preferred digestate production and use pathways are set out in Figure 18, based on feedstock type, scale and operating model. A mix of pathways is inevitable as the biomethane industry expands, but alignment of the digestate processing pathways with the hierarchy of use should yield beneficial results, in terms of both environmental and economic impact.

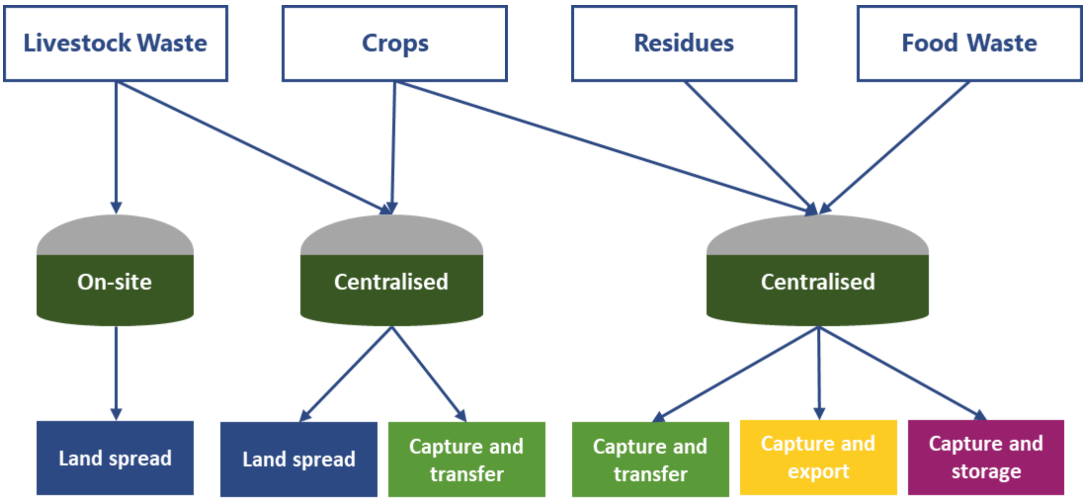


Figure 18: Preferred digestate processing and use pathways for Northern Ireland

8. Market Awareness and Acceptance

Having presented a comprehensive overview of digestate generation, composition, regulations, quantities, and processing technologies available, this section will discuss the reality in terms of encouraging the widespread acceptance of digestate in NI.

Where land spreading is to be carried out, learnings from the UK demonstrate that landowners have shifted from being nervous about the use of digestate around 10 years ago, to now actively looking to source it and demanding it from AD operators. The reason for this shift is ultimately due to an initial lack of understanding from landowners, to accepting that it is now a superior, renewable alternative to inorganic fertilisers. Due to availability of nutrients within digestate compared to manures and slurries, it is also widely accepted as a better alternative. This highlights the critical importance of education in this space. However, notwithstanding the issues of nutrient loading in NI and the consideration of nutrient diversion, removal or export techniques discussed above, wider education of the issues, concerns and opportunities is also necessary.

In the UK, industry bodies like WRAP have been involved in stakeholder engagement in this area. In Northern Ireland, it would be prudent for a comparable organisation to carry out an educational role on the benefits of digestate prior to any future growth, whilst also considering the appropriateness of land for nutrient placement. Furthermore, the carbon benefits that digestate offers over traditional alternatives means that the use of this material will help to reduce the supply chain emissions related to agriculture – a key benefit that should be communicated to landowners in the region. For example, for every 1 tonne of artificial fertiliser that is replaced with digestate, 1 tonne of oil is saved, in addition to 108 tonnes of water, and 7 tonnes of CO_2 emissions.[55] On the contrary, where land spreading is not the main focus, further nutrient and carbon removal is possible, via biochar production, use and export, for example.

8.1 Best Practice Guidance

Best practice guidance has helped to ease the concerns of landowners using digestate across the UK. This refers to sector led guidance which provides confidence to users of digestate that it is an industry accepted material for land use applications.

Key examples include the development of the PAS 110 standard and the accompanying AD quality protocol (ADQP) (both applicable across the UK, including NI), as well as GGSS consultations and responses related to low-emissions storage and spreading.

8.1.1 PAS 110 & ADQP

The British Standards Institute's Publicly Available Specification 110 (BSI PAS 110) is a certification scheme managed by the UK's Environment Agency. It addresses all AD systems that accept source-segregated biowastes. It specifies controls on input materials and the management of the AD process; the minimum quality of whole digestate, separated fibre and separated liquor; information that must be supplied to the digestate recipient.

The AD Quality Protocol (ADQP), published by WRAP, is a means of outlining steps to achieving PAS 110 status. A comprehensive list of appropriate input materials permitted by the PAS 110 is provided in the ADQP. Input materials should be kept separate from any other materials, processes and storage on the same site. Furthermore, quality digestate should not be contaminated with any other material that does not conform to PAS 110 specification.

A key requirement of PAS 110 is that all digestates must be produced by an AD process that includes: a pasteurization step capable of heating all material to at least 70 °C for one hour; or an equivalent alternative treatment validated for its efficacy in reducing plant pathogens.

Compliance with ADQP criteria is considered sufficient to ensure that fully recovered digestates can be used without undermining the effectiveness of the EU's Waste Framework Directive. Therefore, digestate can be handled without the need for waste management controls i.e., if waste feedstocks are used, subsequent digestates cease to be waste. Both the PAS 110 and the ADQP aim to increase market confidence in the quality of products made from waste.

