Ricardo Energy & Environment

Farmyard Manure and Slurry Management and Anaerobic Digestion in Scotland – Practical Application on Farm

Report for ClimateXChange
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Executive summary

This report examines the market potential for anaerobic digestion ("AD") as a tool to manage slurry and farmyard manure ("FYM") arising from Scottish livestock farming. The reduction of greenhouse gas ("GHG") emissions is the primary driver for this project.

Key Findings

1. Without addition of other feedstocks, the anaerobic digestion of slurry and farmyard manure has a proven poor business case at both farm and centralised facility scales, with a high capital cost, low energy yield and absence of gate fee.
2. We found just three slurry/FYM only facilities in Scotland. Two are very small and were commissioned in 2016, meaning their performance has yet to be fully proven. One is medium sized (28,000 tonnes per annum) and processes poultry manure (higher gas yield) alongside cattle slurry. It appears that there are eight slurry/FYM facilities in the UK. Co-digestion is far more common, although slurry and FYM inputs are low in these facilities.
3. While slurry/FYM only facilities are not robustly self-financing, the addition of other feedstocks (co-digestion) can dramatically improve viability. Such feedstocks could include energy crops, food waste or food and drink processing wastes including distillery by-products.
4. Whether on or off-farm, there is a need to incentivise the processing of slurry and FYM alongside other feedstocks which offer greater revenues than slurry and FYM. To some extent, incentive schemes favour wastes (including slurry/FYM) over non-waste crop feedstocks. However, the processing of slurry/FYM has to compete with other waste feedstocks with considerably greater gas yields and an ability to generate gate fees.
5. The forthcoming ban on the landfill of biodegradable waste in Scotland will, we assume, give rise to an increased demand for AD. If so, there could be an opportunity to incentivise the construction and use of co-digestion facilities that include slurry and FYM processing. However, the amount of slurry and FYM that could be treated in this manner is likely to be modest and there is a current declining trend in food waste production.
6. We consider that the impact that AD alone can have upon GHG emissions from slurry and FYM in Scotland will be modest. Slurry and FYM arises in very high volumes across all areas of Scotland. Co-digestion of a large amount of slurry/FYM requires correspondingly large amounts of other feedstocks that have to be available within a reasonable distance. However, there is potential for AD alongside other measures, e.g. improved storage techniques, in reducing GHG emissions from slurry and FYM in Scotland. Areas with the greatest arisings of slurry and FYM, such as Dumfries and Galloway and Aberdeenshire may be worth exploring further.

Discussion

If the poor business case for the AD of slurry and FYM can be overcome, there are several potential benefits, including reduced GHG emissions from slurry and FYM management, improved fertiliser properties compared to raw slurry and reduced use of artificial fertilisers. Market ready AD technology exists but the gas yield of slurry and manure is the lowest of all the most commonly employed AD feedstocks. In addition, AD facilities require regular attention to maintain a healthy process and functioning equipment. Blockages, silting-up, break-down and worn parts are common issues. The national electricity grid in Scotland is heavily constrained in rural areas. That does not necessarily mean connections cannot be made, but it will most likely increase costs. Regulatory authorisations can prevent development at a specific site level, but in general the regulatory regimes are more favourable for facilities with agricultural feedstocks.

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1 Introduction

1.1 Background

This report is to inform the Scottish Government of the market potential to use anaerobic digestion ("AD") for the management of slurry and farmyard manure ("FYM") from Scottish livestock farming.

The Climate Change (Scotland) Act 2009 sets a framework for greenhouse gas ("GHG") emission reductions including reduction targets. In September 2016, the Committee on Climate Change published its fifth report on progress towards meeting Scotland's targets. The report commented that little progress has been made in reducing emissions from agriculture and land use.

The Draft Climate Change Plan (CCP)[1] notes that to meet ambitious targets beyond 2020 there is a need for stronger policies. Policy outcome 4 in the plan is that emissions from the use and storage of manure and slurry will reduce. Figure 1 explains how this policy is to be developed.

Figure 1. Extract from the draft Climate Change Plan (CCP)

Table 14-12: Policy development milestones which contribute to policy outcome 4

Policy development milestone	Delivery route
Determine the potential feasibility of self-financing large-scale anaerobic digesters	We will determine the feasibility of one or more viable large-scale AD plants, mostly using slurry and other wastes as feedstock, accounting for end-to-end issues such as use of digestate, grid connection and feedstock availability.
Engage with farmers to explore the potential for co-operatively owned and managed anaerobic digesters	We will determine the feasibility of creating a number of co-operatives of around 10 farms each to operate viable AD plants, mostly using slurry and other wastes as feedstock, accounting for end-to-end issues such as use of digestate, grid connection and feedstock availability. This may see one of the farmers having responsibility to manage the AD plant and transport feedstock and digestate, backed by a maintenance contract. We will encourage use of CARES funding to maximise community benefit. The number, location and timing of these will depend on factors such as planning permission and financing.

We have focused on dairy-intensive regions of Scotland, considered FYM as well as slurry and addressed current farm business practice and the market ready technologies available for use on farm.

The treatment of slurry and FYM in an AD process brings benefits in relation to GHG emissions. In a sealed and controlled AD process biogas can be fully captured and utilised, helping to mitigate GHG emission from uncovered or unsealed slurry tanks/lagoons. The displacement of artificial fertiliser with digestate also eliminates or reduces the GHG emissions associated with the production of artificial fertilisers and the utilisation of recovered energy can displace the use of fossil fuels. The terms biogas and digestate are defined in Section 1.2.

A glossary of acronyms used in this report is in Appendix 1.

1.2 Anaerobic digestion

Anaerobic digestion is the biological breakdown of organic matter into a gas (biogas), water and residual matter. The residual matter is made up of undigested material and dead micro-organisms. The mixture of water and residual matter is known as digestate. The process takes place in the absence of oxygen (hence it is anaerobic) and usually in sealed tanks known as fermenters or digesters.

The biogas produced is typically circa 60% methane, with the remainder comprising carbon dioxide, and trace levels of other gases. The methane in biogas allows its use as a fuel. Digestate is often suitable for use as a soil conditioner or fertiliser. Subject to intended end use digestate can be used whole, dried or separated into solid and liquid fractions.

[1] The Draft Climate Change Plan (CCP) (*The draft third report on policies and proposals 2017 – 2032*, January 2017)

Materials subjected to AD processes (feedstocks) are usually waste products or purpose grown crop materials. Feedstocks can be mixed, which can bring benefits to process control and energy recovery. Not all mixes are compatible, e.g. slurry mixed with high protein feedstocks can foam which causes process issues and possible infrastructure damage and environmental releases.

The AD process can be undertaken on wet material capable of flowing and being pumped, or dry material that does not flow. Thus, animal slurry is unsuitable for dry AD processes, whereas FYM is suitable for both although it requires pre-processing to be suitable for wet AD. Slurry is a more common feedstock in UK AD processes than FYM. An advantage of slurry as a feedstock is that it is often unnecessary to add water.

1.3 High level financial considerations

Anaerobic digestion facilities have high capital costs. Aside from on-farm AD, facilities normally gain financial returns through gate fees and power generation. The latter may include government incentives where applicable like Feed in tariffs (FiTs). Digestate sale is uncommon and for many operators it is a cost even if only in management time, storage and transportation. The situation for on-farm AD of slurry and FYM is different. The farmer will not gain a gate fee from slurry and FYM. Digestate application costs are reduced due to the proximity to production. Farmers can make potential savings on the cost of artificial fertilisers, although such savings are generally modest. There are other benefits such as reduced risk of diffuse pollution, reduced GHG emission, improved handling characteristics and storage issues with digestate and reduced odour on application to land. However, with the high capital costs the returns from energy production are a key aspect of the business case for on-farm AD of slurry and FYM.

1.4 Scottish agriculture and cattle industry

Both dairy and beef cattle farming practices generate slurry and FYM. However, the greatest quantity of slurry production arises in dairy heavy regions and FYM in beef production areas. Slurry production reduces in the summer months when less animals are housed. There are approximately two and a half times more beef cattle than dairy cattle in Scotland. The split of dairy and beef cattle by total holdings, number and region are shown in Appendix 2. The tables in Appendix 2 show the number of female cattle aged two years or over with offspring. The total number of cattle is therefore higher. The total number of cattle in Scotland, including females, males and calves is 1.8 million. Almost half of all cattle are located in the south west (Figure 2). That region contains five areas defined in the agricultural census, which are East Central, Argyll & Bute, Clyde Valley, Ayrshire and Dumfries and Galloway. The density of cattle in Scotland is shown in Figure 3.

The region with the greatest quantity of dairy cows is the south west with 85% of Scotland's total, followed by the south east at just 8%. The south west also has the greatest number of holdings with dairy cows at 71% of all holdings with dairy cows.

The region with the greatest quantity of beef cows is the south west, with 39% of Scotland's total, followed by the south east at 23%. The south west also has the greatest number of holdings with beef cows at 36% of all holdings with beef cows.

