The Bioeconomy Consultants

NNFCC

# Assessment of digestate drying as an eligible heat use in the Renewable Heat Incentive

**Project Number: 16-015.5**

**March 2016**

**A report for DECC Heat Team**

**Authors:** **David Turley**, Lead Consultant- Biobased Feedstocks

**Lucy Hopwood,** Lead Consultant – Bioenergy & Anaerobic Digestion

**Caitlin Burns**, Consultant

**Davide Di Maio**, Consultant

## Disclaimer



## NNFCC

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

NNFCC, Biocentre,
York Science Park,
Innovation Way,
Heslington, York,
YO10 5DG.

Phone: +44 (0)1904 435182
Fax: +44 (0)1904 435345
E: enquiries@nnfcc.co.uk
Web: www.nnfcc.co.uk

## Executive Summary

Digestate is an organic fertiliser product that is mostly spread to land. The nutrient content of digestate varies dependent on the feedstock mix and the process configuration, but typically material contains reasonable levels of essential nutrients N, P and K. Despite extensive work being done to stimulate markets for and improve confidence in digestate, its value potential remains low and due to its bulky nature, storage, transport and spreading costs can outweigh the inherent value and it often becomes a cost burden to the operator.

The issue of securing suitable markets for digestate is more of a problem for larger plants and those based in urban situations where access to a suitable land bank for spreading is more restricted or costly. In these situations, storage requirements and costs of transport and distribution can be reduced by mechanical or thermal treatment.

Mechanical de-watering technologies, capable of delivering up to 35% dry solids, are widely used in the anaerobic digestion (AD) sector and represent the most cost effective way of increasing the dry solid content of digestate. Beyond this, thermal drying processes are required. Thermal drying is energy intensive but typically relies on using surplus heat emanating from the AD system, via a combined heat and power (CHP) engine or occasionally a dedicated biogas boiler. Even with this essentially 'free' heat source, in the absence of RHI support, payback within a reasonable timeframe would require digestate values much greater than £3-5 per tonne for unprocessed material which is cited as a typical market value in the few circumstances that any value is realised at present.

A European study shows that even at transport distances of up to 100km, transporting unprocessed digestate can be more economically viable and has a lower GHG footprint than drying digestate due to the high energy demand required for drying. Drying digestate provides handling, storage and logistical benefits but little added value in other areas. Liquor fractions can be further refined by non-thermal technologies to reduce volumes and increase the fertiliser value of such products.

The RHI is partially compensating for market failure to drive uptake of digestate drying due to low digestate prices. It is unlikely that digestate drying would be contemplated in the absence of current RHI support. There are a number of markets where drying may be an essential step, to prolong storage periods, protect or enhance the quality of the product, to produce higher value products for more specialist markets (e.g. bagged fertiliser for horticulture, or for combustion), or where drying also facilitates a secondary process, such as pasteurisation. This effectively utilises 'waste' heat, reducing the cost and environmental burden elsewhere in the supply chain.  However, digestate drying should not be prioritised where other valid heat uses are available, e.g. local heat customers or process heat demand.

## Contents

# 1. Background

Renewable heat used for digestate drying is eligible for support under the Renewable Heat Incentive (RHI) and is thought to account for up to 35% of spend under the biogas tariff, amounting to around £2 million per year. In refocussing the RHI to deliver better value for money DECC are considering the need and value of such support and wish to understand the potential costs and benefits in providing such support for digestate drying.

This project is required to provide an assessment of:

1) Digestate production and treatment techniques;
2) The need for and value of drying digestate, and the associated benefits or disbenefits compared to other techniques;
3) The risks associated with supporting digestate drying as an eligible heat use under the Renewable Heat Incentive (RHI).

## 1.1 Approach

The development of digestate production and treatment activity is described based on WRAP's Annual Survey of the Organics Recycling Industry (ASORI) and internal knowledge; this includes information on volumes arising, type, source and destination of digestate produced. Developing trends in markets and current uses for digestate are also drawn from literature including previous ASORI surveys of the UK Anaerobic Digestion (AD) industry and interim findings from the 2015 survey currently being undertaken by NNFCC for WRAP.

The reasons for processing and drying digestate are described, taking account of factors such as environmental, economic, social, political and regulatory drivers and constraints. Results are presented in a summary table, briefly describing the context of the driver or constraint, supplemented with key facts to illustrate the scale of the impact or benefit.

A high-level technology evaluation was then undertaken, drawing on existing knowledge of current and planned activities, company literature, technical specifications and industry discussions, to establish and categorise the range of treatment options available for processing digestate. The most common thermal treatment options and alternative methods (incl. physical, biological and chemical processes) are identified along with relative cost estimates and performance information to enable comparisons to be made.

Information is collated on the energy balance and any digestate compositional changes experienced when using specific techniques, along with assessment of any practical or greenhouse gas (GHG) impacts of these changes. The primary (but not exclusive) focus of this task is on issues that would impact on sustainability reporting and emissions accounting for the Renewable Heat Incentive (RHI) or Renewables Obligation (RO).

## 2. Digestate

Digestate is the residual by-product from anaerobic digestion. It is nutrient-rich and suitable for use as a fertiliser/soil amendment. Digestate volumes are typically around 80-90% of that of the feedstock fed into the digester. All the nutrients (including nitrogen (N), phosphorous (P) and potassium (K)) present in the feedstock remain in the digestate post-digestion, but are typically more available to plants than in the original feed materials.

Digestate can be used whole where it is spread on land with tankers or umbilical pipe systems, or alternatively it can be separated in to liquor and fibre fractions which have different nutrient contents – typically the liquid would contain mostly N and the solids would retain high levels of P and K. Liquid digestate can be more easily spread to growing crops. Separated fibre can be used fresh as a soil conditioner or, after further aerobic composting to stabilise it, as material suitable for making 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 energetic applications.

### 2.1 Digestate production

According to WRAP's Annual Survey of the Organics Recycling Industry (ASORI) an estimated 1.44 million tonnes of digestate was produced in 2012 and 2.12 million tonnes in 2013. The average ratio of output (digestate) to input (feedstock) was calculated as 0.82 for commercial and industrial sites, and 0.87 for on-farm sites.

In December 2015 there were 264 operating AD sites in the UK, 165 farm-fed and 99 waste-fed[1]. These AD facilities have the capacity to process 6.9 million tonnes per annum of feedstock and produce an estimated 5.8 million tonnes per annum of digestate.