8.1.2 Green Gas Support Scheme (GGSS): Digestate Management Consultation

Through the GGSS, the UK Government aims to: encourage continued deployment of AD biomethane plants in GB in order to increase the proportion of green gas in the grid; ensure value for money for the production and use of biomethane; and, minimise a market hiatus for the biomethane industry. Although the GGSS is not applicable in NI, the guidance on digestate management is still relevant. In the guidance it is considered that digestate is a nutrient rich output of AD that can be used as a fertiliser. Used like this it has many benefits, but it also releases ammonia when stored or spread on land. It can also lead to water pollution if it is over-applied or used in the wrong place or at the wrong time.

Ammonia is an air pollutant that combines with other chemicals in the atmosphere to form fine particulate matter which has negative impacts on human health. Ammonia is toxic to some plant species, even at low concentrations, and sensitive species are currently being impacted by ammonia concentrations across large parts of the UK. Ammonia deposition also leads to biodiversity loss in sensitive habitats. Most of the UK's protected habitats are currently receiving excessive nitrogen and any increase in ammonia emissions will exacerbate this situation. The UK government has legally binding targets to reduce ammonia emissions as well as a target to reduce nitrogen deposition in England. As stated in the Future Support for Low Carbon Heat: Impact Assessment, ammonia from AD digestate currently accounts for around 5% of all UK ammonia emissions. Therefore, to maximise carbon savings from the Green Gas Support Scheme, the UK needs to consider all viable ways to mitigate ammonia produced. The same considerations should be made in NI to minimise ammonia emissions and related impacts.

In their April 2020 consultation the UK Government asked for views on digestate and ways to mitigate ammonia emissions throughout the AD process. In further engagement with Defra and the Environmental Agency (EA), two proposals were published for the mitigation of emissions without impacting on GGSS scheme deployment or presenting a significant risk to investment.

Proposal 1 - Digestate needs to be stored in tanks or lagoons of sufficient size to comply with spreading restrictions to protect water and air quality and installing fixed covers on these new storage units will reduce ammonia emissions. Currently only food waste standard rules permits require these storage units to be covered, slurry and manures based digestate do not need to be covered. The EA has updated environmental standard rules permits to require all new storage tanks and lagoons to have covers. Existing sites will all be required to have fixed or floating covers. Similar measures could be applied across NI in order to minimise ammonia emissions and improve market/consumer acceptance of AD in the region.

Proposal 2 - There are a number of available techniques for land spreading digestate with varying impacts on ammonia emissions, from surface broadcast (splash plate) to low emission spreading equipment such as trailing hose, trailing shoe or injection. Current estimates suggest that 93% of the AD industry already uses low emission spreading equipment. To capture the remaining 7%, the UK government identified 2 scenarios through which digestate is spread. Defra's Clean Air Strategy sets out government plans to require that digestate is spread using low emission techniques by 2025 but it is intended that participants must adhere to either of the following from the start of the GGSS scheme:

- digestate is spread using low emission spreading of digestate as defined in the Code of Good Agricultural Practice for reducing ammonia emissions;
- where the participant contracts another person to spread the digestate, that person complies with the National Association of Agricultural Contractors (NAAC) standards (or equivalent).

These proposals and additional mitigating measures should be carefully considered at the outset of any future growth, both in GB and NI. It is important to balance the costs and benefits for producers and users, as well as the impact on the local, regional and national economy and the wider environment. As has been learned in GB, it is easier to require enhanced treatment and processing from the outset to allow producers to consider additional technical and compliance costs in their original business model, than it is to request them at a later date when retrofitting new equipment and modifying the business model would then be necessary.

8.2 DAERA's SBRI Projects

In order promote the market acceptance of digestate across NI specifically, DAERA awarded £600,000 to NI companies to develop sustainable solutions for livestock slurry. The key aim being to reduce surplus phosphorus and to ensure the efficient recycling of organic nutrients within NI agriculture whilst contributing to climate targets. The funding is provided by the Department for the Economy's Small Business Research Initiative (SBRI) and DAERA's Green Growth Fund. The funding is being used by companies to create practical and economically viable models where livestock slurry can be separated with minimal nitrogen and methane losses, ideally to produce feedstocks which can be used to produce biogas or biomethane via anaerobic digestion (AD). Nutrients remaining in digestates post energy production will also be suitably processed to provide a replacement for artificial fertiliser for use in NI or for export. These projects highlight the issues and promising research taking place across NI, in order to effectively manage livestock slurries and digestates generated in the region.

Notable research in this area includes the pyrolysis of digestate in order to generate biochar, biooil and syngas, whereby syngas can be used as an energy source for the process. This biochar is capable of retaining 64% of phosphorus (addressing a notable problem across NI), in addition to a CO_2 removal rate of 563 kg CO_2 eq per head in NI.[56] This presents a very real opportunity to capitalise on the production of higher value digestates with promising carbon benefits, whist at the same time addressing key concerns relating to nutrient overloading in NI.

Furthermore, an additional SBRI project demonstrated that AD can be part of the nutrient solution, by taking nutrients off farms (in the form of slurry solids) and bringing these back to AD plants. Digestate management (i.e., management of the nutrients when they pass through AD) is a crucial part of this narrative. This SBRI focused on the management of digestates, considering a number of different scenarios for dealing with nutrient imbalances across NI, including: manure export; addressing legacy P in soils; diet changes in livestock. It is recommended that an ideal system for NI would potentially be one where AD acts as a nutrient hub for sustainable redistribution, potentially out of NI. A combination of production, processing and use techniques discussed throughout this report should therefore be considered to deliver such change and to capture such opportunity.

9. Digestate Business Models in Practice

This section discusses the range of strategies that are currently in place to manage digestate across the UK at present. This will give some insight into how Northern Ireland should look to manage digestate based on their own circumstances.

9.1 Biogas & Biomethane Production Configurations

The location and type of digestate generated in practice will depend upon the AD configurations themselves. There are a number of different configurations of biomethane production sites. For example:

- a large, centralised plant that imports feedstocks from lots of sites;
- many small AD plants that all produce biogas independently to then pipe/transport to a central upgrading facility;
- many small sites that produce biomethane that is then sent to a central injection hub.