Figure 2. Percentage split of cattle (including females, males and calves) by Scottish region

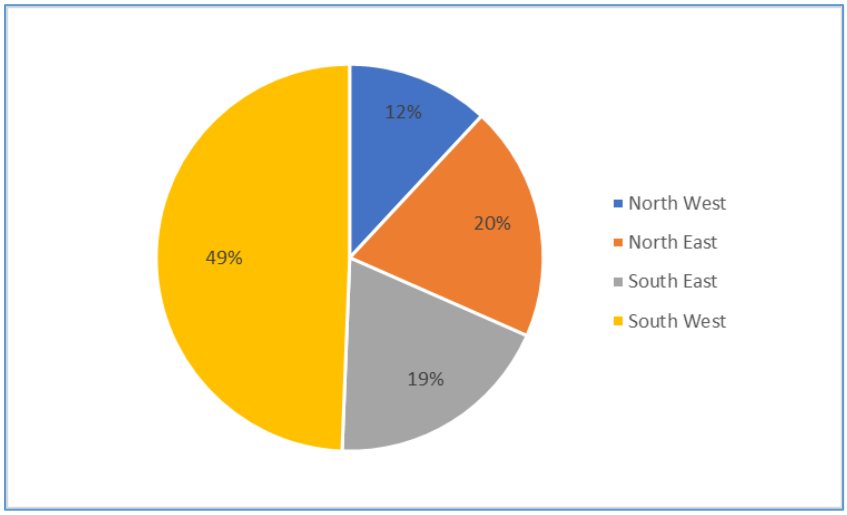
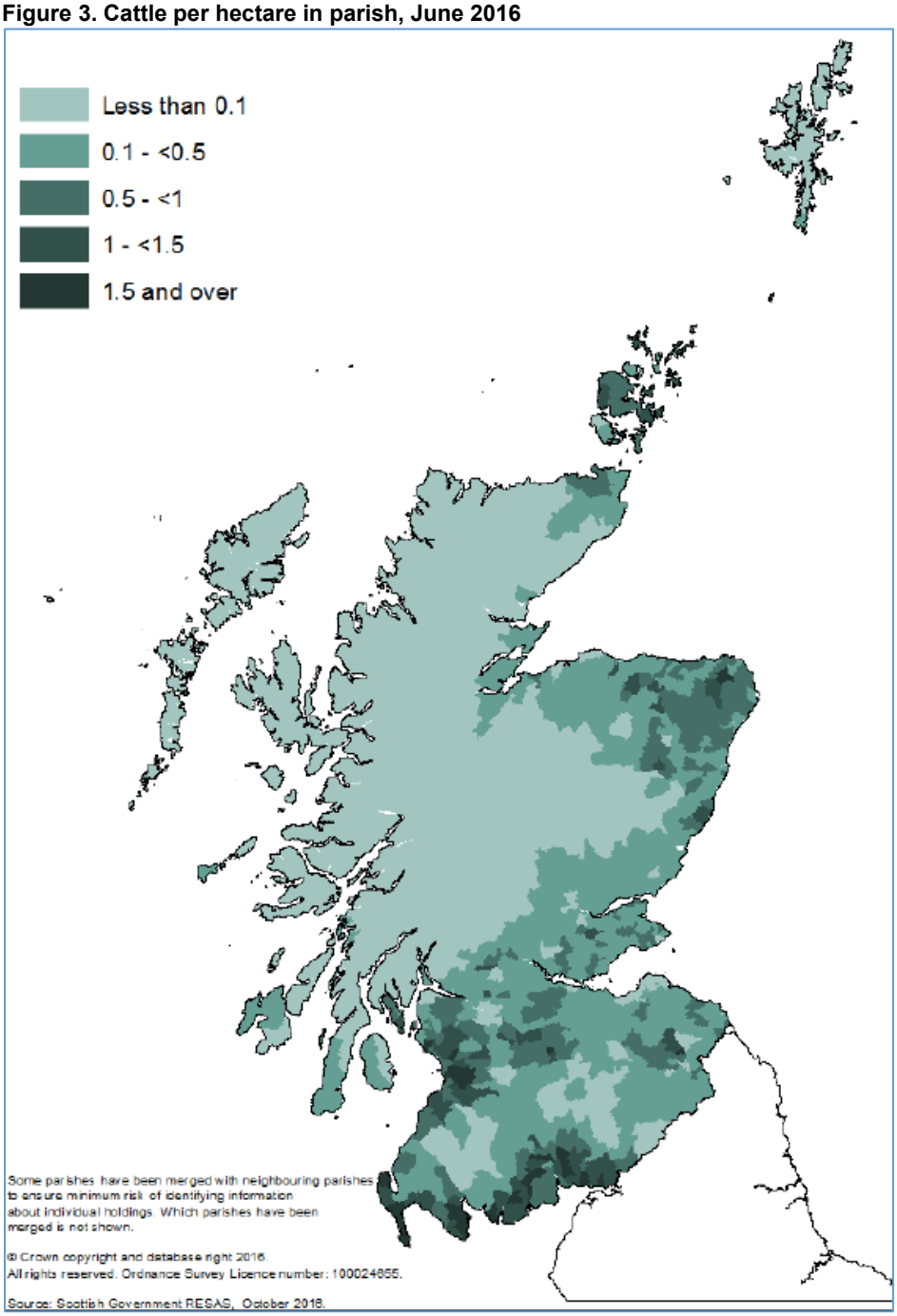


Figure 3. Cattle per hectare in parish, June 2016



1.5 Scottish slurry and FYM arisings

Based on 2015 agricultural census data, the total cattle slurry arising is estimated to be 5.56 million m^3/year and for cattle FYM it is 13.75 million m^3/year. Charts of cattle slurry and cattle FYM arisings by region are provided in Appendix 3. Thirty two percent of all cattle slurry arises in Dumfries and Galloway, 71% of which is from dairy cows. Twenty seven percent of cattle FYM arises in Aberdeenshire, 98% of which is from beef cows.

Remaining slurry and FYM arises in smaller volumes across the other authorities. Slurry and FYM from other animals arises in smaller volumes.

- Pigs: Slurry (731,200 m^3/year) and FYM (1,448,200 m^3/year)
- Sheep: Slurry (59,700 m^3/year) and FYM (987,500 m^3/year)
- Poultry: FYM (847,900 m^3/year)

Poultry FYM (high biogas yield) mostly arises in West Lothian (22%), Perth & Kinross (16%), Fife (15%), Dumfries & Galloway (9%), Edinburgh (9%), Aberdeenshire (8%), Angus (7%) and Scottish Borders (6%).

2 Slurry, FYM and AD Technology

This section considers the properties of slurry and FYM as AD feedstocks and technologies and operational considerations involved in their processing in AD facilities.

2.1 Slurry and FYM as AD feedstocks

Cattle slurry is relatively simple to treat compared to, for example, packaged food wastes. Slurry contamination is normally low and typically limited to grit. It is reasonably homogenous, has low variability, is of favourable small particle size, is easy to pump and often requires no water addition. However, and crucially, it has a low potential to produce biogas.

Cattle derived FYM requires more preparation for a typical wet AD process and the presence of straw can be problematic as it can form floating layers in tanks and it does not degrade well in the process. Farmyard manure has better biogas potential on a unit volume of fresh material basis, although unlike slurry it requires dilution for a wet AD process, which reduces that benefit.

AD feedstock characteristics determines the technology required to process them. Key characteristics are listed below.

- Potential to produce biogas
- Dry matter ("DM") content (linked to above point), i.e. how much of a feedstock sample taken and analysed in a laboratory will remain after drying
- The level of contamination
- Homogeneity
- Particle size
- Variability between delivered loads
- Compatibility with other feedstocks where mixed

Reported DM content and biogas yield for waste feedstocks vary a little between studies. Indicative values are provided in Table 1. When compared to other common feedstocks, cattle slurry has a very low biogas potential, e.g. it is around a fifth of that for household food waste and grass silage. Poultry manure has a good gas potential but is a problematic feedstock to treat on its own and it is typically co-digested with other feedstocks.

Table 1. Indicative dry matter and biogas potential of feedstocks[2]

Property	Cattle manure	Dairy cattle slurry	Beef cattle slurry	Pig slurry	Poultry/layers	Poultry broilers	Sugar beet waste	Wheat silage	Maize silage	Grass silage	Vegetables	C&I[1] food wastes	Household food waste	Garden waste
Dry Matter (%)	25	9	9	5	30	65	18	38	30	21	20	23	23	35
Biogas (m^3/t fresh weight)	45	22	22	26	110	239	81	193	148	111	101	104	104	151

[1] Commercial and industrial

[2] *AEA-ADAS, 2011 (other than cattle manure- Redman, 2010 & Masstock, 2010)*

2.2 Typical wet AD technology

Wet AD processing of cattle slurry typically requires the equipment listed below.

- Raw feedstock holding tank (most likely an existing slurry tank)
- Pumps and macerators
- Digester/s with mixing device (mechanical agitator, gas circulation or hydraulic circulation)
- Gas storage (external to digester or flexible membrane forming the roof closure to the digester or digestate storage tank) and gas utilisation devices (engine or boiler)
- Heat exchangers to use gas utilisation heat to warm digester/s
- Digestate storage tank and digester separator or dryer (optional and to separate solid and liquid)

Digesters are typically glass coated steel panels bolted together, stainless steel, pre-cast sectional concrete or continuous pour concrete. The decision on material is informed by cost, lifespan and maintenance requirements. All sealed tanks require pressure relief valves for emergency release of gas, sealed penetrations for feeding and emptying and sealed penetrations for mixing arrangements, temperature control pipework and commonly instrumentation. Most tanks have inspection windows, access manways and external access stairs and platforms. Digester insulation is fundamental to ensuring adequate process temperature and some digester designs incorporate devices for continual removal of settled grit or floating light material from the tanks. Although not typical for slurry only, some AD systems include provision for removal of contaminant material (sinking and floating) prior to the digesters.

As we discuss above, digesters are more than simply tanks alone. It may be possible to retrofit existing farm tanks to serve as digesters. However, the tank would have to be of suitable dimensions, of sound construction, be very corrosion resistant, be able to be penetrated with equipment and pipework, be able to support loads of ancillary equipment and have reasonable life remaining. Besides rate of feeding, the tank size affects how long material remains in the tank. Appropriate retention time is crucial to ensure an effective AD process. Above all, a retrofitted tank would have to ensure low risk of escape of contents to the environment. At face value, it may seem a cheaper option than new build, but it may not always be suitable or cost effective and we conclude that complete new build is the most likely route.

Biogas is typically combusted in engines to generate electricity, generally with heat recovery, or in boilers. Engines with heat recovery are known as combined heat and power engines ("CHP"). The biological process needs to be maintained at a controlled temperature (typically 30°C to 40°C) to sustain the biology of the digester. To allow this, heat from biogas combustion is used to heat the digester. Designs vary, but for slurry only AD it is likely that in excess of half of all biogas will be used to heat the process. Tank insulation is therefore important.