**Table 1: Example farm-fed AD plant sizes, based on average-sized livestock farms in the UK** ***(for illustrative purposes only – not typical of current developments)***

| | Excretal output (kg/hd/day) | Average herd size | Average annual production per herd* (tonnes) | Supplementary crop feedstock (tonnes) | Typical AD plant size** | Digestate output (tonnes) |
|---|---|---|---|---|---|---|
| **Dairy Cattle** | 53 | 133 | 1400 | 4000 | 177 kWe | 4698 |
| **Beef Cattle** | 29.1 | 30 | 175 | 4000 | 172 kWe | 3632 |
| **Pigs** | 7.3 | 400 | 1065 | 4000 | 190 kWe | 4407 |

* Considering number of days housed per year (c. 200 for dairy & beef)
** Assuming supplementary feedstock used, generated on-site[2]

There are a further 348 farm-fed and 153 waste-fed AD plants under development (from planning application to construction)[1]. Assuming a 50% attrition rate, a further 6.15 million

[1] NNFCC (2015) AD Deployment in the UK, database extract December 2015.
[2] NNFCC (2011) Farm-Scale AD Plant Efficiency. DECC

tonnes per annum of feedstock will be consumed and 5.18 million tonnes per annum more digestate produced, bringing the total to 11 million tonnes per annum by 2019 (Figure 1).

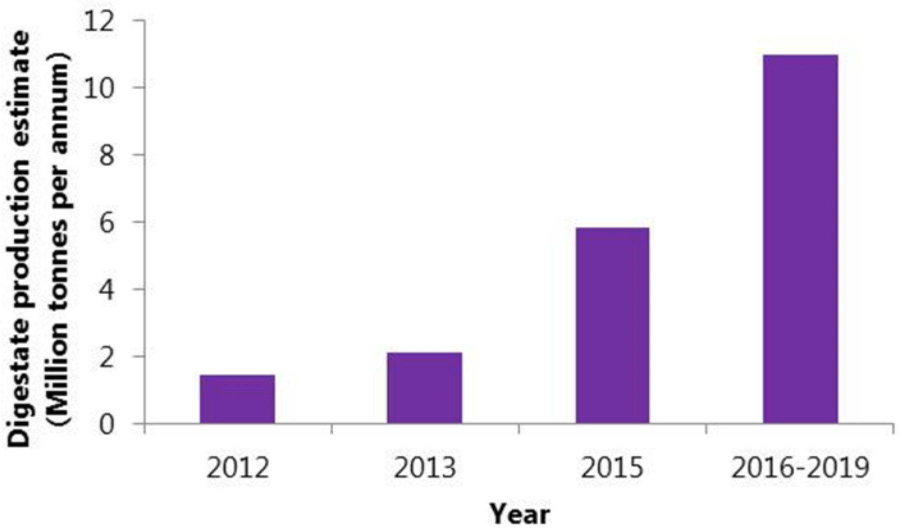


**Figure 1: Estimate of digestate production using data from WRAP ASORI surveys in 2012 and 2013, NNFCCs AD database for 2015 and predicted growth (2016-2019) assuming 50 % attrition rate.**

## 2.2 Current use of digestate

The dry solids content of untreated digestate is typically around 5% for manure and slurry fed-systems, but can be much lower for waste water treatment applications. Increasing the dry matter content to around 25-35% with mechanical separation will allow the fibre fraction to be stacked for ease of storage on hard-standing or subsequent composting. Further thermal treatment to around 90% dry matter produces a friable material that can be stored for extended periods and handled with conventional farm machinery.

WRAP's ASORI surveys provide an indication of how digestate is being used. Where digestate was utilised, 97% went to agriculture (mostly as whole digestate and liquor) in 2013. Very small tonnages were reported for use in other applications (Table 2).

**Table 2: Use of digestate in 2013 for surveyed sites. Figures rounded to nearest 10,000 tonnes (* represents <5,000 tonnes). Source: WRAP 2013 AD survey**

| | Agriculture | Field-grown horticulture | Landfill restoration | Energy Recovery | Other |
|---|---|---|---|---|---|
| Commercial | 640,000 | | 10,000 | | (*) |
| Demonstration (R&D) | 10,000 | (*) | | | |
| Industrial | 40,000 | | | 20,000 | |
| On-farm | 430,000 | | | | |
| **Total tonnes (reported)** | **1,130,000** | **(*)** | **10,000** | **20,000** | **(*)** |
| **Application % of total** | 97% | 0% | 1% | 2% | 0% |
| Industrial – discharging to sewer (tonnes) | 45,000 | | | | |

In areas designated as Nitrate Vulnerable Zones (NVZ), restrictions are placed on application of digestate to land in terms of total permitted loadings and ‘closed’ periods when digestate cannot be applied during the autumn and winter period. These restrictions and other best practice guidelines, as well as the practical limitations on when digestate materials can be applied to growing crops limits the land area available for spreading during particular periods. As such, AD plant operators are required to have sufficient storage to buffer against such problems. In NVZ areas, this includes a requirement to hold digestate storage capacity for around 6 months of plant operation. Under the Environmental Permitting Regulations, for a Standard Permit, the amount of digestate that can be stored on a specific site is also limited to 75,000$m^3$. This storage restriction can be extended through a risk-based assessment under a Bespoke Permit though this can add significant extra cost.

For larger operators or those with limited ability to store digestate, there is interest in reducing the volume of material, both to reduce the amount of storage required and to reduce transport and spreading costs.

Spreading is typically done using conventional manure and slurry spreading equipment, or modified versions thereof. Spreading costs can be significant, up to £5 – 8 per tonne dependent on the physical loading and spreading methods used and the transport distance from source to destination.

### 2.2.1 Whole digestate

For farm-based AD facilities, the vast majority of whole digestate is used on site (92%), with the rest provided free of charge (FOC) to off-site users. For commercial sites, in 2013, 19% was sold to users off site, 27% was provided free of charge and 26% was removed at a cost to the operator. For industrial sites, 44% incurred a cost for users to remove whole digestate; 33% supplied digestate free of charge and 23% was disposed of to sewer at a cost.

### 2.2.2 Separated digestate

Where digestate is separated, the majority (44%) of fibre is used on site by the operating business; the remainder is sold to off-site users (24%), the producer pays for removal (29), or is landfilled (1%). For separated liquor, the majority (95%) relates to arisings at drinks manufacturers and similar industrial effluent treatment sites and was disposed of via the sewer. The majority of separated liquor produced by other sites was used on the operator’s own premises.