The latter of these points is not favourable due to the cost of the upgrader which is not viable at smaller sites. Furthermore, the central upgrading hub does not work well in practice due to issues associated with transporting the biogas (it is a low-density product and thus, expensive to transport). As such, the preferred model for biomethane production is a larger-scale AD facility, treating over 50,000 tonnes of feedstock per annum, with upgrading & injection on-site, bringing in feedstocks from other producers. This system benefits from economies of scale too.

Although biogas upgrading to biomethane is not typically feasible at micro or small scale, technologies are emerging that offer increased connectivity between sites that could, in effect, allow biomethane production at farm scale. Systems being proposed and in the early stages of commercial roll-out are typically one of the two solutions below:

- A mobile biogas upgrader that travels around a group of farms routinely. Farms would need to be able to store sufficient biogas on site, but higher volumes could allow mobile versions of conventional gas-upgrading equipment to be used. Upgraded biomethane could be delivered to a grid injection point elsewhere or used on farm, and/or in vehicles if needed.
- A physical pipeline to deliver biogas to a central location for upgrading to biomethane, for subsequent injection or local use.

Such solutions offer a means of valorising manure, whilst keeping capital costs low for farmers. Value of the biomethane (whether sold to third party or used on site) would be aligned with the market value of natural gas.[vii]

Biomethane at this scale could also be used as a vehicle fuel for domestic, commercial or agricultural vehicles. Compressed natural gas (CNG) tractors are commercially available and liquified natural gas

[vii] Additional revenue, for example from RTFO or GGSS, would depend on compliance with these schemes. This would have to be confirmed on a case-by-case basis with the relevant authority (Department for Transport and Ofgem, respectively).

(LNG) tractors are being developed, to offer a fully circular farming solution in the future, where the farm produces the fuel from their waste to run the vehicles needed to support their farming activities.

The AD landscape in NI is currently dominated by smaller scale farm-based AD facilities that could potentially serve a central upgrading or injection hub in the future, given the investment in the AD capacity has already occurred, and relocating production is not feasible. These facilities could also benefit from one of the two more recently commercialised models set out above. However, it would be prudent in the future for NI to target the commissioning of larger-scale, more efficient, AD facilities that can benefit from the most preferential AD configurations as described above. In order to develop larger sites, more advanced planning is required to ensure all aspects of the project are carefully planned from early community engagement to avoid public or key stakeholder objections, through to siting, design and construction, to digestate management.

9.2 Management of Digestate

As stated throughout this report, digestate is primarily used as a biofertiliser and spread to land, making use of its valuable nutrient content. If there are suitable offtakers available nearby, a simple method of managing this co-product would be to supply material to nearby farms, or indeed, using this material on the AD site's own land. Digestate offtake agreements are important here as they tie offtakers into legal contracts meaning that offtake is guaranteed for the producer. However, it is not always easy to find suitable offtakers of digestate, hence why it is incredibly important for AD site operators to have a plan in place to ensure that this material is utilised efficiently from the outset. Early engagement with the local community, nearby landowners and others involved in the storage, supply and offtake is essential, to ensure projects are suitably planned and designed, and digestate does not become a burden for operators post-commissioning. Digestate should be actively managed alongside the energy offtake as it can potentially be a valuable co-product, it should be actively marketed as a biofertiliser, thus positively focussing on its benefits. Furthermore, digestate should not be considered as being disposed of as that gives a negative impression that it is a waste and is problematic to the producer.

A key challenge for producers and offtakers comes as it is not always appropriate to spread digestate to land due to the time of the year and the potential overloading of land with nutrients. This is exacerbated in NI as the country is entirely based within an NVZ meaning that it must comply with strict regulations to minimise environmental pollution due to fertilisers. As such, it is critical that storage is taken into account when looking at the management of digestate in practice. For smaller-scale sites it is common to have 6-8 months of storage capacity on-site, in the form of tanks or covered lagoons, whilst for larger-scale facilities off-site storage is also common. Off-site storage, such as tanks or lagoons located away from the production facility but close to where the digestate is to be used, can bring a multitude of benefits. This configuration requires a reduced footprint on the production site which eases land demand and makes planning and development permissions easier, reducing the burden for the main developer if a third-party is brought in to manage off-site activities, and aiding logistics during a short spreading window. Off-site storage means digestate can be removed from site routinely, as required and transported to the storage location year-round, and then distributed directly from the remote facilities as soon as regulations and the weather permits. This management approach leads to reduced concentration of vehicle movements in a short period, again reducing planning concerns, and means when spreading can occur time is not wasted transporting material long distances, making the operation much more efficient. Remote storage is regulated in the same way as on-site storage, and the business and operating models need to be carefully refined at the outset, to ensure sufficient investment is allocated by the developers or third-parties, and the offtake agreements are negotiated to deliver a cost-neutral or positive revenue.

AD operators can opt to work independently or with the help of a digestate management company who remove the pressures and burdens of having to offload the material themselves. For example, a digestate management company would typically work with a number of AD sites in a given region. They collect digestate from AD operators as and when it is generated on site. This removes the issue of AD operators requiring large areas for the storage of digestate and also allow a direct focus on marketing, sale and placement of digestate which is important given the inherent value of the material, and the additional revenue it can deliver to a production facility.

Digestate management companies act as a middleman to find suitable offtakers for this material – a key benefit of this being that they typically have access to a much wider range of potential customers, meaning that this valuable material can more effectively get to where it needs to go. A critical part of these operations comes with the need for storage, as outlined above. Management companies collect digestate from many sites at various points of the year. At times when spreading is not permitted, there is subsequently a huge surplus of this material in circulation. A common approach here is to establish where digestate is being produced and where it is subsequently needed, then for the third-party to set up central storage facilities. Such facilities should ideally be no more than 15 miles away from the producer or user, given that it becomes costly and inefficient to transport digestate longer distances. With digestate storage spread across the region, there is not a build-up of material in one particular place, and it is ready and waiting in a suitable location for spreading, when it is permitted for use.