Biogas can be refined to increase its methane content and improve its properties, whereafter it is typically input to the gas grid or used as a vehicle fuel. The capital cost is high and mostly suited to high gas yield facilities, which would not likely include sole processing of slurry and FYM.

Additional technology is often required where other wastes, including FYM, are to be processed. Examples are listed below.

- Contained floor/bay/clamp for solid wastes (subject to design some wastes are placed into open-top tanks sunk into the ground)
- Hopper with screw feed for solid wastes
- Shredders and mixers (with water addition) for solid wastes
- Depackaging machines for contaminant removal (packaged food waste etc.)
- Contaminant removal processes (more likely than with just slurry and FYM)
- Storage arrangements for removed contaminants
- Pasteurisation equipment to treat waste feedstock or digestate containing animal by-products
- Potentially a weighbridge

Where other wastes (not needed for FYM) are being processed, it is likely that a process building will be required which may need to be installed with air containment and odour treatment equipment. More complex facilities require more staff input and so an office, control room and welfare facilities

may be required. Facility designs can become more involved and costly where animal by-products are to be processed as there is a need to maintain separate dirty and clean areas.

Slurry-only plants are generally the simplest plants technologically. Food waste plants tend to be the most complex and most expensive. However, such plants can give rise to higher revenues through both higher gas/energy yields and gate fees.

Irrespective of facility type, containment of AD plants, i.e. kerbing and bunding and sealed drainage, is a high priority for regulators. There have been numerous examples of spills, leaks and pollution events from all sizes of facilities. In recent years facilities have been constructed on farms without bunded containment. Regulators are now increasingly demanding fully bunded tank farms and that can increase capital costs considerably.

2.3 Technologies not considered

Other than in this section of this report, this report does not consider the technologies listed below.

- Technologies primarily used to treat wastewater such as up-flow anaerobic sludge blanket (UASB) technology, which is not suited to slurry and FYM
- Dry AD
- Lagoon AD
- Containerised/packaged AD

Dry AD, Lagoon AD and packaged AD are all technically feasible. However, we consider it unlikely they could be deployed in Scotland to the extent that appreciable impact upon GHG emissions from slurry and FYM can be achieved.

Dry AD processes are uncommon and there is limited information and track record of use for treating agricultural wastes, albeit some information exists[3 & 4]. The paucity of data and limited track record does not allow robust assessment within the context of this study and market ready technologies. With future development and demonstration, dry AD may bring benefits to the treatment of FYM.

Lagoon AD processes have been employed for slurry processing. A lagoon is excavated into the ground, lined and covered to allow anaerobic conditions and biogas generation. Alternatively, some applications use bag technology. The approach is lower cost than a typical process undertaken in above ground tanks. However, there is less ability to control the process, e.g. mixing or temperature control, and a greater potential for leaks to groundwater or surface water. Lagoon AD is most beneficial in climates warmer than the UK and for high strength liquid wastes with minimal grit contamination, e.g. from a food production factory. These process limitations impact upon the production of biogas from slurry and lagoon AD requires a comparatively large footprint area. For these reasons, this study does not consider lagoon AD.

Package AD units are supplied within shipping container style containers, lending themselves to rapid deployment and ease of movement. They can also bring advantages in remote locations where transport of construction materials is impractical. However, the units are limited in throughput capacity and unsuited to large-scale application on a single site. To fulfil the Scottish Government's objective of reducing GHG emissions from slurry and FYM at a national level would require application on many small farms. This is considered unrealistic and would deviate from the Scottish Government's intended approach (Figure 1).

2.4 Operator time requirements

A small slurry only facility (typically < 5,000 tonnes per annum) may require no more than an average of an hour or two of attention each day. Nonetheless, that is not insignificant given the demands on a farmer's time.

A large (tens of thousands of tonnes per annum) centralised slurry AD plant would require full-time attention, probably by more than one person.

[3] http://www.wrap.org.uk/sites/files/wrap/Methanogen%20-%20DIAD%202%20feasibility%20study.pdf

[4] http://www.jdb.se/sbfi/files/Rapport_On_Farm_Biogas_production_with_solid_manure_in_organic_farming.pdf

A moderately sized facility (e.g. circa 20,000 to 30,000 tonnes per annum) taking several feedstocks would certainly require multiple full-time employees. If packaged food waste or household kitchen waste, that number could be around ten full-time employees. On such facilities, staff costs, along with maintenance costs, are often the greatest operational cost.

2.5 Implications of technology to feasibility

All of the technology described in Section 2.2 is proven and market ready. There are differences in performance, cost and maintenance requirements between different designs and equipment from different suppliers. Whilst differences in performance exist, they are not of order of magnitude difference.

Close management of process conditions and attention to maintenance is essential on any scale or type of AD facility. An operator has to be prepared to invest time and money in keeping the biological process healthy and the plant operational. Pumps, macerators, agitators and gas compressors will always require frequent maintenance and blockages and issues with grit are common issues. If the operator lacks the inclination or necessary skill and there is no maintenance contract in place, the facility will not be viable in the long-term.

A small single farm AD facility to process slurry only could typically involve a capital cost in the order of £250k. A large centralised AD ("CAD") plant (i.e. tens of thousands of tonnes per annum) predominantly processing slurry will cost several million pounds. For context, a 20,000 to 30,000 tonnes per annum food waste AD facility would approximately cost in the region of £4m to £6m.

Capital costs vary notably subject to scale and nature of the feedstocks to be processed. Whatever technology is employed, capital costs are nonetheless high. For the AD of slurry and FYM to be viable, self-financing and sustainable in the long-term, there has to be financial return on the facility. Returns are principally likely to come from energy use and potentially from gate fees where other wastes are processed.

Actual experiences in Scotland and across the UK of the processing of slurry and FYM are discussed in Section 0.

3 Experience to date

3.1 Market dynamics

The UK's AD market is dynamic. In the past five years the number of facilities in Scotland and across the UK has risen notably. We now have greater use of energy crops and more upgrading to biomethane. In the past two years there have been some reports of over-capacity and falling gate fees, particularly in England[5]. There are also increasing eligibility restrictions and reduced payments for government incentive schemes for renewable energy production. Market dynamics can be highly varied at a local level. When UK wide surveys have been undertaken[5 & 6], Scottish returns have been limited so findings may not be truly representative, reflecting the relatively lower number of AD facilities in Scotland. To add to the complexity, many existing facilities have medium to long-term contracts with favourable gate fees and are in receipt of incentive payments at favourable rates no longer available. As such, there are AD plants operating at present that may not be viable if constructed today. Development drivers at the time of development may not be so favourable now.

Considering the above points, caution is required when reviewing experiences of existing or former AD facilities, including between regions. Nonetheless, such a review is useful to inform this study. We reviewed readily available data and case studies for common themes and insightful experiences. Some data discrepancy exists, including some facilities listed as operational that are no longer operating and some contradictory information on feedstocks processed and operational capacity. Such inherent limitations in the data reflect the dynamic nature of AD. In many cases the wastes listed are the design intent, whereas during operation opportunities and experiences arise that lead operators to make changes. We have catalogued available facility data for selected facilities in brief case study form in Appendices 4 and 5. Discussion of key findings is provided below.

3.2 Scottish AD industry

Scottish AD facility locations are shown in Figure 4.

Figure 4. Location of Scotland's AD facilities

Contains OS data © Crown copyright and database right (2017)

[5] WRAP Gate Fees Report 2017

[6] A survey of the organics reprocessing industry in Scotland in 2014, ZWS/Ricardo-AEA Ltd, April 2016

Our records combined with those of the AD Portal[7] indicate 48 Scottish AD facilities, although we recently identified that two of these (small farm based) are no longer operating. Six facilities only process sewage sludge, eight process municipal/commercial waste, eight process industrial waste and 28 (including the two non-operational) process waste or non-waste agricultural feedstocks. Some facilities process more than one feedstock type (see Figure 4), hence why the numbers cited total more than 48. Five facilities are recorded as only processing slurry/manure (two no longer in operation). Therefore, there are only three on-farm AD facilities that treat slurry and FYM only. There are a further 16 facilities that are reported to process animal slurries and manure alongside other wastes and crop feedstocks (crops apply to 14 of the 16 facilities), with a combined processing capacity of 300,500 tonnes per annum.

Alongside data in Section 1.5, it is evident that very little slurry and FYM is captured for processing in Scottish AD facilities. Furthermore, 14 of 19 farm AD facilities in Scotland process crop feedstocks.

3.3 Slurry and FYM in AD - UK experience

At April 2017, there were 401 AD facilities in the UK[7], excluding those dedicated to treating sewage sludge. Over half (221) are shown to process animal slurries and/or manures. However, the sole processing of those wastes is uncommon at just 6% (24, with a combined capacity of 165,000 tonnes per annum). The respective percentage for Scotland alone is 12% (five out of 42). We found that two such facilities in Scotland are no longer operating, so the true number is three. As detailed in Section 3.1, the available data is not complete. Indeed, it is probable that there are less than 221 processing slurry and FYM in the UK. However, we can reliably say that sole processing of slurry and FYM is uncommon, whereas processing as part of a mix with other wastes is far more common.

Facilities solely processing slurry and FYM are of relatively low capacity. Of 24 UK facilities, the largest (Broadwigg Farm in Dumfries and Galloway) has a capacity of 28,000 tonnes per annum and only five facilities have a capacity in excess of 10,000 tonnes per annum.

The three operational facilities in Scotland that solely process slurry or FYM are listed below. Two have only recently been put into operation and one also processes poultry manure, which has a higher biogas potential than cattle slurry and cattle FYM (see Table 1).