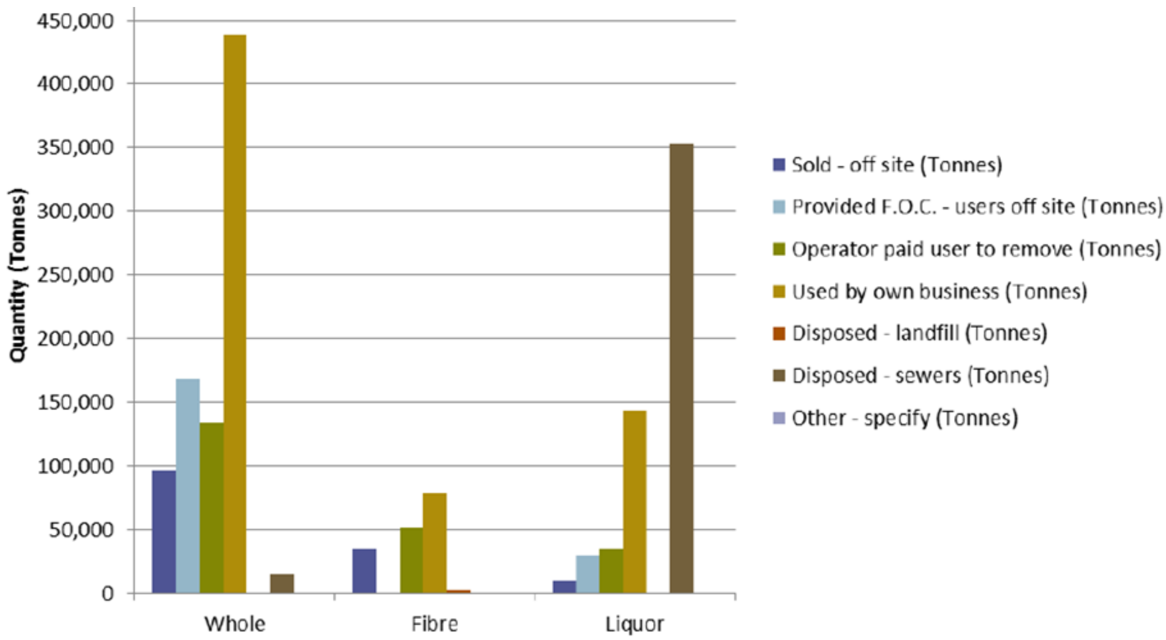


**Figure 2: End destination of whole digestate or separated fibre and liquor. Source: WRP 2013 AD survey**

## 2.3 Value of digestate

In order to sell digestate as a biofertiliser, digestate must meet the standards set out in the Quality Protocol and BSI PAS110 specification (England & Wales) or the SEPA position statement (Scotland). PAS110 specifies minimum quality parameters for whole digestate, separated fibre and separated liquor derived from source-segregated biowaste. However, there is no requirement for materials to be specifically dried or dewatered.

For larger operators (commercial and industrial sites) disposal of digestate typically represents a cost to the business. Where digestate is sold offsite, WRAP surveys indicate an average price of around £3.73 and similar studies up to £5 per tonne[3], but data on this is very limited and commercially sensitive.

Some industry literature indicates that agents for digestate driers in some cases offer to buy back granulated quality digestate from industrial processors for £25 per tonne or more, but this is difficult to corroborate and it is not clear whether this is tied to leased turn-key offerings where the RHI payment is claimed by the owner of the digestate driers and site owners/operators just supply feedstock.  This requires further investigation.

There is currently a relatively small market for sale of digestate. A large proportion of digestate is given away at no cost or operators are paying for its removal (to cover transport and spreading costs). To date the vast majority of digestate has been applied to agricultural

[3] Zero Waste Scotland Report, 2010. Digestate market development in Scotland
http://www.wrap.org.uk/sites/files/wrap/Zero_Waste_Scotland_Digestate_Market_Development.pdf

land or used in low value horticultural applications. As the industry has grown, so has the number of AD plant operators processing digestate, though data on this is limited.

As land-spreading is the most common pathway for use of digestate, the rationale for considering additional processing options will be determined by availability of land to spread digestate balanced against the additional costs to optimise storage, transport and spreading.

### 2.3.1 Nutrient value of digestate

The nutrient-availability and value for any digestate will vary dependent on source, composition, application rates and current prices. However, the nutrient value of digestate can be significant when factoring in the fertiliser replacement value, especially when used on-site. Examples of fertiliser values per hectare for two types of whole digestate are provided here, based on the fertiliser prices listed below:

- Ammonium nitrate (34.5% N) = £0.95 /kg nutrient
- Phosphate-TSP (46% $P_2O_5$) = £0.89 /kg nutrient
- Muriate of Potash (60% $K_2O$) = £0.55 /kg nutrient

For a manure-based digestate this equates to £7.21/$m^3$ for NPK; for food-based digestate this is equivalent to £5.56/$m^3$ for NPK[4].

## 2.4 Summary

The market for digestate is not well developed, despite extensive research and marketing activities being conducted over recent years to raise awareness and confidence. Already the UK is experiencing problems with use and disposal, constrained by land availability and landowners' willingness to actively receive and spread digestate. Over the next 3 – 5 years the volume of digestate produced is expected to double, and whilst faced with the same land constraints, the only options are to further develop the market or to use treatment techniques to reduce the volume and potentially increase the value of the digestate output.

The current market value is difficult to quantify as each business case differs based on contractual arrangements, composition, quality, consistency, volume and location. Many AD operators look at digestate as a cost neutral component of the business, with few realising a value of £3 – 5 per tonne for use in agriculture, and no other higher value applications commercially proven or even at the point of demonstration, although several are at the R&D stage. In order to realise a greater market value, the product needs to be: more consistent; easier to handle, store and spread; and better understood by a wider range of end users. Digestate treatment methods will enable this to be achieved combined with additional marketing and communications to improve user awareness.

[4] WRAP Cymru (2011) Digestates: Realising the fertiliser benefits for crops and grassland

## 3. Digestate treatment

Digestate processing can be partial, primarily for the purpose of volume reduction, or it can be complete, refining digestate to water, a solid biofertiliser fraction, and a fertiliser concentrate. A number of treatment techniques are available, at varying levels of maturity, targeting different production and end-use applications and scales.

WRAP's 2013 ASORI survey indicated that around 40% of sites undertook some form of digestate processing, most using either a form of mechanical press or centrifuge to dewater digestate – no site indicated they were thermally treating (drying) digestate using either fossil or renewable heat in 2013. However these figures need to be used with caution as the most significant increase in uptake of RHI to support digestate drying is more recent than the latest survey.

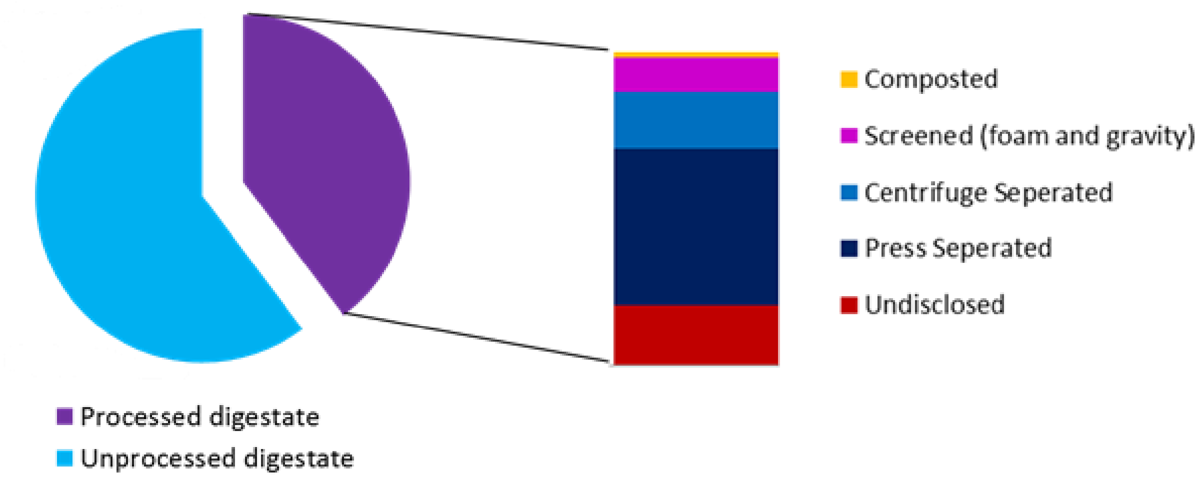


**Figure 3: Approaches adopted for processing digestate at AD sites (% of sites surveyed) (drawn from WRAPs AD surveys for 2013)**

A summary of the main drivers and constraints which lead to digestate treatment are provided in Table 2 below.