It is recommended that the storage facilities used for digestate are monitored closely to understand how much additional digestate can be added at any given site, and how much is available for land spreading. Digestate requires regular active management and should be allocated sufficient human and physical resource from the outset, to ensure the material is fully valorised. It is common to have an individual, either employed or contracted, at every site to manage these operations, with a number of other individuals contracted throughout the year to handle the logistics and spreading, as required.

In terms of opportunities identified for NI, it is recommended that a centralised co-operative type model should be adopted focussing on larger-scale plants, procuring feedstocks from a number of satellite farms. Digestate would then be processed centrally and distributed back to feedstock providers if appropriate, potentially benefitting from existing slurry storage capacity, and potentially also further processed and exported to other EU countries where they have a high nutrient deficit. This model is common in Denmark, another nation where livestock waste is the predominant feedstock source. The production and use pathways illustrated in Figure 18 show that the digestate types targeting land spreading will likely be derived from livestock wastes, where existing slurry and manure storage capacity could be available, thus reducing the need for further investment.

Where land spreading is not the preferred use, as is likely to be the case for significant volumes in NI, locating processing facilities adjacent to centralised AD plants will eliminate the need for liquid storage and reduce investment needs in such infrastructure. A large centralised digestate processing facility would continually process the digestate output, producing drier products which could then be stored in covered housing or further processed to bag or containerise for sale, distribution or export. Where this approach is favoured, the digestate processing facility would likely be owned and operated by the AD business.

9.3 Digestate Pricing

Digestate pricing information is not widely available beyond fertiliser applications, so this section will focus on inherent fertiliser value as a proxy. When land spread, the value of digestate is dictated by its nutrient content and the price of synthetic fertilisers, which have increased considerably during the past year, due to a large rise in energy prices and supply difficulties. The price of nitrogen (N, based on UK-produced ammonium nitrate), phosphate (P, based on triple superphosphate) and potash (K, based on muriate of potash) in synthetic form is currently around £1.83, £1.39 and £0.99/kg, respectively.[57] These prices have fallen slightly in recent months, but according to the agricultural trade press, are expected to remain elevated for the foreseeable.

Based on current fertiliser prices, the inherent value of typical whole, separated fibre and separated liquid digestates based on their major nutrient content would be as shown in Table 10.

Table 10: The theoretical value (£) of the total amount of nutrients present in farm-based whole, separated liquid and separated fibre digestates.[58]

	Total N	Total P_2O_5	Total K_2O	Total value/ (tonne or m^3)
Whole digestate				
Nutrient content (kg/m^3)	3.6	1.7	4.4	
Financial value (£/m^3)	6.59	2.36	4.36	**£13.31**
Separated liquor				
Nutrient content (kg/m^3)	1.9	0.6	2.5	
Financial value (£/m^3)	3.48	0.83	2.48	**£6.79**
Separated Fibre				
Nutrient content (kg/t)	5.6	4.7	6.0	
Financial value (£/t)	10.25	6.53	5.94	**£22.72**

However, in many cases AD developers will assume in their financial models that digestate will be taken by a third party at no cost, as this has historically been the case and may be necessary at times, when supply outweighs demand on a short-term basis. In WRAP's industry survey, respondents were asked about digestate pricing, and it did appear to vary depending on the situation. For whole digestate, prices ranged from -£10 per tonne (i.e. a cost to operators) to £5 per tonne for the product, including transport and application (ex-works). For fibre, prices ranged from -£2.80 per tonne (cost) to £5 per tonne (ex-works).[59]

Based on industry knowledge, separated (solid) digestate is currently attracting prices of around £3-5 per tonne where sufficient landbank is available, most typically in the eastern regions of England.

However, where landbank is less readily available (i.e., predominantly livestock areas in the west), prices are more typically around £1-3 per tonne. For separated liquid digestate, prices presented in the survey ranged from £0 – 5 per tonne, and based on industry knowledge, it is attracting prices that are similar to solid digestate in livestock prominent areas (£1-3 per tonne), where landbank is constrained and alternative slurries and manure are readily available.[60]

The commercial position with regard to digestate for land spreading has changed significantly over the past decade, as market awareness and acceptance has drastically improved. Now recipients understand the value of the material and foresee fewer risks in its use, they are willing to pay for it as an alternative to buying inorganic fertiliser. Given experience can be shared between GB and NI, it would be envisaged that local markets would be willing to pay for the material from the outset of any further sector growth.

In terms of alternative products and uses, commercial data is not available to value the outputs in the same way. However, the processing equipment supplier would typically present a financial model to the producer ahead of agreeing a sale, and appropriate diligence should be carried out on the commercial values prior to making any commitment. Alternative markets and uses are more established elsewhere in Europe, so values and returns should be sought and checked appropriately.

9.4 Digestate Transport Costs

In terms of the transport, costs inevitably increase as distances increase. Although these costs are commercially sensitive, it is fair to assume that the prices for digestate transport are similar to those seen for manures and crop feedstocks (Table 12). Note that for digestates that do not meet end of waste criteria (i.e., PAS 110 standard digestates) an additional 30% should be added to account for costs associated with waste handling licencing and storage.