- Balmangan Farm (Dumfries and Galloway/ cattle slurry): Commissioned in 2016 and has a capacity of 5,500 tonnes per annum.
- Crofthead Farm (Dumfries and Galloway/ cattle slurry): Commissioned in 2016 and has a capacity of 3,000 tonnes per annum.
- Broadwigg Farm (Dumfries and Galloway/ cattle slurry and poultry manure): Commissioned in 2015 and has a capacity of 28,000 tonnes per annum.

We undertook a desk-based review (case studies, articles, planning applications etc.) of the 24 facilities and spoke to a small number on the telephone. This review highlighted the following additional findings:

- Five were confirmed to not be operating
- Five appear to be processing poultry manure alongside other feedstocks (also applies to one of the five that is no longer operating)
- Evidence suggests 12 of the 24 currently process, or processed (one instance), other feedstocks in addition to slurry or FYM (including 8 appearing to also process crop feedstocks)

Costs and revenues of AD business cases involve many factors such as throughput, feedstock type and mix, location, proximity to grid energy distribution and incentive scheme rates applicable at the time of development. There is no 'one size fits all' and so it is not possible to provide a typical business case. However, there is sufficient evidence to indicate that the business case for facilities processing only slurry or FYM is weak. This is also indicated in other studies[8,9,10 & 11]. Of the schemes

[7] http://www.biogas-info.co.uk/resources/biogas-map/

[8] Should food form part of the farm recipe? Article in Recycling & Waste World, September 19 2013

[9] Farm Scale Renewable Energy Guide, SRUC/Scottish Government, undated

[10] Driving Innovation in AD: Marches Biogas Agri Digestore, Marches Biogas/WRAP, April 2016

[11] Anaerobic Digestion across the UK and Europe, Suzie Cave/Northern Ireland Assembly, 18 February 2013

listed in the AD portal as only processing slurry or FYM, it seems several no longer operate or have diversified into other feedstocks. Further information on slurry only schemes is provided below. However, the case studies in Appendices 4 and 5 show that the business case improves once other feedstocks have been included. We reviewed one case study[12] of a facility constructed in 2014 in Scotland which provided a detailed breakdown of forecast revenues, cost and profit. The facility was still in the early stages of operation at the time and had been designed to operate on cattle slurry and energy crops. We consider that the forecast energy yield from slurry and FYM alone is overstated and therefore the business case looks optimistic. Notwithstanding that, one scenario costed (slurry only) was forecast to generate an income of £70,000 (13 year payback) based on 2014 incentive scheme tariffs. If current incentive tariffs are used instead, that profit is notably diminished and the payback period made even longer.

In 2004/5, seven farms with small-scale slurry fed AD facilities were fully funded by the Scottish Executive including the first five years of maintenance and parts. The farmers only paid for consumed electricity. The funding was provided to reduce the risk of impact on bathing water quality in coastal waters from farm run-off in Dumfries and Galloway and Ayrshire. This driver reportedly aided planning and permitting decisions. All seven were noted to be operational in a 2010 report[13]. None are operational today. To help gain a better understanding of these facilities we reviewed four case studies[14], online articles and spoke to one of the farmers.

- Each farm has a head of cattle between 200 and 350 animals
- All noted the Scottish Executive funding as a key factor that allowed the development
- Capital costs were in the region of c.£160k to c.£300k
- All used similar technology and insulated glass coated steel tanks that were gas mixed
- All used the gas generated to heat the AD tanks and one used it in a small Rayburn cooker
- All suffered from grit accumulation in tanks and problems with pumps and the gas mixing and three noted that it led to the shutdown of the plant after five years
- All noted gas yields were lower than anticipated, with two commenting that their farmhouse could not be heated as hoped
- Two commented that capital costs would dissuade farmers from installing AD
- Two noted that digestate is a better product than raw slurry, being less odorous, easier to spread and more effective
- One did not use the AD plant in the summer and felt that the financial side would ‘stack-up better with a few thousand cows kept in all year round’

With reference to the low gas yields, cattle slurry and cattle FYM have notably low gas potentials (Table 1). In the UK, it is always necessary to utilise some of the gas generated to heat the tanks to maintain biological activity. However, it is interesting that there was insufficient residual heat for other uses other than a small Rayburn cooker. Other problems encountered, i.e. grit accumulation and issues with pumps and mixing arrangements are not uncommon on AD facilities (Section 2.5). The technology utilised was broadly typical for a wet AD process. Evidently, the benefits of the AD facilities were insufficient for most of the farmers to persist with maintenance and operation much beyond the five-year period where maintenance was being undertaken for them.

The seven Scottish facilities discussed above were all small facilities, and such small-scale facilities may not meet climate change objectives at a national scale. There has only been one largescale facility in the UK, located in Holsworthy in Devon. The site was constructed to operate as a centralised AD (“CAD”) facility. The facility is a typical wet AD process and was designed to generate electricity via CHP. One of the authors of this report, Simon Ford, visited the facility in May 2003 (waste receipt/operation began in 2002). The following details are from literature provided during the visit.

- Capacity of 146,000 tonnes per annum of cattle, pig and poultry manure plus some organic food waste
- Manure to be collected from 30 local farms within a 5-6 mile radius
- Food processing waste to be collected direct from food processors in the southwest
- Waste inputs pasteurised prior to the digestion process

[12] http://www.renewableenergyonfarms.co.uk/project/south-region/east-knockbrex

[13] Digestate Market Development in Scotland, Zero Waste Scotland/AEA, 2010

[14] A Review of Anaerobic Digestion Plants on UK Farms, Royal Agricultural Society of England/Angela Bywater, 2011

- Digestate (bio-fertiliser) to be provided to the farms that supplied the manures
- The facility will collect waste and distribute digestate using its own lorries
- Total project cost will be £7.7million, part funded by a £3.85 million EU grant (Objective 5(b)) administered by MAFF (now Defra) and the District Council of Torridge
- The EU grant allowed construction of digestate storage facilities on the supplying farms
- Budgeted 3.9 million m^3/year of methane, or 39 million kWh of energy per year
- Two CHP engines will be used to generate electricity and heat, with a total power capacity of 2.1 MW and budgeted power production of 14.4 million kWh per year
- Electricity produced to be sold at 5.81p per kWh (2002 price level), index linked to RPI, according to the NFFO (Non-Fossil Fuel Obligation) granted to Holsworthy Biogas
- Anticipated that excess heat (c. 15 million kWh per year) will be sold through a new district heating system to supply the town of Holsworthy. [This did not happen]
- Anticipated 8,960 tonnes/year CO_2 emissions saving based on current mix of fuels at power plants (13,020 tonnes/year if only displacing coal), plus additional CO_2 savings from manure handling and heat use

Strathclyde University produced a case study on the Holsworthy facility[15], in the early years of operation. The study notes the feedstock is manure from 3,750 dairy cows from 25 farms within 5 miles, litter from 200,000 hens and chickens and miscellaneous commercial food waste at 40 tonnes per day. The food waste was incurring a gate fee whereas the manure was not. The plant was processing circa 400 tonnes per day with a biogas yield of circa 40m^3 per tonne of feedstock. The plant funds the collection of feedstocks but farmers collect the digestate from site. The gas yield (40 m^3 per tonne of feedstock) is greater than can be obtained from slurry alone and reflects the input of poultry manure and to a lesser extent the small volume of food waste input. However, when compared to other feedstocks (see Table 1) the gas yield is still low suggesting a high input of slurry.

In a PhD thesis[16] literature review, the author cites a lifecycle assessment by Crumby *et al*. (2005) for the Holsworthy facility. The feedstocks being received were 57% farm slurry, 19% blood, 11% food waste, 8% chicken manure and 5% other on-farm wastes. The facility was processing an average 277 m^3/day (approximately 277 tonnes per day) to produce 1.32 MW of electricity from a biogas yield of 36 m^3 per tonne of feedstock.

The Holsworthy facility was purchased by the current operators, Andigestion Ltd, in 2005. In a BBC news article[17] (7 February 2005) the original operators (Holsworthy Biogas) were quoted as saying 'although it has been operating profitably, the current income was not sufficient to support the necessary reinvestment to upgrade the plant and comply with the necessary legislation'. Andigestion gradually turned the AD process into a food only process. It currently processes >70,000 tonnes per year of food waste generating an average 3.2MW.

Some sources, e.g. the RASE report[18], refer to the Holsworthy facility as being uneconomic prior to its change of ownership. Strathclyde University undertook a modelling exercise and note 'Overall, our model does not predict the Holsworthy plant to be profitable, even taking into account the 50% capital grant that was received'.

There is sufficient evidence to indicate that the AD of slurry or FYM only scenario will not be suitable to address the Scottish Governments goals (see Figure 1), although inclusion of poultry litter may improve viability. Possible scenarios are, therefore, on-farm AD with inclusion of energy crop feedstock, on-farm AD with a wider mix of feedstocks (food waste etc.) or inclusion of slurry and FYM in off-farm AD facilities processing a range of feedstocks. European and UK policy and legislation has recently moved to limit energy crops and encourage the use of waste based feedstocks[19] (see Section 4.3). Case studies (Appendices 4 and 5) indicate that inclusion of some crop feedstocks can notably improve the viability of small-scale on farm AD facilities processing slurry or FYM. At a larger scale, other waste feedstocks (distillery waste, household food waste etc.) present an opportunity in

[15] http://www.esru.strath.ac.uk/EandE/Web_sites/03-04/biomass/case%20studyhols.html

[16] Assessing the multifunctional role of anaerobic digestion in England, Robert Charles Dominic Tickner, September 2014

[17] http://news.bbc.co.uk/1/hi/england/devon/4243649.stm

[18] A Review of Anaerobic Digestion Plants on UK Farms, Royal Agricultural Society of England/Angela Bywater, 2011

[19] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/land-use-change

Scotland. Ricardo delivered a recent report for Zero Waste Scotland[20] ("ZWS") which mapped bioresource arisings across Scotland, from which we conclude that opportunities for co-digestion exist. Incentivising any facility to process slurry and FYM, when other more lucrative feedstocks are available, will be a challenge however.