**Table 3: Summary of main drivers and constraints**

| Driver/Constraint | Description |
|---|---|
| **Environmental** | |
| **Efficient nutrient placement and effective plant uptake**<br>***(min. 25-35% DS & separate liquid fraction)*** | By processing digestate nutrients become more concentrated in the solid and liquid fractions; if drying digestate rather than pressing the nitrogen in the liquid is lost so reducing the overall nutrient value of the product. Processed digestate can be applied more accurately according to the plants requirements and more effective uptake is therefore achieved. |

| | |
|---|---|
| **Reduced emissions from transport**<br><br>***(min. 25-35% DS & separate liquid fraction)*** | By reducing the volume of digestate for export from site and spreading, it is possible to reduce the transport requirements and therefore the associated GHG emissions from this step; however, this makes a minimal contribution to overall supply chain emissions, so impact is minimal. |
| **Reduced GHG intensity of biogas (heat/power) for Sustainability reporting**<br><br>***(min. 90% DS)*** | By processing and drying digestate the calorific value of the product is increased (as dry matter increases), meaning a greater percent of total supply chain emissions can be apportioned to digestate, causing less of a GHG burden on the energy outputs for the purpose of reporting against Sustainability Criteria. |
| **Economic** | |
| **Reduced storage costs (CAPEX)**<br>***(min. 25-35% DS & separate liquid fraction)*** | Processing digestate immediately post-digestion can lead to reduced storage requirements; if separated, storage tanks for liquor will be smaller and solids can be stored on less costly hard-standing. |
| ***(min. 90% DS)*** | If dried to remove the liquid a storage tank or lagoon will not be required thereby reducing capital costs significantly. |
| **Reduced transport and spreading costs (OPEX)**<br><br>***(min. 25-35% DS & separate liquid fraction)*** | Processing digestate allows spreading to be carried out more efficiently, either using existing solid and liquid manure/slurry spreading equipment or umbilical systems direct to land, for example. This also reduces distribution and spreading costs, as fewer vehicle movements, less diesel and labour will be required. |
| **Increased returns through improved quality**<br>***(min. 25-35% DS & separate liquid fraction)*** | By condensing nutrients in separated or treated digestate fractions, it is likely increased returns will be achieved from digestate sales; although this is yet to transpire in the market. |
| **Social** | |
| **Reducing transport requirements for distribution from site**<br><br>***(min. 25-35% DS & separate liquid fraction)*** | Often transport of feedstock into site and digestate away from site causes great concern at the planning stage of any project. Reducing the volume of digestate exported from site by processing or drying can be a positive factor in securing planning permission, particularly for larger urban facilities. |
| **Political** | |
| **Financial incentives**<br><br>***(min. 90% DS)*** | Since the reduction in FIT rates for AD and the imminent degression to RHI tariffs for biomethane and biogas combustion, the need to maximise value at every point in the supply chain is essential. RHI support for digestate processing offers an additional revenue stream, without which many plants would fail to demonstrate financial viability and come to fruition. |

| | |
|---|---|
| **Regulatory** | |
| **Nitrate Vulnerable Zone (NVZ) regulations**<br><br>***(min. 25-35% DS & separate liquid fraction)*** | In NVZ areas, restrictions are placed on land-spreading in terms of total permitted loadings and 'closed' periods when digestate cannot be applied. These restrictions and other best practice guidelines, as well as the practical limitations on when digestate materials can be applied to growing crops limits the land area available for spreading during particular periods. As such, plant operators are required to have sufficient storage to buffer against such problems. Operators are required to hold digestate storage capacity for around 6 months of plant operation. |
| **Environmental Permitting (EP) regulations**<br><br>***(min. 25-35% DS & separate liquid fraction)*** | Under a Standard Permit, the maximum storage capacity of a site shall not exceed 75,000$m^3$. This storage restriction can be extended through a risk-based assessment under a Bespoke Permit though this can add significant extra cost (CAPEX and OPEX). |
| **Technical** | |
| **Targeting higher value markets (e.g. bagged for horticultural use)**<br><br>***(min. 90% DS)*** | In order to extend the market opportunities and maximise revenue potential of digestate, it is important to consider higher value markets than agriculture. Examples include professional and amateur horticulture (e.g. greenhouses, allotments, gardens, etc); where products would not be transported in tankers or trailers, or spread using large machines, it would likely be sold in bags and spread by hand on small areas of land. In such cases it is essential to process and often dry the digestate, to reduce the volume and weight and to enable bagging and long-term storage; ensuring quality does not deteriorate over time as would be the case with whole digestate. |
| **Animal bedding**<br><br>***(min. 90% DS)*** | Digestate can be used as bedding for livestock, before being fed back into the AD system when fouled – thus operating a closed-loop system. In this case the digestate needs to be separated, dried and possibly pasteurised (depending on input feedstocks and process configuration) immediately post-digestion and prior to use. |
| **Post-digestion pasteurisation**<br><br>***(min. 90% DS)*** | Occasionally, when markets are highly regulated or subject to strict best practice guidance there is a need to pasteurise digestate prior to land-spreading. An example is where non-waste material such as slurry, manure and crops have been digested which do not require pasteurisation pre-digestion. An example application is organic agriculture, where digestate should be pasteurised before being spread to field-grown vegetables, which may come into contact with the consumer. This application can be costly, but without it the |

| | |
|---|---|
| | value of the end produce would be compromised and the quality no longer assured. |
| **Energy recovery**<br><br>***(min. 90% DS)*** | Theoretically, digestate can be pelletised and burned to generate energy through a biomass boiler; however, there are technical challenges around composition, and concerns around the energy balance and economics. If this market opportunity were to expand, in instances where co-location of digestate production and combustion are possible to reduce transport costs and to improve the heat supply on-site, material would need to be dried to pellet and burn effectively. |

## 3.1 Processing Techniques

Dewatering is commonly used to reduce the volume of digestate. Dewatering separates the material into two fractions: a solid fraction (typically 25-35% dry matter) which can be used as a soil improver, and a liquid fraction (typically ≤ 6% DM) that can be used as a liquid fertiliser. Dewatering can be achieved using:

- Mechanical dewatering[5] - for solid-liquid fraction separation using screw presses, belt presses, or centrifuges.
- Biological dewatering[6] - 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%.

Gaining information on energy use and costs is difficult, but Table 4 provides a comparison of commonly used equipment. Figure 4 highlights the main pathways for digestate processing and use.