Table 11: Anticipated cost expected for the transport of digestates.[61]

Distance (km)	Price (£/tonne)
10	4.50
20	4.77
30	5.23
50	5.23
75	7.31
100	8.46

While the transport and storage of digestates is critical for effective digestate management in NI, it is expected to add considerably to the overall cost of implementing an effective plan going forward. As a result, maximising the value and resultant revenue from digestate is important, whilst seeking a secure market and obtaining buy-in from long-term offtakers where possible. A mutually beneficial relationship between developers, operators, feedstock suppliers, digestate offtakers and logistical partners is advantageous, to ensure all parts of the value chain are optimised.

10. Conclusion

To conclude this appraisal of digestate production and use in Northern Ireland, this section outlines the main challenges and opportunities, and subsequently presents a set of key recommendations with regards to digestate management as the biomethane sector expands.

10.1 Challenges

Some of the primary challenges associated with the management and eventual use of digestates stem from the current situation with nutrient loading in NI, and regulations relating to waste and the spreading of fertilisers to land which can be complex and prohibitive in some cases. Other challenges relate to the perceived quality and potential of this material when used for land spreading, and the lack of confidence in alternative processing techniques or end markets. In order to address these challenges, improved awareness and communication around AD and more specifically digestate is essential; looking to other nations with more established markets, also having experienced periods of rapid growth, a wealth of experience exists upon which NI can base its approach to future expansion. Key learnings from elsewhere in the UK emphasise the value and importance of clear and positive engagement with the community. The use of clear, non-technical language and consistent terminology is important, to effectively communicate some of the less well understood areas and to promote the opportunities such production presents. Digestate is a technical term not well understood outside the core industry, with perceptions of it being a post-digestion output arising from an industrial waste processing plant. Although partly true, this instantly presents an unattractive image, whilst considering digestate as a valuable co-product arising from a biomethane facility and referring to it as a biofertiliser when land spread presents a more positive and favourable perception. It is therefore recommended that digestate is referred to as a co-product which can be almost as valuable as the gas output from an AD facility in many cases, when managed correctly, and promoted as a biofertiliser when land spread which makes its end use and value much clearer.

As a biofertiliser, this co-product is rich in nitrogen, phosphorous and potassium (NPK). However, when excess nitrogen and phosphorous are applied to land they can cause a host of environmental issues such as plant loss, soil imbalance, water contamination, and algal growth for example. As a result of widespread nitrogen pollution, the EU's Nitrates Directive was published, and the rules of this Directive transposed into UK law. Nitrate vulnerable zones (NVZs) are designated as part of this legislation, meaning that areas falling into said zones must comply with strict rules around the spreading of nitrogen containing fertilisers. The entirety of Northern Ireland falls under the designation of an NVZ, posing limits on N and P loading to land across the country and also introducing seasonal spreading restrictions, meaning that during the autumn and winter months, fertiliser cannot be spread. This creates a notable challenge for producers, as the output is generated year-round, but it can only be spread at certain times of the year, and it must be carefully managed so as to not overload soils with nutrients. As such, sufficient storage capacity during closed periods is absolutely critical and can be a costly element for any development, especially if not planned and integrated effectively at the outset, thus requiring corrective action post-production. To guide the most effective management and use of digestate, and to prevent nutrient issues being exacerbated as capacity increases, the hierarchy of use should be followed and appropriate production and use pathways considered. Only digestate derived from agricultural wastes should be returned to land, with other pathways pursuing other processing options.

Where AD facilities are processing waste materials, it may be difficult to handle, store and transport the resultant output. Waste materials are required to be treated as a waste and incur the costs and relevant controls associated with it being a waste. As such it is prudent for AD operators to look to generate outputs that meet end of waste criteria in order to avoid these restrictions. Such criteria fall within the PAS 110 standard and the accompanying ADQP (in order to qualify under the Biofertiliser Certification Scheme). As well as ensuring that producers and users of digestate do not need to comply with onerous waste management regulations and controls, the meeting of said criteria also demonstrates to end users that relevant outputs are of an accepted quality, providing confidence to end users that the product meets a well-known industry standard. While this offers a potential solution to the challenge of market acceptance, getting certified in itself can also be a testing experience with producers needing to comply with a 38-page checklist of requirements in order to demonstrate the quality of the material for use as a biofertiliser.[26] Having clear guidance for producers and users, effective administration of regulations and certification schemes, and accessible test facilities to comply with scheme requirements, is essential to ensure the market value can be demonstrated and confidence levels are high from the outset.

Where potential users of digestate are not well informed on the benefits associated with its use, it can cause critical issues in regard to the marketable nature of this co-product. As the main driver behind the AD industry is the production of biogas and biomethane, rather than digestate, many stakeholders across the agricultural sector who are not well informed on the process often assume it is an unwanted by-product. This means there can be a tendency to reject digestate as a biofertiliser based on an incorrect view surrounding the potential of this material and again terminology and positive communication around its production, value and benefits should be prevalent – the same applies in other markets. While it is true that some digestates are not generated to an appropriate standard to spread on land (i.e., may contain plastics and other pollutants), the PAS 110 and ADQP should provide confidence to end users that the material being supplied is of a high standard. It is therefore recommended that AD operators in NI look to produce quality digestate that meets these standards as a minimum, in order to build and retain confidence in the market.

Where digestate is produced from slurry and manure, the nutrient loading issue will be improved marginally and in the short-term, as placement and uptake becomes easier. However, where digestates are produced from other materials, such as food waste, crops and residues, where inherent nutrients would not otherwise return to land, the issue of nutrient loading could be exacerbated. Therefore, careful management of digestate is necessary, to improve the situation in NI and to reduce the loading of nutrients on land wherever possible. Other options, beyond land spreading should therefore be considered for larger-scale centralised plants, in line with the hierarchy of use and aligned with the preferred production and use pathways described in Chapter 7.