3.4 Slurry and FYM in AD- EU experience

We reviewed a report[21] published by the Northern Ireland Assembly which includes a review of AD in a number of European countries. Selected information is summarised below and indicates that there are few plants that use solely slurry and FYM and facilities receive substantial incentives.

- Agricultural CAD facilities typically use livestock manures and crops as feedstocks, as well as other material such as from food processing. Such facilities can involve a number of farms, roughly within a 10km (c.6 mile) radius.
- The economics of AD remain finely balanced and it is vital to get the feedstock and size of the plant right. Supplementing manure and slurry with crops can make all the difference.
- Originally most plants were built to accommodate slurry only, but low biogas yields were uneconomical and biogas yield was greatly enhanced by use of crop silages. European biogas plants are commonly fed a 'diet' of 70 percent green crop silage and 30 percent slurry.
- The current (as at 2013) economics for on farm AD are favourable in Germany. An Act guarantees a premium price for 20 years for renewable energy. From January 2012, new biomass plants are paid on the basis of their allocated plant capacity, on a sliding scale from €0.143/kWh (<150kW) to €0.06/kWh (<20MW). Plants using at least 80% slurry and recovering >60% of heat will be eligible for a flat rate tariff of € 0.25/kWh.
- Germany uses a system where digesters often use purposely grown crops instead of manure and slurry. However, the NNFCC[22]has stated that digesters using high proportions of crops typically require specialist modifications and higher initial investment. The NNFCC inform that due to the lack of large amounts of available land in the UK the German model would not be suitable.
- Most of Denmark's biogas is produced by collective co-digestion units. These units mainly process agricultural effluents (liquid manure) mixed with commercial food processing waste and municipal food waste. Heat recovery from cogeneration is used extensively due to the large amount of small district heating networks which supply 60% of Denmark's households.
- Sweden gives priority to heat production for district heating system (1/3 of energy produced). Government grants subsidise 30% of the investment costs for biogas units.

[20] Biorefining Potential for Scotland, Ricardo Energy & Environment/ZWS, May 2017

[21] Anaerobic Digestion across the UK and Europe, Suzie Cave/Northern Ireland Assembly, 18 February 2013

[22] http://www.nnfcc.co.uk/

4 Practicalities of implementation in Scotland

4.1 Energy use

Anaerobic digestion facilities can be used to generate biomethane (biogas upgrading), electricity and heat, noting they also have parasitic demands for heat and electricity. As evidenced by case studies (Appendices 4 and 5) parasitic heat demand alone can consume a significant quantity of the biogas produced on small slurry only facilities. Surplus heat and electricity can be used on site or distributed for off-site uses. Biomethane can be used as a vehicle fuel or injected into the gas distribution network.

Dairy farms are typically the most energy intensive of farm types. Typical energy uses on farms are shown in Table 2.

Table 2. Typical energy demand on farms

Farm type	Heat uses	Electricity
Dairy	Washdown water (modest demand) Pasteurisation (significant demand) Space heating	Chillers Milking equipment
Beef	Grain drying (August to October)*	Fans for grain driers
Poultry	Space heating Washdown water	Ventilation systems Lighting

* *Drying facilities can have heat loads of hundreds of kW, but only during harvest season. Some farms utilise the drying facilities for drying other products such as wood chip or wood logs outside of this period.*

Three potential scenarios exist for electricity generated through AD:

1) electricity used on site
2) electricity partially used on site, with the balance exported to the distribution network
3) electricity generated on site fully exported to the distribution network
4) community or local energy supply

DairyCo conducted research into the annual electricity consumption on dairy farms and concluded that average annual consumption should be in the range of 350–425kWh$_e$ per cow[23]. Some of the case study farms (Appendices 4 and 5) using slurry only AD with herds around 300 head found that nearly all biogas was utilised in heating the AD process. If we generously assume that only 50% is required for that purpose, that we ignore the parasitic electric demand and that animals are housed for eight months/ year, we estimate that the biogas produced could generate circa 7.2kW$_e$, or circa 60,000kWh$_e$ annually. Using the DairyCo demand assumption, the demand would be at least 105,000kWh$_e$. On that basis, it is unlikely that an AD facility, solely fed slurry, on a dairy farm would be in a position to export electricity.

Export of electricity to the national grid is most likely when the AD facility also receives high gas yield feedstocks. However, in some parts of Scotland, grid access is considerably constrained. There are two Distribution Network Operators (DNOs) in Scotland. The DNOs are required to publish 'heat maps' to indicate where the electrical grid constraints are at a substation level. Substation density is loosely linked to demand and so to population density. There is, therefore, normally only a choice of one substation for a farm to connect to. A lack of end-user demand connected to rural substations means there are limits to the amount of generation that can be connected. Only 23% of all the grid connection points on the Scottish and Southern Electricity Networks ("SSEN") network are unconstrained[24]. These are primarily in urban areas, so unlikely to be suitable for a farm AD connection. This is true in the Aberdeenshire area, where there is a higher proportion of beef cows being farmed. This does not mean that it would not be possible to secure a grid connection, however it would likely mean it would be more expensive.

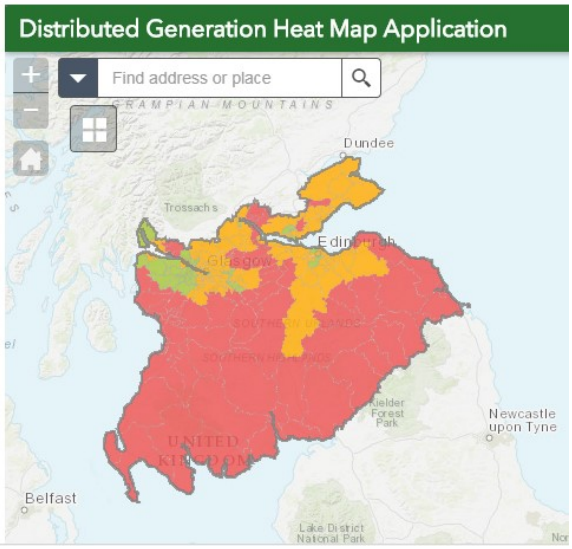
Figure 5 shows the 'heat map' for the other DNO is Scotland, Scottish Power Energy Networks ("SPEN"). This shows that rural areas in the south, including Dumfries and Galloway, are also

[23] http://www.yougen.co.uk/upload/Morrisons_RenewableEnergy_Yougen.pdf

[24] Figures obtained 02/11/2017

constrained. This would potentially have an impact on the grid access that would be available for any new AD schemes. However, it was recently announced by Ofgem[25] that SPEN were awarded funding to allow the roll out of an Active Network Management zone in Dumfries and Galloway. Using Active Network Management will allow increased network access to distributed generators that would otherwise be constrained. However, it does increase other uncertainties such as the cost of connection and the timescales for connection.

Figure 5: Scottish Power Energy Networks 'heat map' identifying electricity distribution network constraints



4.2 Authorisations

Anaerobic digestion can potentially cause pollution and the Scottish Environment Protection Agency ("SEPA") regulates sites, and early engagement is recommended. Subject to criteria discussed below, SEPA issues authorisations or exemptions separately, or combined, for:

- The AD process
- Combustion of biogas
- Off-site storage of digestate
- Land application of digestate

Facilities processing wastes containing animal by-products ("ABP"- not slurry or FYM) also require authorisation from the Animal and Plant Health Agency ("APHA"). Facility design will need to comply with requirements relating to bio-security and the separation of clean and dirty areas. There will be a requirement for feedstock to be processed to a minimum particle size and for feedstock or digestate to be pasteurised and periodic sampling undertaken to confirm pathogen kill.

The requirements for authorisations are often lower where only agricultural waste, or agricultural waste with non-waste agricultural feedstocks, are input. Other than land-spreading, the activities above may also require planning consent.

Where certain criteria are met[26], SEPA does not apply waste regulatory control to the digestate produced. If non-compliant, a WML or WML exemption is required for off-site storage of digestate and land application. Compliance depends on waste type and whether it has been mixed with other wastes, digestate quality and usage criteria and associated certification to the BSI PAS110:2014 standard.

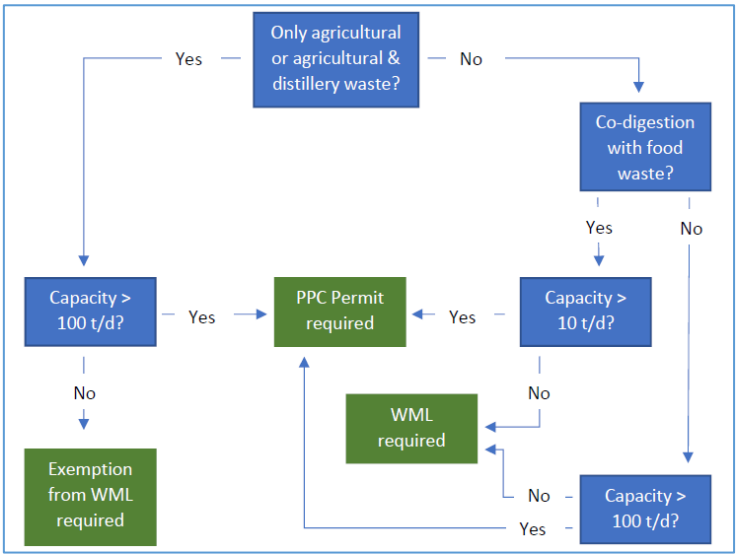
The permission most likely to impact upon viability and development cost is the SEPA authorisation for the AD process (discussed below). Land application of digestate is most likely to be undertaken under an exemption from licensing. Where combustion of biogas is at a level that requires a permit in its own right, it is likely to be incorporated within a single permit including the AD process itself.