[5] Includes screening, centrifuge and pressing (see Figure 3)
[6] Includes composting (see Figure 3)

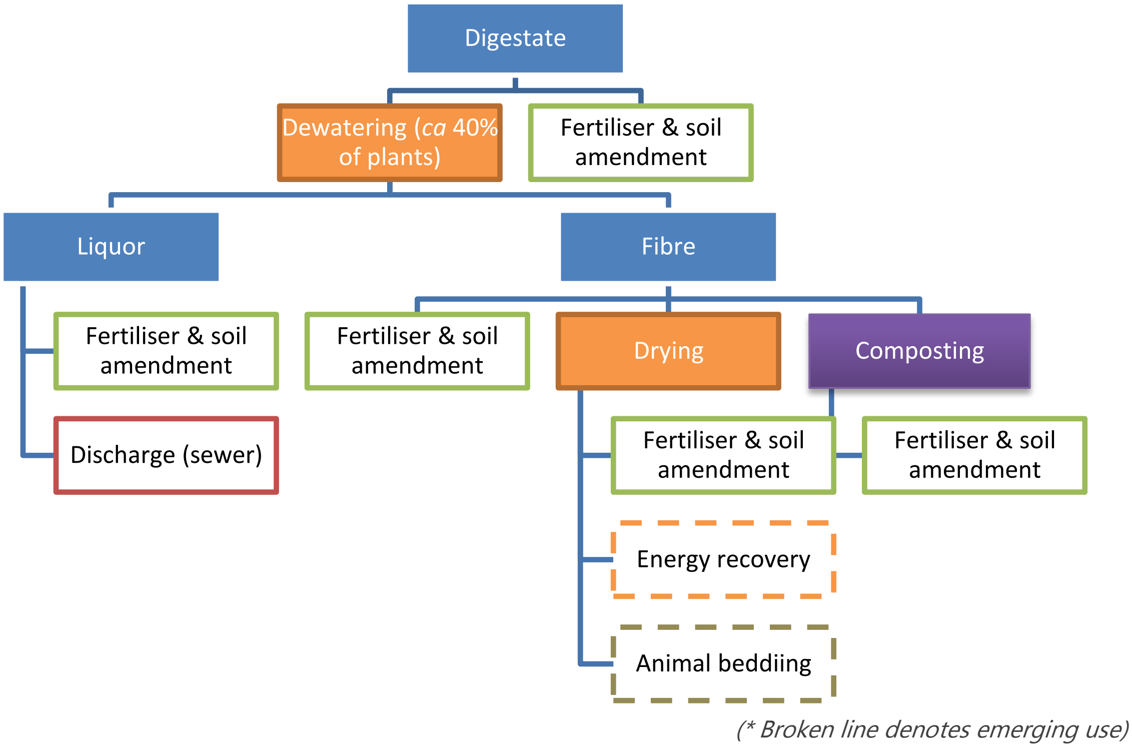


**Figure 4: Pathways for Digestate processing and use**

### 3.1.1 Mechanical treatment

Mechanical treatment removes excess water from the digestate, to increase dry matter content in the solid fraction and potentially produce nitrogen rich liquor for more targeted land spreading or use in higher value applications (although not yet commercially recognised, this nitrogen-rich liquor could be used in horticultural applications too).

- 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.

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.

### 3.1.2 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. The disadvantage of this approach is the treatment area required, labour requirements for physical moving and turning of material and the extended treatment time. Runoff also needs to be captured, adding infrastructure costs, which results in higher relative CAPEX and OPEX than dewatering alone.

### 3.1.3 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:

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 is not widespread and much of the technology has been adapted from treatment of sewage sludge in the water industry. The capital cost of drying equipment can be significant, dependent on scale and complexity (i.e. specific requirements of dry product).

Drying generally makes use of otherwise ‘waste’ heat from biogas CHP systems, which is often difficult to use elsewhere, particularly in rural areas or adjacent to large plants where supply outweighs demand from suitable existing or potential new heat users. By utilising this ‘waste’ resource from biogas CHP facilities, costs and GHG impact can be reduced elsewhere in the supply chain, e.g. storage, transport, spreading, improving overall sustainability and viability of such plants.

### Table 4: Digestate processing equipment

| Step 1 Thickening or primary dewatering | Step 2 Separation/ drying | Step 3 Concentration of separated liquid fraction | Energy consumption | Throughput | Capex | Opex | Comment (DS=dry solids) |
|---|---|---|---|---|---|---|---|
| Belt Press | | | Low (1.5-2 kWh/$m^3$)[8] | Large range of unit sizes | Low-Medium: £100K+ | Low | For treating digestate >0.5% DS<br>Produces a cake of 18-25% DS Higher efficiency of solids capture than screw press |
| Centrifuge | | | Low (3 – 5 kWh/$m^3$)[8] | 13-20 $m^3$/h + | Low-Medium: £105K for 10,000 tpa capacity[7] | No info | For treating digestate >1% DS<br>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/$m^3$)[8] | | Low: £15,000 for 500 $kW_e$ plant | Low | Delivers up to 30-38%DS<br>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<br>Produces up to 95%DS |
| | Belt Drying (Direct heat) | | 1MWth per tonne water removed | (250kg ->1 tonne/hr) | Medium-High: £270-£295K for 0.5$MW_{th}$ unit (£70-100K for drier alone) | High | For treating digestate >18%DS<br>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<br>Produces up to 99%DS |
| | | Evaporator (Indirect heat) | Moderate (0.35$MWh_{th}$/ton evaporated) | 10,800 kg/hr examples | High (£1.3m) | High | For treating liquor at 1-2% DS<br>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<br>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] WRAP report. Assessing the Costs and Benefits for Production and Beneficial Application of Anaerobic Digestate to Agricultural Land in Wales. http://www.aquaenviro.co.uk/wp-content/uploads/2015/10/Assessing-the-Costs-and-Benefits-for-Production-and-Beneficial-Application-of-Anaerobic-Digestate-to-Agricultural-Land-in-Wales-WRAP-Final-Report-2014.pdf

[8] IAE Bioenergy Task 37 Publication: Nutrient Recovery by Biogas Digestate Processing. Available to view at: http://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/NUTRIENT_RECOVERY_RZ_web1.pdf

# 4. Digestate Drying

The remainder of the report focusses on thermal treatment (drying) techniques and the associated benefits or impacts of undertaking such activities.

## 4.1 Economics

Table 5 examines the impact of several scenarios on the pay-back period for a typical belt dryer, with or without non-domestic RHI support (at March 2016 rates). In all scenarios examined, the output of dried digestate was constrained by the available heat energy.