10.2 Opportunities

Notable opportunities for digestate come with the fact that it is produced as a valuable co-product in a process developed for the production of biogas. It offers comparable benefits to synthetic fertilisers when land spread but with a considerably greener selling point, as it is not derived from fossil resources and the emissions associated with its production are much lower than for traditional fertilisers. This means that the use of digestate in place of synthetic fertilisers can significantly improve the environmental footprint of landowners i.e., offering a sizeable opportunity to players operating across the agricultural sector who are looking to reduce their emissions. This benefit may not offer huge appeal to farmers and landowners at present, but as carbon markets continue to develop, manufacturers become more accountable for their supply chain emissions, and consumers become more conscious of their purchasing habits, it will become more meaningful for producers.

Furthermore, it is estimated that up to 1.6-2 million tonnes of digestate per annum could be produced in NI by 2030, demonstrating that a considerable amount of synthetic fertiliser could be displaced in the future. Providing that it is managed in line with the hierarchy of use and stored at appropriate locations, the generation of such prominent volumes offer the opportunity for end-users across the country to benefit from the use of this material. Again, the importance of storage at appropriate sites should be stressed, as this means the material can be distributed and managed in line with the preferred production and use pathways, reducing the nutrient burden within NI and allowing higher value applications to be targeted, offering both economic and environmental benefits.

Dedicated digestate management resource should be committed from an early stage, to plan, execute and deliver a strategy for its production, storage, distribution and use, securing maximum value for producers and maximum benefit for users. Such resource could be shared across facilities and the strategy managed centrally by a dedicated digestate management business, thus reducing costs, allowing more flexible management and offering a stable uninterrupted supply to users, at times and locations to suit them. In larger centralised facilities, dedicated resource will be essential to oversee operations, to secure appropriate markets and to negotiate commercial arrangements with offtakers, both within and outside NI. A wealth of digestate management experience exists in the UK, with many businesses being willing to share insights and offer guidance to new production facilities and offtakers, for mutual benefit.

Where landbank is constrained or management issues prevail, digestate can also be used in applications other than as an agricultural fertiliser. Whilst liquid digestate can be spread easily to growing crops, the separated fibre can be used fresh as a soil conditioner or, after further aerobic composting to stabilise it, as material suitable for transforming into a compost product potentially targeting higher-value markets outside of agriculture, such as horticulture and landscaping. Alternatively, it can be dried or further processed to ease handling and storage requirements, and subsequently used as a potentially higher value fertiliser or soil improver, or for use in energetic or material applications. These opportunities are highlighted by the vast array of digestate processing technologies that are currently available. While digestate processing is not widely carried out beyond traditional mechanical separation processes at present, activity in the wider processing technology space demonstrates industry interest in the upgrading of digestate for higher value applications. This provides a huge opportunity for digestate producers in the future who are limited by land spreading restrictions or are simply looking for higher value outlets for this co-product.

Further processing presents a significant opportunity in NI, to capture, convert and divert nutrients from agriculture, to address overloading issues on land. As a result, despite land spreading being the most common application, other options should be considered and pursued as a priority in line with the hierarchy of use. Notable opportunities for NI include the processing of digestate into pellet or prilled form, allowing for physical export to other countries currently facing a nutrient deficit, or the processing of digestate into biochar, allowing capture and removal of nutrients and carbon from the system. Appropriate technologies exist to allow these pathways to be pursued, but typically such processing would occur at larger-scale, hence a focus on centralised AD facilities is prudent, where both the AD system and subsequent digestate processing steps benefit from economies of scale, and the back-end system, subsequent marketing and logistics can be managed centrally.

It is evident from the review that by focussing on community engagement and open communication around the challenges and solutions from the outset, opportunities exist to develop local supply chains, targeting higher value markets such as domestic and commercial applications, via wholesale and retail outlets with the compost-like material, or with pelleted, prilled or biochar-based products. A combination of bulk, lower-value markets, and more niche yet higher-value outlets should be considered, to minimise risk and maximise returns.

10.3 Recommendations

Based on the research and analysis provided throughout this document, there are a series of key recommendations that should be taken forward in order to ensure effective digestate management as the biomethane sector gets ready to grow in NI over the coming years (see Table 12).

Table 12: Key recommendations to generate an effective digestate management in NI.

Management	**Hierarchy of use**	• Due to issues with nutrient loading in NI, increasing production of digestate should be considered an opportunity for improved nutrient management, as opposed to being viewed as a risk of exacerbating the issue. • As a result, the **hierarchy of use** should be considered for new developments, and digestate only used for land spreading where nutrient management practices are neutral or improved. • Where livestock wastes are digested that would otherwise be spread to land, the resultant digestate can be spread to land with careful management, monitoring and placement of nutrients, to ensure effective plant take up, and in compliance with the necessary regulations. • Where other feedstocks are used, such as food waste, crops and residues, which would otherwise not result in nutrient return to land, alternative digestate processing and use pathways should be prioritised, to reduce additional nutrient burden. • Where alternative production pathways still result in a nutrient-rich product, export from NI agriculture to alternative markets or more preferably to countries experiencing a nutrient deficit should be pursued.
	Generating an effective digestate management plan	• A dedicated digestate management resource should be committed at an early stage to plan, execute and deliver a strategy in line with the hierarchy for use, for the production, storage and distribution of digestate. • It is recommended that such a resource is shared across facilities, and the strategy **managed centrally** by a dedicated digestate management business - who can provide more flexible management, and offer stable, uninterrupted supply to users. • A wealth of digestate management currently exists in the UK. It is therefore recommended that introductions are made with experienced businesses who may be willing to share valuable insight and offer guidance to new AD facilities and digestate offtakers.
	Managing a variety of outlets for digestate	• In addition to using digestate as a biofertiliser for use on agricultural land, digestate managers should consider potentially **targeting higher-value markets** outside of agriculture. • While digestate processing is not widely carried out beyond traditional mechanical separation, activity in the wider processing technology space demonstrates industry interest in the upgrading of digestate for higher value applications, which again can be managed and operated centrally. Therefore, it is recommended that updates in this area are monitored to establish suitable processing routes for the future. • Furthermore, there is an opportunity to develop new domestic and international supply chains, with local branding and marketing campaigns to target higher value markets via wholesale and retail outlets.