[25] https://www.ofgem.gov.uk/publications-and-updates/decision-2017-electricity-distribution-innovation-roll-out-mechanism

[26] Compliance with SEPA Position statement: Regulation of Outputs from Anaerobic Digestion Processes, version 5, February 2017

Before operation, operators must apply to SEPA for either a pollution, prevention and control ("PPC") permit, a waste management licence ("WML") or a WML exemption. Applications and ongoing monitoring and reporting for PPC permits require the most effort and WML exemptions the least. Applicable authorisations for specific AD operations are shown in Figure 6.

Figure 6. SEPA Authorisations for AD processes



At a specific site level, regulatory requirements could prevent development. However, there are no regulatory requirements that will automatically prevent the AD of slurry and FYM, the utilisation of biogas or the storage and land-spreading of digestate.

4.3 Incentive schemes

Incentives are available to operators of AD facilities through the schemes listed below. Both schemes are administered by Ofgem and require prospective participants to apply for accreditation.

- Feed-in-tariffs (FiTs) for electricity generated and exported
- Non-Domestic Renewable Heat Incentive (RHI) for heat used for eligible purposes

Feed-in-Tariffs (FiTs)

Eligible AD facilities with an electrical capacity ≤5MW$_e$ (likely to include an on-farm CAD facility) can apply for FiTs. Participants receive payments through their energy supplier for power generated with additional payments for any power generated that is exported to the grid. Current tariff rates are presented in Table 3. Generation tariffs are reduced ("degressed") at quarterly intervals.

Table 3. FiT Tariff rates for newly accredited AD facilities (accredited October to December 2017)

Capacity band	Generation tariff rate (p/kWh)	Export tariff rate (p/kWh)
0 - 250kWe	4.99	5.03
250 – 500kWe	4.72	5.03
500kWe – 5MWe	1.76	5.03

Prospective participants can apply ahead of facility commissioning to secure the current generation tariff (a process known as 'preliminary accreditation'). Accreditations are collectively capped to a total of 5MW$_e$ of capacity a quarter. If the cap is exceeded, any excess capacity is held for processing until the next quarterly period. The scheme works on a 'first come, first served' basis.

Recent reforms mean that newly accredited facilities are subject to feedstock restrictions. Where electricity generated from biogas not derived from feedstocks classified as wastes or residues exceeds 50% of the total biogas yield (by energy content), the facility will not be entitled to FiT generation payments for the proportion in excess of 50%. For example, if the proportion of biogas derived from feedstocks other than wastes or residues is 60% by energy content, the facility will only receive generation payments on 90% of its output as it exceeded the 50% threshold by 10%. Slurry and FYM are wastes, so this presents an opportunity. For a crop and slurry or FYM facility, the respective biogas yields (Table 1) mean the majority of the feedstock would need to comprise slurry

to ensure >50% of the biogas is from waste feedstock. For example, based on Table 1 gas yields a grass silage and slurry facility would require at least c.84% slurry feedstock for tariffs to remain at Table 3 levels.

Applicants also need to demonstrate that feedstocks meet sustainability criteria, comprising limits on lifecycle GHG emissions and criteria relating to land used to produce the feedstock. Slurry and FYM are deemed to have met the criteria without the need to provide evidence.

Non-Domestic Renewable Heat Incentive (RHI)

Heat produced by AD facilities is eligible for payments under the RHI scheme. Payment is direct from Ofgem to participants where the heat is from an eligible source and for an eligible use, principally those listed below.

- The provision of space heating to a building
- The provision of hot water within a building, either for domestic or industrial purposes
- Carrying out a process within a building
- Carrying out cleaning and/or drying on a commercial basis other than in a building

The regulations governing the RHI define what can be considered 'building'. Broadly speaking this is any permanent or long-lasting structure which is wholly enclosed on all sides except for doors and windows. While heat used to support the AD process is considered an eligible use, its use is deducted from any payments. In the past, heat used for the drying of digestate was considered an eligible use of heat. Under planned reforms to the RHI, this is expected to stop (timescales unclear).

Current tariff rates for newly accredited AD schemes are presented in Table 4.

Table 4. RHI Tariff rates for new biogas installations (accredited between 1st July and before 20th September 2017)

Tariff Band	Capacity range (output)	Tariff Rate (p/kWh)
Small commercial biogas	Less than 200kW$_{th}$	2.88
Medium commercial biogas	200 to less than 600kW$_{th}$	2.26
Large commercial biogas	600kW$_{th}$ and above	0.86

Tariffs are degressed according to assessment of modelled spend against budgets, assessed quarterly. If one or more tariffs are projected to overspend, degressions in the range of 5 – 15% per quarter are made.

Unlike the FiTs scheme, prospective participants can only apply for accreditation following facility commissioning. This means that they will be subject to any tariff degressions that may occur during development of the scheme. This is expected to be addressed in future (timescales unclear) by the introduction of a system of tariff guarantees, allowing developers to apply for a guaranteed tariff upon demonstration of financial close for the development.

Applicants must demonstrate that feedstocks meet sustainability criteria, comprising limits on lifecycle GHG emissions and criteria relating to land used to produce the feedstock. Slurry and FYM are deemed to have met the criteria without the need to provide evidence beyond their status as a waste.

Planned reforms (timescales unclear) to the RHI mean that newly accredited AD schemes will be subject to feedstock restrictions, in a similar manner as for the FiT scheme.

4.4 Financing options

There are typically three stages to the development of renewable energy projects, each with potentially different sources of funding (Table 5).

Table 5. Potential funding options for facility development

Project stage	Funding options	Potential investors
Scoping	a) Grant b) Equity	a) Grant bodies b) Private individuals
Planning/ permitting	a) Grant/ Soft loan b) Equity	a) Grant bodies b) Private individuals
Construction	a) Equity b) Debt	a) Private individuals b) Commercial funders

The risks are highest during scoping and planning/permitting, which can be lengthy processes. In these stages, insurmountable barriers (e.g. technical, financial, planning and regulatory) may arise and a high proportion of renewable projects fail in these stages. It is, therefore, less likely to be possible to borrow money to fund these stages, thus it typically requires some form of grant funding (sources such as Local Energy Scotland through the Rural Energy Challenge fund[27] or Innovation Infrastructure fund or through the Low Carbon Infrastructure Transition programme[28]). Alternatively, farmers may wish to use their own equity in investing in these stages.

Scoping studies can be completed for around £10,000, much in line with available grants[29]. Planning and permitting applications can be significantly more expensive, influenced by the size, capacity and feedstocks for the planned facility. Small-scale facilities using only on-farm waste may be passed as permitted development (planning) and gain an exemption from waste management licensing. However, large facilities and those accepting third party waste will need full planning permission and will not qualify for licensing exemptions. A planning application will be most expensive where a full Environmental Impact Assessment will be required which and may cost in excess of £100,000. There are overlaps in what is required for planning and permitting, but permitting/licensing could cost in excess of £50,000.

An AD facility developer may be eligible for loan finance for 'feasibility and set-up costs' such as through the Local Energy Scotland Community and Renewable Energy Scheme ("CARES"30). This would require a detailed business plan and a robust feasibility study to be completed. Each funded project is expected to receive up to £150,000 and the total budget for 2017/2018 is £500,000. This would potentially benefit a small number of small on-farm AD projects. However, the amount of slurry and FYM that could be accommodated would be modest and so, therefore, would be the impact on GHG emissions.

Once planning/permitting and, if applicable, grid connections are secured, this opens-up additional sources of finance. Construction risk can often be mitigated contractually or with insurance, meaning commercial lenders are more willing to lend, whilst potentially taking an equity stake in the project. Lenders will require thorough commercial and technical due diligence process be undertaken before finance is offered. Key criteria that lenders might expect before funding an AD scheme are listed below.

- Securing all necessary permits and consents
- Negotiating commercially advantageous feedstock, digestate management and offtake (power purchase agreements, including heat if applicable)
- Ability to deliver capital projects on time and to budget

There are some developers who are prepared to take a greater stake in the project and will build and operate schemes on farmland, providing finance for planning/permitting, grid connections and construction. However, they will take a greater share of the profits, paying the farmer site rental, plant operation fees and feedstock costs. This de-risks projects for farmers, but reduces their revenues[31].

In recent years there have been tax allowances available for renewable projects including AD. These included incentives through the Enterprise Investment Scheme and the Seed Enterprise Investment Scheme. These no longer exist, although it is possible that this could change in the future.

[27] http://www.localenergy.scot/funding/rural-energy-challenge-fund/ This is currently closed for funding, but Local Energy Scotland will run a number of grant innovation funding calls which an AD scheme may be eligible for.

[28] http://www.gov.scot/Topics/Business-Industry/Energy/Action/lowcarbon/LCITP There are no current open calls for funding, however there are further calls planned.