**Table 5: Impact of initial dry solids content of digestate, RHI payment and digestate sale price on estimated pay-back period (years) for dryer CAPEX (excl. OPEX)**

| | | Payback period (years) Drying from 18% to 90% DS | | Payback period (years) Drying from 35% to 90% DS | |
|---|---|---|---|---|---|
| **Plant size** | Digestate sale price | no RHI | With RHI | no RHI | With RHI |
| **500 $kW_e$** | £0/t | - | 0.9 | - | 0.9 |
| | £5/t | 38.4 | 0.8 | 15.0 | 0.8 |
| | £25/t | 7.7 | 0.7 | 3.0 | 0.6 |
| **1000 $kW_e$** | £0/t | - | 1.9 | - | 1.9 |
| | £5/t | 30.7 | 1.8 | 23.5 | 1.8 |
| | £25/t | 6.1 | 1.5 | 4.7 | 1.4 |

Assumptions:
CHP efficiency: 36% electrical, 40% heat.
Plant size and availability limit total heat available and all of this is used for drying digestate (i.e. more digestate can be dried where less heat energy input is required); 25% of plant heat output is assumes parasitic energy to heat AD tank.
Heat energy is available as waste heat (i.e. at no charge)
50 tonne feedstock consumed per year per $kW_e$ of installed electrical power capacity (typical range 20-90tpa), digestate mass is 85% of feedstock mass.
CAPEX: £175,000 for a 500 $kW_{th}$ plant and £280,000 for a 1$MW_{th}$ plant
OPEX: heat input will be zero cost, from CHP; labour, power & maintanence costs not included in the calculations.
Non-domestic RHI payment: 5.99 p/kWh for medium systems (200-<600 $kW_{th}$) and 2.24 p/$kWh_{th}$ for large systems (600 $kW_{th}$ and above)

Where market value cannot be realised or the digestate component of the business operates as cost-neutral, i.e. the cost of transport and spreading outweighs nutrient benefit, the revenue from the additional drying step will be zero and commercial payback will not occur. Digestate drying will not always increase the value of the end product; however, cost savings, such as reduced storage and transport requirements could be balanced against the investment cost, but this would only make a sound business case where digestate disposal costs would be greater than the cost of investment in the dryer.

For all the scenarios examined, it's clear that at a market value of £5 per tonne for digestate, which is only be achievable in the most favourable circumstances in the UK at present, and without non-domestic RHI support, the payback period for drying equipment is excessively long (>15 years) and as most investors or developers would look for payback over 10-15 years (i.e. the guaranteed lifetime of the equipment), it would not justify investment. RHI support considerably shortens the payback period to less than 2 years making investment much more attractive, even for the largest plant scales examined.

Further work is required to assess the validity of digestate buy-back contracts offering £25 per tonne or more for dried material, but at these values even in the absence of non-domestic RHI payments payback periods are much shorter, especially where dewatering steps are included (3-5 years). Providing RHI support significantly reduces the pay-back period to 1-2 years. However, the likelihood of achieving this level of income from digestate at present or in the near future in the UK is low; equally securing this level of income from higher value applications is not likely to occur in the near term as many such applications are still at the R&D stage, so not likely to be commercialised in the next 3 – 5 years.

The RHI support is necessary for projects to proceed and is being used to address a current market failure in digestate, but it may not be the most appropriate mechanism for doing so. Direct support to producers and/or users of digestate may be more appropriate, protecting the RHI budget for specific heat generators and users who would otherwise be using fossil-fuels to provide their energy needs. As equipment is relatively newly developed or recently adapted for processing digestate the lifetime is relatively unknown; currently guarantees are offered for a typical duration of 10-15 years, meaning equipment would be depreciated over this period and payback would need to occur within this timeframe for an operator to justify investment.

### 4.1.1 Alternative heat uses

In order to maximise the use of heat generated through biogas combustion, plants must be close to existing heat customers, such as public buildings, residential areas, process industries or other industrial or commercial users. In the absence of local heat users there is limited potential to establish new uses, either due to planning constraints, practical or logistical reasons around storage, distribution or use, or economic reasons, where additional infrastructure costs are prohibitive, for example. Seasonality of heat demand is also an issue, as typically more surplus heat is generated through the hottest months of the year (as parasitic requirements for maintaining tank and substance temperatures are lower) which also coincides with when domestic and commercial demand is at its lowest.

Therefore in the absence of a local process industry where demand is relatively stable all year round it can be difficult to utilise surplus heat. Drying of digestate is one of few applications where demand is constant but can also work within the confines of supply flexibility, should additional parasitic heat be required, or production ramped down for servicing or maintenance at any point.

Until the added value of the end product can be realised in the market, digestate drying is likely to require continued support. The RHI is providing this support at present, but may not be the most appropriate mechanism for addressing a market failure in all circumstances. However, in cases where the heat is used efficiently and drying digestate is the only option for an AD site, to reduce volumes, add value and enable them to target a very specific market with the end product and the alternative would be for them to use fossil-fuel as the energy source then the RHI is the best mechanism for supporting such activity. This would fit with the intentions of the RHI, to displace fossil-fuel use and to optimise the use of renewable heat in energy intensive industries.

## 4.2 Energy Use

The thermal energy demand to evaporate water is significant at around 1$MW_{th}$ to dry off one tonne of water. For evaporation technologies using a vacuum, a thermal energy demand of about 300 – 350 $kWh_{th}$ is needed per tonne of water evaporated[8], significantly reducing the energy demand over more conventional belt and drum drying systems but adding to capital cost and process complexity.

Table 6 provides a conservative indication of the energy required to dry one tonne of digestate from either 5%, or more typically 18-35% dry solids (following mechanical dewatering). Typically after mechanical treatment, this equates to between 550-720$kWh_{th}$ per tonne of dried digestate (at 90% dry matter). This relies on use of surplus heat from biogas combustion. Actual process energy use will be larger than this figure due to heat energy losses in the drying system and a small amount of electrical energy will be required for fans and mechanical operations.

Many digestate drying systems are currently marketed on the back of utilising surplus heat from AD systems. However, for policy purposes, the emissions otherwise avoided by using biogas derived heat to dry digestate can be calculated (see Table 6 which reports emission estimates for drying digestate using either natural gas or heating oil). The key benefit is making use of surplus ('waste') heat from AD that would otherwise not be utilised.

**Table 6: Energy expended in drying digestate and equivalent fossil emissions avoided**

| | Initial dry matter (%) | Final dry matter (%) | $kWh_{th}$ per tonne of fresh digestate | Equivalent GHG emissions if gas was used to dry digestate[1] | Equivalent GHG emissions if heating oil was used to dry digestate[2] |
|---|---|---|---|---|---|
| **Without dewatering** | 5% | 90% | 850 | 220 $gCO_2$/t fresh digestate | 285 $gCO_2$/t fresh digestate |
| **With dewatering** | 18-35% | 90% | 550-720 | 142-186 $gCO_2$/t fresh digestate | 184-242 $gCO_2$/t fresh digestate |

[1] Assuming a counterfactual GHG emission of 72 $gCO_2$/MJ (EU average for natural gas)

[2] Assuming a counterfactual GHG emission of 87 $gCO_2$/MJ (EU average for 'heat')

## 4.3 Ammonia emissions

The AD process degrades organic nitrogen compounds, releasing ammonium $NH_4$-N. This can be readily lost through heating of digestate or through volatilisation when digestate is added to land.