		• It is recommended that a combination of bulk, lower-value markets (e.g., agriculture) and more niche, higher-value markets are considered by digestate managers, in order to minimise risk and maximise returns, delivering both economic and environmental gain.
Market	**Using better language when discussing digestate**	• Digestate is a term that is not well understood outside of the AD industry. The perception is that it is a post-digestion output arising from an industrial waste processing plant, and while this is true, it instantly presents an unattractive image of this material. • Digestate presents a positive opportunity for effective nutrient management in NI, providing the investment required to capture, transfer and potentially export nutrients to reduce the current problem; this should be communicated positively amongst the wider community. • By referring to digestate as "**biofertiliser**" when used for land spreading, this presents a more positive and favourable perception of digestate. • In general, it is recommended that **clear, non-technical language** should be used when describing digestate, and **consistent terminology** is important to effectively communicate some of the less well understood areas of this material.
	Ensuring market demand for digestate and creating consumer confidence	• In order to ensure that consumers are confident in the use of digestate, it is essential that awareness and communication around its production, safety and use is improved. • As such, it is recommended that key players across the supply chain are well **educated on the benefits** that digestate can offer, through both communication and demonstration. • This demonstrates the value and importance of **clear and positive engagement** within the community – digestate is a co-product that has the potential to be equally as valuable as the gas output from an AD facility when managed correctly. • Furthermore, it is recommended that digestate producers become BCS accredited in order to provide confidence that digestate spread to land is of a recognised standard and quality.
Regulatory	**Compliance with waste management regulations**	• Waste materials must be treated as wastes and incur the costs associated with waste management. As such it is recommended that AD operators avoid the generation of digestates that would be classified as wastes. • End-of-waste criteria relevant to digestate is outlined within the **PAS 110** standard and the accompanying anaerobic digestion quality protocol (**ADQP**) which applies across the UK. Compliance with both means that a digestate will be certified under the Biofertiliser Certification Scheme (**BCS**) where it is used for land spreading. • AD operators should look to produce PAS 110 quality digestates and be certified under the BCS in order demonstrate that EoW has been achieved, where land-spreading is the target outlet.
	Getting certified under the BCS	• Avoiding the generation of waste classified digestates in itself is a challenge as producers must comply with a 38-page checklist of requirements when targeting land spreading: https://www.biofertiliser.org.uk/upload/bcs_checklist_apr2021_final_june.pdf • In order to mitigate challenges associated with certification, it is recommended that producers and users of digestate across NI are provided with **clear guidance** on material requirements, regulations and certification schemes by appropriate administrative bodies in NI. • Furthermore, digestate **testing facilities** should be readily accessible to producers and approved by administrative bodies to demonstrate compliance with scheme requirements.
	Compliance with land spreading regulations	• The entirety of NI falls under the designation of an NVZ, meaning that users of nitrogen containing fertilisers (including digestates) must comply with strict rules around land spreading (e.g., spreading limits, spreading times etc.). • This means that during the autumn and winter months, digestate cannot be spread to land, posing a challenge for producers given that it is generated year-round, and it must be carefully managed so as to avoid nutrient loading. Therefore, the **storage** of digestate is critical during closed periods. • It is recommended that digestate management plans in NI should consider appropriateness of land spreading as a priority, and where nutrient loading problems would be increased as a result, alternative processing and use pathways should be pursued. Where land spreading remains the most appropriate use, the requirement for sufficient storage capacity should be considered and integrated at the outset, as this can be a costly element for any AD development, especially if corrective action post-digestate production is required. • Storage can be centrally managed in all cases, regardless of end use, to ease the operational and logistical burden, whilst maximising market access and value to both producer and user.

Annex I

Table 13: Summary of end-of-waste (EoW) criteria relating to digestates, as set out in the Waste Framework Directive

<table>
<tr><th>Parameter</th><th colspan="2">Criteria</th></tr>
<tr><td>1) Minimum organic matter content</td><td colspan="2">15% on dry matter weight</td></tr>
<tr><td>2) Minimum stability</td><td colspan="2">Unless an eligible alternative method has been specified by the competent authorities, the producer must demonstrate to meet at least one of the following three stability criteria for digestate:
• Respirometric index of maximum 50mmol O_2/kg organic matter/hr, measured according to standard EN 16087-1.
• Organic acids content of maximum 1500mg/l
• Residual biogas potential of maximum 0.25l/g volatile solids.
As an eligible alternative, the competent authorities of a Member State may complement or replace the three methods described above with another method and associated limit value providing equivalent stability guarantees.</td></tr>
<tr><td>3) No content of pathogens</td><td colspan="2">No Salmonella sp. in 25g sample 1000 CFU/g fresh mass for E. Coli</td></tr>
<tr><td>4) Limited content of viable weeds and plant propagules</td><td colspan="2">2 viable weed seeds per litre of compost/digestate</td></tr>
<tr><td>5) Limited content of macroscopic impurities</td><td colspan="2">0.5% on dry matter weight for glass, metal and plastics > 2mm to be determined by the dry sieving method</td></tr>
<tr><td rowspan="2">6) Limited content of heavy metals and organic pollutants</td><td>Contaminant</td><td>mg/kg (dry weight)</td></tr>
<tr><td>Cd
Cr
Cu
Hg
Ni
Pb
Zn
PAH_{16}</td><td>1.5
100
200
1
50
120
600
6</td></tr>
</table>

Annex II

Table 14: Commercial and pre-commercial digestate processing technologies.[62]