[29] http://adbioresources.org/our-work/third-party-services/farmers-consultancy-service

[30] http://www.localenergy.scot/funding/cares-loan/

[31] https://www.qilaenergy.com/#ad-30-plants

5 SWOT analysis

On-farm (slurry/ FYM only)

Strengths

- Least complicated technology (applies to slurry not FYM)
- No road transport or minimal (if co-operative)
- Simplest planning and permitting

Weaknesses

- Large amount of facilities needed to make much GHG impact
- Low biogas/energy yield (export unlikely & on-farm limited especially without poultry litter)
- No gate fees
- Demonstrated poor financial business case
- Poor track record and low uptake in UK
- Processing of FYM overly complicated for a single farm
- Lender funding highly unlikely

Opportunities

- Poultry manure (good biogas & energy yield) inclusion boosts business case
- CARES funding

Threats

- Declining incentive payments
- Farmer motivation (poor uptake to date)
- Risk farmer may not have skills to operate and maintain facility

On-farm (slurry, FYM & crop feedstock)

Strengths

- More financially viable/ more attractive to farmers than slurry/FYM only
- Lender funding more likely than slurry/FYM only
- Feedstocks can be on-farm or locally sourced
- Allows slurry and FYM to be treated on farm
- Supports farming economy
- Can potentially allow grid connection or biomethane production
- Technology for crop processing can be suitable for FYM processing, potentially improving probability of AD in Aberdeenshire
- Farms, esp. dairy and poultry, have notable heat demands

Weaknesses

- Large amount of facilities needed to make much GHG impact
- Energy crops can change land use away from food production and potentially away from biodiversity value
- Soil Association consider energy crops degrade soil quality
- Higher capital cost than slurry only, but with higher returns
- No gate fees

Opportunities

- CARES funding
- Recently introduced incentive scheme rules encourage >50% waste feedstocks, i.e. slurry and FYM more likely to be desirable in crop based AD

Threats

- Declining incentive payments
- Risk farmer may not have skills to operate and maintain facility

On or off-farm (slurry, FYM & mixed feedstock)

Strengths

- If merchant facilities can be incentivised to take slurry/FYM then can use existing capacity, saving on capital cost
- Gate fees can be gained if on-farm/ farmer owned
- Best business case
- Lender funding likely
- High energy yield
- Slurry use can reduce water consumption

Weaknesses

- Whether on or off farm there will be more road transport
- Most complicated facility type (expensive, high maintenance and lot of operator input required)
- Need for authorisation from APHA if taking animal by-products
- Likely to involve most complex planning and permitting requirements

Opportunities

- Landfill ban on organic waste could increase need for new AD capacity in Scotland. Opportunity to incentivise slurry/FYM inclusion and design faciltiies from outset to co-digest with slurry/FYM

Threats

- Declining incentive payments
- If operator (farmer or non-farmer) is not incentivised to process low energy yield slurry/FYM there will always be a commercial argument to process other feedstocks in place of slurry/FYM.

Any facility taking slurry & FYM

Strengths

- Helps to minimise GHG emissions from agriculture
- Digestate has low odour compared to raw slurry
- Digestate has better fertiliser properties than raw slurry
- Where dry feedstocks (esp. crop based but also food) are used slurry inclusion can reduce water consumption

Weaknesses

- Slurry and FYM has little biogas potential and other feedstocks will be more attractive and viable in comparison
- Rural areas including Dumfries & Galloway and Aberdeenshire have constrained electricity grid, which can increase connection costs
- Gas grid distribution limited in Scotland if generating Biomethane
- To be financially viable, additional feedstocks required
- Increased transport on roads if taking slurry and FYM off-farm
- If using CAD or inputting into a merchant facility taking other feedstocks, farmers will typically travel up to 6 miles

Opportunities

- Incentive schemes could potentially follow the German model and provide higher payments for energy from slurry and manure
- Recent changes to FiT and RHI regimes promote waste feedstocks over non-waste feedstocks and slurry and FYM are widely available wastes.
- Need to justify feedstock sustainability criteria for incentive schemes does not apply to slurry & FYM
- Recently introduced active network management in Dumfries and Galloway may improve possibility of getting an electricity grid connection
- If mixing with high gas yield feedstocks, biomethane to grid, road tanker or fuel filling stations might be feasible

Threats

- Declining incentive scheme payments
- Increasing eligibility requirements for incentive schemes
- Heat for drying digestate expected to be made ineligible for RHI payments

One of the key findings of the SWOT analysis for on-farm AD is that co-digestion of additional feedstocks is required to boost energy yield and ensure financial viability. Crop feedstocks are commonly used to do this, but they do not attract a gate fee for the operator. Waste feedstocks such as kitchen waste do attract gate fees, but the facilities required are more complex and more expensive to develop and operate. In any on-farm scenario there will be a need for a very high number of facilities to make much impact on GHG emissions in Scotland. If considering an on or off-farm CAD facility, a key limitation is that it is only likely to be able to process slurry/FYM from within an approximate six-mile radius as result of limitations in how far farmers will be prepared to transport the feedstock. In that respect, any AD solution of any type is likely to require many facilities across Scotland to make much impact on Scotland's GHG emissions.

6 Conclusions

Slurry and FYM arise in very high volumes (for cattle, estimated at 5.56 million m^3/year and 13.75 million m^3/year respectively) and is widely distributed across many farms in all areas of Scotland. At present, levels of slurry and manure entering AD facilities in the country is negligible.

The AD of slurry and FYM alone has a demonstrated poor business case, founded on its low biogas yield. That is reflected in very low numbers of such facilities across the UK as well as several examples of facility closure and facilities that have sought addition of higher gas yield feedstocks. The business case, and therefore viability, is much stronger when other feedstocks are processed in addition, or in place of slurry and FYM. However, that increases development and operation cost and to co-digest a large amount of slurry/FYM requires correspondingly large amounts of other feedstocks, which have to be available within a reasonable distance. For these reasons, we consider that widespread construction of AD facilities to process slurry and FYM, with or without other feedstocks, is unrealistic. Furthermore, several sources indicate that where agricultural CAD, of any scale, facilities have been constructed in the UK (one example) and in continental Europe, farmers typically travel up to 6 miles (c. 10km) to deposit the material. Therefore, a limited number of facilities will only be able to serve a limited number of farms.

For the above reasons, we conclude that the impact that AD can have upon GHG emissions from slurry and FYM will be modest. However, AD could have a part to play, alongside other measures, in reducing GHG emissions from slurry and FYM. Dumfries and Galloway and Aberdeenshire are the two areas with the greatest arisings of slurry and FYM respectively and so are the best candidate authorities to focus upon.

The inclusion of poultry manure (higher biogas yield) and the co-digestion with crop feedstocks or other wastes substantially improves the business case. However, whether on or off-farm the drivers for slurry or FYM inclusion (co-digestion) are limited owing to its low gas yield. For a small on-farm scheme the fact that the farm generates slurry or FYM that has to be managed is a driver, along with the potential benefits in reduction of water consumption in the AD process. At a merchant AD facility level it will be hard to persuade operators to process slurry and FYM as it does not generate a gate fee and has low biogas yield.

In Germany, a higher incentive payment for renewable energy generation is made where the feedstock is slurry or FYM, in order to encourage its use and to compensate an operator for its low gas yield. Such a measure employed in Scotland may well encourage the AD of slurry and FYM. If so, there is greater potential for slurry and FYM to be input into existing AD facilities.

The forthcoming ban on the landfill of biodegradable waste in Scotland will, we assume, give rise to an increased demand for AD. If so, there could be an opportunity to incentivise the construction and use of co-digestion facilities that include slurry and FYM processing.

If the poor business case for the AD of slurry and FYM in any type of facility can be overcome, it will bring several benefits as listed below.

- Reduced GHG emissions from slurry and FYM management
- Improved fertiliser properties compared to raw digestate
- Reduced use of artificial fertilisers
- Reduced odour emission from land-spreading of raw digestate and FYM
- Reduced GHG emissions from replacement of fossil fuels with renewable energy
- If on-farm, any electricity generated can be used on site as well as heat generated (heat utilisation is particularly attractive for dairy and poultry farms)

Appendices

Appendix 1 – Glossary of acronyms used

ABP	Animal by-products
AD	Anaerobic digestion
APHA	Animal and Plant Health Agency
BEIS	UK Government department for Business, Energy and Industrial Strategy
BSI	British Standards Institution
CAD	Centralised anaerobic digestion
CARES	Community and Renewable Energy Scheme
CCP	Draft climate change plan
CHP	Combined heat and power
CO_2	Carbon dioxide
Defra	UK Government Department for Environment, Food and Rural Affairs
DM	Dry matter
DNO	Distribution network operator
EU	European Union
FYM	Farmyard manure
FiT	Feed-in tariff
GHG	Greenhouse gas
kWh	Kilowatt hour
kW_e	Kilowatt electric
kW_{th}	Kilowatt thermal
MAFF	Ministry of Agriculture, Fisheries and Food (now Defra)
MW	Megawatt
NFFO	Non-fossil fuel obligation
Ofgem	The Office of Gas and Electricity Markets
PAS	Publicly available specification
PhD	Doctor of philosophy
PPC	Pollution prevention and control
RHI	Renewable heat incentive
RPI	Retail price index
SEPA	Scottish Environmental Protection Agency
SPEN	Scottish Power Energy Networks (a DNO)
SSEN	Scottish and Southern Electricity Networks (a DNO)
UK	United Kingdom
WML	Waste management licence
ZWS	Zero Waste Scotland

Appendix 2 – Distribution of cattle by region, herd size and number of holdings

Number of holdings with dairy cows[1] and number of dairy cows by region and size group, June 2016

Herd size group	North West		North East		South East		South West		Scotland	
	Holdings	Number	Holdings	Number	Holdings	Number	Holdings	Number	Holdings	Number
1-4	125	163	116	170	106	153	361	608	708	1,094
5-19	c	c	c	c	9	90	86	764	117	1,033
20-49	c	c	c	c	9	299	61	2,064	75	2,513
50-74	7	438	5	325	12	780	83	5,284	107	6,827
75-99	c	c	c	c	9	789	107	9,382	122	10,672
100-149	8	1,007	9	1,134	17	2,086	219	27,248	253	31,475
150 & over	8	2,355	21	5,848	33	9,829	378	103,548	440	121,580
Total	**167**	**4,438**	**165**	**7,832**	**195**	**14,026**	**1,295**	**148,898**	**1,822**	**175,194**

[1]Female dairy cattle aged 2 years old and over with offspring
c data suppressed to prevent disclosure of individual holdings.