Previous studies have shown that nitrogen losses during digestate drying can be significant, primarily due to volatilisation of ammonia and ammonium compounds. Maurer and Muller found that drying of digestate from a dry matter content of 5-6% to 89-90% resulted in Nitrogen losses of 0.028-0.058g/g dry matter, of which 0.024-0.042g/g dry matter was due to volatilisation of ammonium[9]. Meanwhile, Muller also demonstrated that the drying of digestate results in significant nitrogen losses, with drying of untreated digestate resulting in nitrogen losses up to 43%[10], although when adopting dewatering stages losses can be reduced to as low as 7%.

Using the data of Maurer and Muller, it can be estimated that in the worst case scenario, an extended drying process taking whole digestate from 5-6% to 89-90% dry solids results in N losses of 1.9-2.9kg per tonne of fresh digestate. Assuming that all of the volatilised nitrogen is eventually converted to $N_2O$, each tonne of fresh digestate dried can be estimated to result in the emission of 3-6.2kg $N_2O$ with an equivalent GHG potential of 900-1,850 $kgCO_{2eq}$. While this is clearly a significant source of emissions, the vast majority of drying systems are equipped with technology to prevent release of nitrogen emissions. Losses can be reduced by treating digestate (e.g. acidifying prior to drying[11]) or by scrubbing ammonia from air used for drying to retain the nutrient value of the digestate cake and liquor fractions – this is common practice on all commercially available drying systems, for air quality and nutrient retention purposes.

However, due to providing additional energy requirements there remains a risk that such systems are not used on a frequent basis. Ultimately, this data shows that digestate drying could result in significant release of GHG emissions to the environment. There is therefore a need to adopt strict regulations to ensure that where such practices occur, systems are used to minimise this source of emissions.

## 4.4 Nutrient Value

The nutrient content of digestate reflects feedstock inputs and is therefore very variable. However, it provides a useful supply of nitrogen (N), phosphorus (P) and potassium (K) all of which are major crop nutrients.

---

[9] Maurer and Muller. 2012. Drying characteristics and nitrogen loss of biogas digestate during drying process.

[10] Muller. 2012. Ammonia (NH3) emissions during drying of untreated and dewatered biogas digestate in a hybrid waste-heat/solar dryer

[11] Drying of separated digestate solids: Effects of pH and temperature on ammonium contents http://www.reusewaste.eu/research-briefs/ReUseWaste_brief_12_Thanos_DEC_2014.pdf

The amount of N in digestate that is available for uptake by crops is equivalent to the total amount of ammoniacal N (TAN)[12] in the digestate. Additional N is available in organic complexes but will be released over an extended time period. Available N in digestate can be used as a substitute for inorganic-N on a 1:1 basis.

**Table 7: Typical nutrient content of digestate from AD plants utilising mixed feedstocks and equivalent GHG emissions avoided where inorganic fertiliser is replaced**

| | Total N | $P_2O_5$ | $K_2O$ | TOTAL avoided emissions |
|---|---|---|---|---|
| **Nutrient content range[13]** | 4.5-6.7 kg | 1.4-3.4 kg | 2.8-5.3 kg | |
| **kg $CO_2$/t digestate (fresh weight) avoided by replacing inorganic fertiliser sources[14]** | 20.6-30.6 | 1.4 – 2.6 | 1.5 – 2.8 | 23.4-36.0 |

Estimates of the typical nutrient content of digestate were taken from a review of the fertiliser value of digestate for the Scottish Government[13] (Table 7). However, as feedstocks vary widely the data can only be taken as indicative. Where digestate is subject to separation, the liquid fraction will contain proportionally more of the nitrogen (65-75%) and ammoniacal-N (70-80%), while the solid fraction will retain most of the P (55-65%) and K (70-80%)[15]. Additional processing can be undertaken on the liquor to concentrate it and increase its value as a liquid fertiliser.

In practice, whole digestate is only able to replace a proportion of crop N demand as high levels of application would result in over-supply of P and K and increase the risk of P leaching to water. This effectively limits annual application rates of whole digestate per hectare of available land.

## 4.5 GHG impacts

Drying digestate benefits supply chain GHG emissions in two ways. Firstly, by displacing inorganic fertiliser with digestate; utilising standard GHG emission factors for inorganic fertilisers, GHG emissions avoided are estimated as 23-36kg $CO_2$ per tonne of whole digestate applied to land (Table 7). Alternatively displacing slurry and manure on livestock farms, where this material is used to feed the digester, emissions will be captured through

12 Defra project WQ0206, 'Agronomic Benefits and Environmental Impacts of Spreading Organic Materials to Land'

13 http://www.gov.scot/resource/doc/1057/0053041.pdf Nutrient Value of Digestate from Farm-Based Biogas Plants in Scotland. Report for Scottish Executive Environment and Rural Affairs Department - ADA/009/06

14 CO2 equivalent Emission coefficients per unit of fertiliser were derived from Biograce II default values. http://www.biograce.net/content/ghgcalculationtools/standardvalues

15 Bauer *et al*. (2009) quoted in: IAE Bioenergy Task 37 Publication: Nutrient Recovery by Biogas Digestate Processing. Available to view at: http://www.iea-biogas.net/files/daten-redaktion/download/Technical%20Brochures/NUTRIENT_RECOVERY_RZ_web1.pdf

the process and reduced overall. Emissions associated with treatment of slurries and manures through AD are zero for the purpose of sustainability reporting; however, recent proposals from the European Commission to change the methodology for calculating and reporting emissions from co-digestion plants recommends potential savings that can be achieved through utilisation of manures/slurries should be accounted for and a GHG credit of 45.05g$CO_{2eq}$/MJ manure has been proposed.

Secondly, according to the methodology adopted under the Renewable Energy Directive, upstream supply chain emissions should be allocated to products and co-products of a multi-output process based on their respective absolute energy contents. There is currently very little guidance on whether digestate should be treated as a co-product or as a process residue. In the event digestate can be considered a co-product, supply chain emissions can be allocated from the biogas to the digestate, thereby reducing emissions of the resulting biogas product (i.e. biomethane/heat/electricity). However, the energy in the digestate depends upon its moisture content. At 88% moisture digestate is calculated to have no energy when using the CEN approach for determining the calorific values of fuels. However, digestate at 0% moisture has an energy content of 17.83 MJ/kg[16]. Consequently, drying digestate can increase its energy content and thereby reduce the supply chain emissions allocated to the biogas product, for accounting purposes.

Mechanical separation of digestate to 35% dry matter would enable operators to allocate 25% of supply chain emissions to the digestate. Thermal treatment (drying) of digestate to 90% dry matter increases the allocation to 38% and would enable feedstocks that may otherwise be deemed unsustainable to comply with the GHG criteria, under the current regulations.

[16] B2C2

## 5. Other study findings

Other studies have examined the relative benefits, or otherwise of drying digestate. The EU funded INEMAD project[17] compared the economic and GHG impacts of applying either fresh or dried digestate (dried to 80% DM using a belt dryer with ammonia scrubbing) to land. It was assumed that heat was provided as waste heat and the cost of the belt dryer was depreciated over 15-20 years.