Company	Technology	Location	Description of Technology	Status
Dorset Green Machines	Dorset Dryer	Netherlands	The drying installation is designed to use residual heat in a highly cost-effective way. In case of a biogas installation, the drying installation replaces the emergency cooler. With a 500 KW installation, for instance, only two ventilators are used, which means that electricity consumption hardly rises. The airflow through the product is kept extremely low, so as to prevent dust from being generated. When drying digestate, it is also necessary to clean the air.	Commercial
Terra Nova Energy	TerraNova® Ultra	Germany	Hydrothermal carbonisation	Commercial
Antaco	Hydrothermal carbonisation	UK	Hydrothermal carbonisation	Commercial
NuReSys	Struvite crystallization technology	Belgium	During AD, hydrolysis takes place and organic matter, ammonia, phosphate, potassium, magnesium, calcium, and sulphur are released to the bulk liquid. Organic matter is mainly converted into methane while both ammonia and phosphate are not consumed during the process (Campos et al., 2019). Phosphorus can be extracted through several different mechanisms (e.g. struvite precipitation).	Commercial
Ostara Nutrient Recovery Technologies	Crystal Green	Canada	Extractive Phosphorous Recovery	Commercial
CCm Technologies (CCmT)	CCU	UK	CCm Technologies has developed a method of producing fertiliser and soil conditioner through the use of captured carbon dioxide from industrial power generators. The first full-scale fertiliser manufacturing plant has been successfully commissioned at CCm's Technology Centre in Swindon before its deployment to Viridor's multi-waste site in Somerset.	Commercial
Groot Zevert Vergisting	GENIUS & RePeat	Netherlands	In phase 1 (GENIUS-NK) the digestate is separated into a solid and a liquid fraction by means of a decanter. The N-rich liquid fraction will be processed into a nitrogen-potassium (NK-)	Commercial

			concentrate and clean water through a combination of DAF and membrane filtration (RO). In phase 2 (GENIUS-Total) the system will be extended with an ammonium stripper (NAR) before the micro-filtration step. Finally, an evaporator will concentrate the output from the RO step, increasing the amount of produced clean water. Final products will be ammonium sulphate (AS) and liquid K fertilizer (K-concentrate). The P-rich solid fraction will be treated with a P-stripper called "Re-P-eat" through a process of acid (H_2SO_4) and base $Ca(OH)_2$ addition. The products of this process will be mineral calcium phosphate (CaP) and a P-poor organic soil conditioner.	
Incover Project EU	Adsorption Columns	EU	An environmentally innocuous and degradable material used in an in-line filter that captures phosphorous from wastewater streams	Pre-commercial
Incover Project EU	Sludge Treatment Wetland	EU	Wetlands are constructed using specialized filter material then a network of pipes are used to pump sludge/digestate into the wetlands. The digestate is dewatered by evapotranspiration and the digestate is turned into a good soil conditioner with high dry matter	Pre-commercial (TRL 9 - ready for market)
Incover Project EU	Evaporative Systems	EU	The systems consist of a big basin with a protected liner. A layer of sand is used to allow treated material (e.g. wastewater) to spread to trees planted on top. Trees uptake nutrients and dewater any sludge	Pre-commercial (TRL 8)
Incover Project EU	PHA Production	EU	PHAs are polyesters that are produced by fermentative microorganisms during anaerobic digestion (AD). They are a precursor for a range of bioplastics.	TRL 6-7
BioCover	SyreN	Denmark	Mobile acidification system. Lowering the pH of slurry has shown to reduce the levels of ammonia. When the pH drops ammonia is changed to ammonium which doesn't evaporate.	Commercial
Colson	AMFER	Netherlands	Nitrogen Removal/Ammonia Stripping. The process of removing nitrogen, usually in the form of ammonia, from digestate or wastewater.	Commercial
Amandus Kahl	Pellet Technology	Germany	Produces equipment for drying digestate and processing into pellets	Commercial
Nawrocki Pelleting Technology	Pellet Technology	UK	Produces equipment for drying digestate and processing into pellets	Commercial
Kesir	Pellet Technology	UK	Produces equipment for drying digestate and processing into pellets	Commercial

Veolia	ANITA	France	ANITA™ solutions contribute to the objective of an energy-neutral wastewater treatment plant while responding to more stringent regulation in terms of nitrogen concentration in treated water.	Commercial
DTU	Anammox	Denmark	Stable nitrogen removal. The process of removing nitrogen, usually in the form of ammonia, from digestate or wastewater.	Pre-commercial
Byosis	ByoFlex	Netherlands	N-stripping and recovery	Commercial
Purac	DeAmmon	Sweden	Compared to traditional nitrogen removal processes, DeAmmon® needs 60% less power and it requires no additional carbon.	Commercial
Profi Nutrients	Nutrient removal	Netherlands	This Dutch company offers a range of standard technologies to separate nutrients. They have a simple struvite precipitation option using magnesium hydroxide to separate the P; caustic stripping and acid scrubbing to recover N as ammonium sulphate.	Pre-commercial
Boerger	Bioselect Separator	Germany	Digestate flows through the Bioselect vessel through a sealed slotted screen, which separates the outer vessel from an auger chamber. The liquid then filters through the screen to the outer vessel. The liquid phase is discharged whereas the solid particles remain in the filter area where they are conveyed by a rotating auger unit to a postpress channel. It has been applied to digestates treating from 6 to 15% dry solids and achieving up to 35% dewatered fibre.	Commercial
Weltec kumac	Weltec Biopower	Germany	The fully automated processing system "Kumac" reduces the liquid manure and digestate volume by 50 percent. In a four-stage procedure, clear water, liquid fertiliser concentrate and valuable solid matter are extracted from the source material.	Commercial

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