Based on transport of unprocessed digestate and separated dried fibre over 100km, it was found that the costs of drying and transporting fibre outweighed the additional transport costs for untreated digestate. In addition, the emissions associated with drying digestate were higher, primarily due to emissions from electricity used to drive air fans and drying belts. It was estimated that dried fibre and liquor would have to be transported more than 307km before the emissions from drying fell below that for use of fresh digestate.

The European Biogas Association (EBA) also questions the value of supporting digestate drying from an environmental and energetic standpoint[18].

In related work for WRAP Cymru[19], it was identified that mechanical dewatering of digestate from food waste (in this case using a mechanical centrifuge and treating of liquor to dispose of water to sewer or watercourse) was economically beneficial at dry solid contents of 10%, due to the added costs of transporting fresh digestate (80km roundtrip), but not at 20% dry solids (though transport distance will have a significant impact here). This is not surprising as in the latter case there is only limited additional benefit to be gained from mechanical dewatering processes.

[17] Improved Nutrition and Energy Management through Anaerobic Digestion. WORKING PAPER 48 Should policies consider digestate drying as a justifiable application of heat coming from a CHP-unit? (FP7 funded project)

[18] http://european-biogas.eu/wp-content/uploads/files/2013/10/EBA-opinion_Digestate-drying_220513.pdf

[19] http://www.eunomia.co.uk/reports-tools/assessing-the-costs-and-benefits-for-production-and-beneficial-application-of-anaerobic-digestate-to-agricultural-land-in-wales/

## 6. Discussion

Currently, digestate in both raw form and as separated fibre and liquor are low value products that in almost all circumstances are spread to agricultural land or used in low value horticultural applications. In the case of smaller farm-based plants digesting manures and crops, spreading digestate to their own land or that of neighbouring farmers is the cheapest and simplest option but often the cost of transport and spreading outweighs the nutrient value, making digestate a cost neutral activity for many AD operations.

The issue of digestate disposal is more of a problem for larger plants and those based in urban situations where access to a suitable land bank for spreading is more restricted or costly. In these situations, storage requirements and costs of transport and distribution can be reduced by dewatering digestate, and by drying digestate and/or evaporating or further treating liquor fractions. Water removal and clean-up allowing disposal to sewer or waterways under permit is a significant benefit to large plants with disposal problems where distribution costs to land would otherwise be prohibitive.

Very little digestate is currently sold (only around 19% of digestate arisings from the commercial sector (the predominant source)). This reflects the current low market value for digestate of typically £3-5 per fresh tonne or less declared by plant operators, but it is difficult to obtain robust data on digestate prices as it varies on a case by case basis dependent on contractual arrangements, responsibilities, land availability and recognition of the wider benefits.

Mechanical dewatering technologies, capable of delivering up to 35% dry solids are already widely used in the AD sector. These technologies represent the most cost effective way of increasing the dry solid content of digestate, but within limits. Mechanical dewatering can be used to prepare digestate for composting for example if not applying directly to land, or for easing storage and handling difficulties during closed periods for example. However, beyond this thermal drying processes would be required.

There are a number of markets where drying may be an essential step, to prolong storage periods, protect or enhance the quality of the product, to produce higher value products for more specialist markets (e.g. bagged fertiliser for horticulture, or for combustion), or where drying also facilitates a secondary process, such as pasteurisation. This effectively utilises 'waste' heat, reducing the cost and environmental burden elsewhere in the supply chain.

A key question is whether in the absence of the RHI, use of fossil fuels would be contemplated to dry digestate? Given its low market value, the high costs of equipment purchase and high energy costs, it is unlikely that anyone would consider paying for energy to dry digestate for lower value mainstream markets such as agriculture and horticulture. Such systems rely on the use of underutilised heat emanating from the AD system. Even with such ‘free’ heat, in the absence of RHI support, payback within a reasonable timeframe would require stable digestate values much greater than £5 per tonne.

In cases where the heat is used efficiently and drying digestate is the only option for an AD site, to reduce volumes, add value and enable them to target a very specific market with the end product (such as bagging, bedding or combustion) they may look to use fossil fuels to supplement the surplus heat from the system, or if other heat uses are available they may need to use fossil fuels to serve the entire drying process requirements whilst diverting the useful heat from the plant elsewhere.

Only thermal drying can produce very dry digestate (>35% dry matter), but is there any added intrinsic value to this?  It does provide some benefits:

- easier handling
- reducing storage requirements
- increased storage life
- reduced transport costs and reduced number of trips to field
- access to a wider range of potentially higher value end markets

The impacts of digestate and fibre drying also need to be separated from those of liquor treatment. The intentions here can be to either a) to clean up water to allow easier on-site disposal (which also tends to produce a concentrated fertiliser solution or fertiliser product as a by-product) or simply to reduce the volume of liquor, producing a more concentrated product for application to land. Different technologies are appropriate for each of these objectives and only evaporation of liquor would potentially be eligible for RHI payment.

Mechanical separation of digestate to 35% dry matter would enable operators under the Renewable Energy Directive LCA methodology to allocate 25% of supply chain emissions to the digestate. Thermal treatment (drying) of digestate to 90% dry matter increases the allocation to 38% and would enable feedstocks that may otherwise be deemed unsustainable to comply with the GHG criteria.

The RHI is partially compensating for market failure to drive uptake of digestate drying due to low digestate prices. It is unlikely that digestate drying would be contemplated in the absence of RHI support or other forms of market intervention. It is also likely that where the use of heat for valid drying reasons, such as broadening market reach to energy applications or higher value markets, or to aid pasteurisation for safe spreading to field-grown vegetables would not occur without support. These examples, however, are often a key driver in the entire AD project and therefore the removal of RHI support for all digestate drying would likely prevent some plants going ahead and could ultimately impact negatively on AD deployment rates in the UK.

It would be potentially damaging to the industry to remove support for digestate drying in its entirety; however, valid reasons and applications need to be demonstrated to prevent digestate being dried for no other reason than to increase revenue by claiming RHI. Digestate drying should not be prioritised where other valid heat uses are available, e.g. local heat customers, process heat demand, etc.

In completing this review it is clear that there is relatively little data in the public domain covering issues such as:

- market value of digestate and processed digestate fractions and the dry solids content associated with such prices (where relevant), as well as information on the prevalence or otherwise of dried digestate buy-back offers and what these comprise.
- costs for drying equipment, which appear to be quite variable (commonly it is not clear whether installation and/or dewatering and/or nutrient capture technologies are included in industry prices)
- prevalence of mechanical and thermal drying combinations and the associated operational parameters
- detailed economic and GHG footprint calculations relevant to UK feedstocks and UK digestate disposal practices
- information on the nutrient content of digestate from documented sources and associated sub-fractions where separated. It is difficult to compare between studies to gain such information. In the absence of this, relatively generic data is used.
- efficiency of nutrient containment in fibre and liquor drying systems.

Further work on these areas would help improve any more detailed analysis in the future.

# NNFCC

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

NNFCC, Biocentre,
York Science Park,
Innovation Way,
Heslington, York,
YO10 5DG.

Phone: +44 (0)1904 435182
Fax: +44 (0)1904 435345
E: enquiries@nnfcc.co.uk
Web: www.nnfcc.co.uk