Number of holdings with beef cows[1] and number of beef cows by region and size group, June 2016

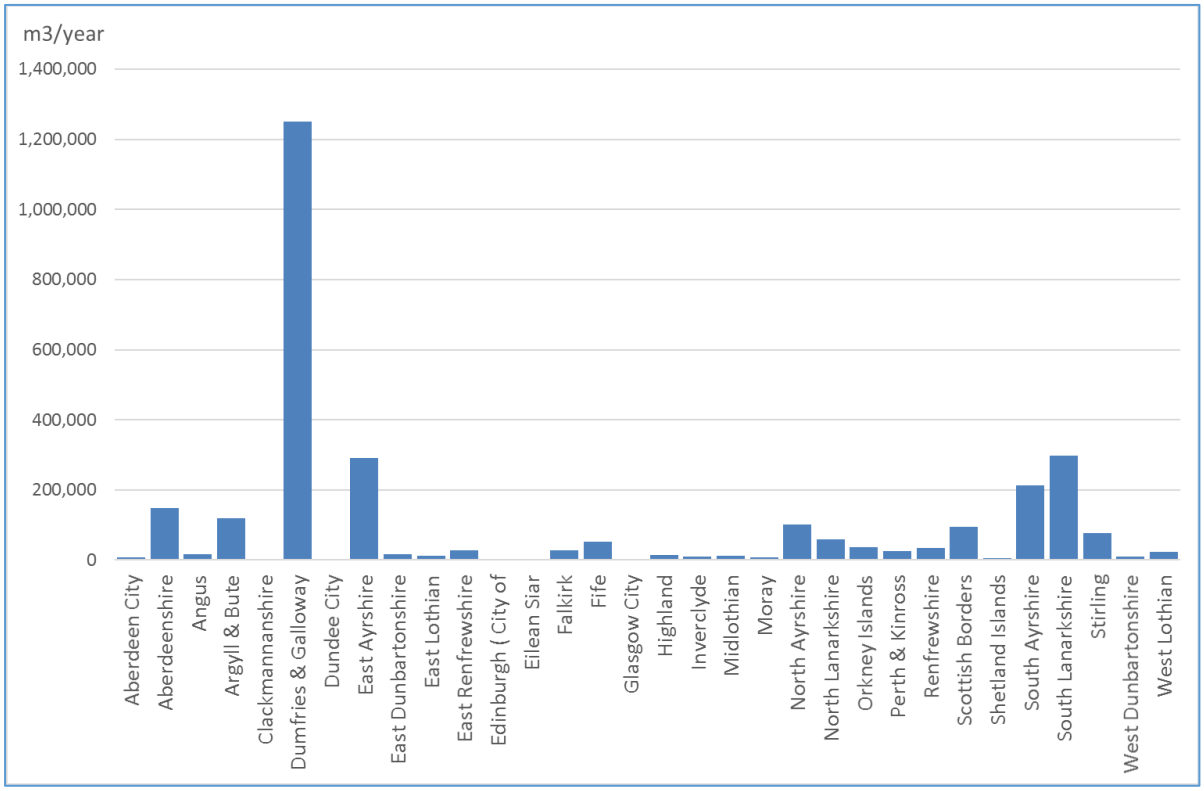
Herd size group	North West		North East		South East		South West		Scotland	
	Holdings	Number	Holdings	Number	Holdings	Number	Holdings	Number	Holdings	Number
1-4	793	1,836	266	544	211	414	629	1,330	1,899	4,124
5-19	917	9,176	337	3,849	252	2,794	697	7,464	2,203	23,283
20-49	479	15,505	363	12,021	383	12,741	813	26,915	2,038	67,182
50-74	174	10,682	200	12,365	232	14,187	429	26,150	1,035	63,384
75-99	101	8,685	143	12,227	173	14,798	291	24,944	708	60,654
100-149	124	14,747	146	17,713	167	19,829	279	33,668	716	85,957
150 & over	78	17,084	128	29,163	157	36,769	192	49,040	555	132,056
Total	**2,666**	**77,715**	**1,583**	**87,882**	**1,575**	**101,532**	**3,330**	**169,511**	**9,154**	**436,640**

[1]Female beef cattle aged 2 years old and over with offspring

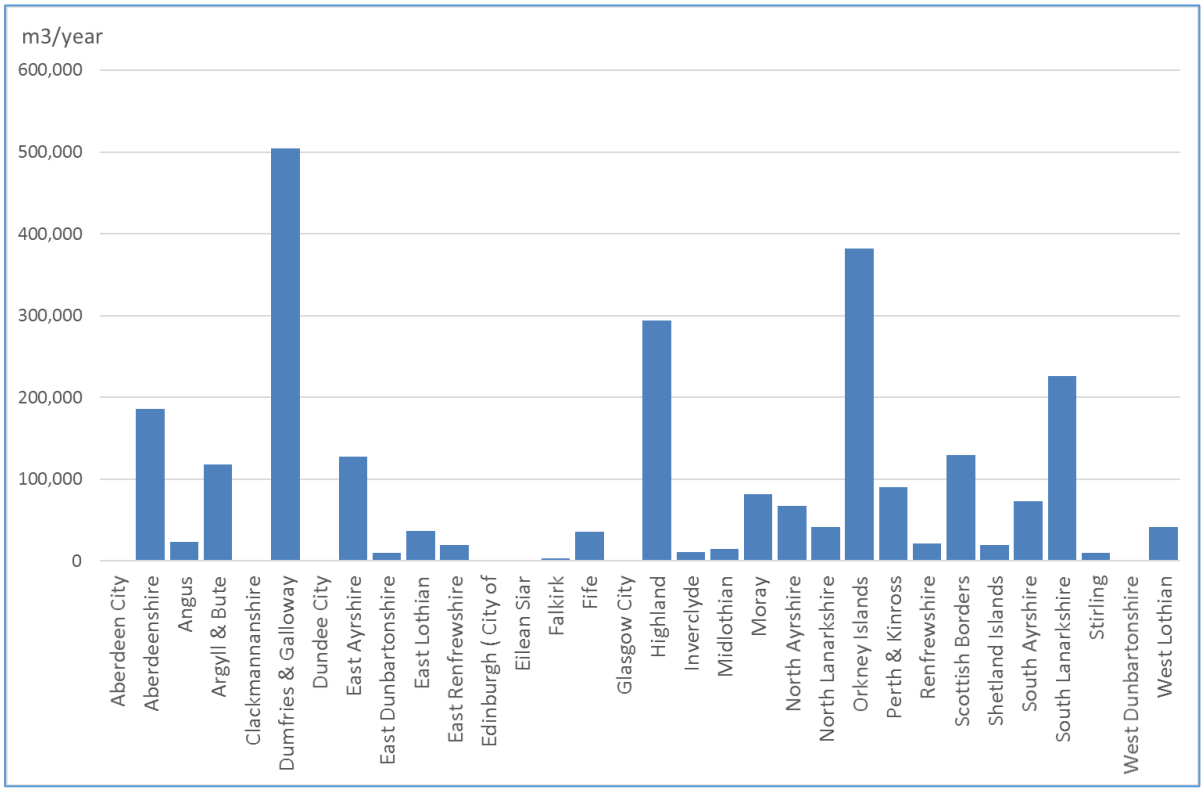
Source: June 2016 agricultural census data published by the Scottish Government

Appendix 3 – Slurry and FYM arisings by region

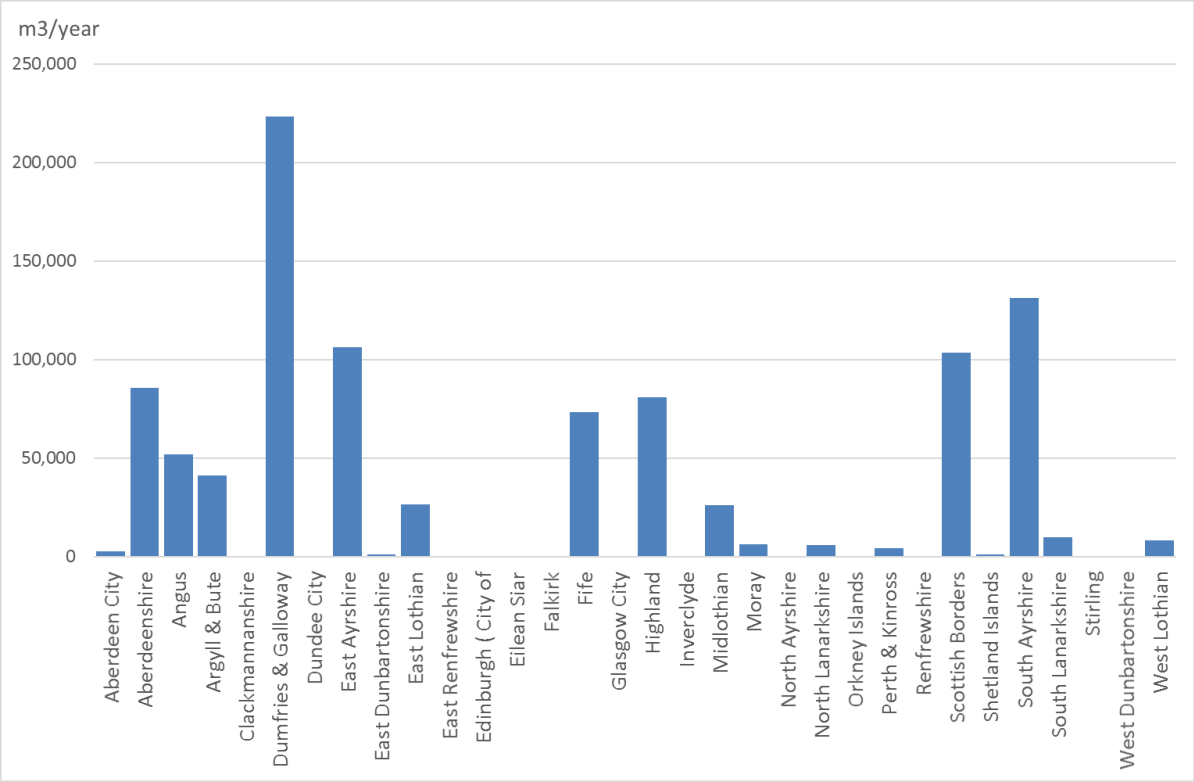
Slurry arising from dairy cattle (2015)



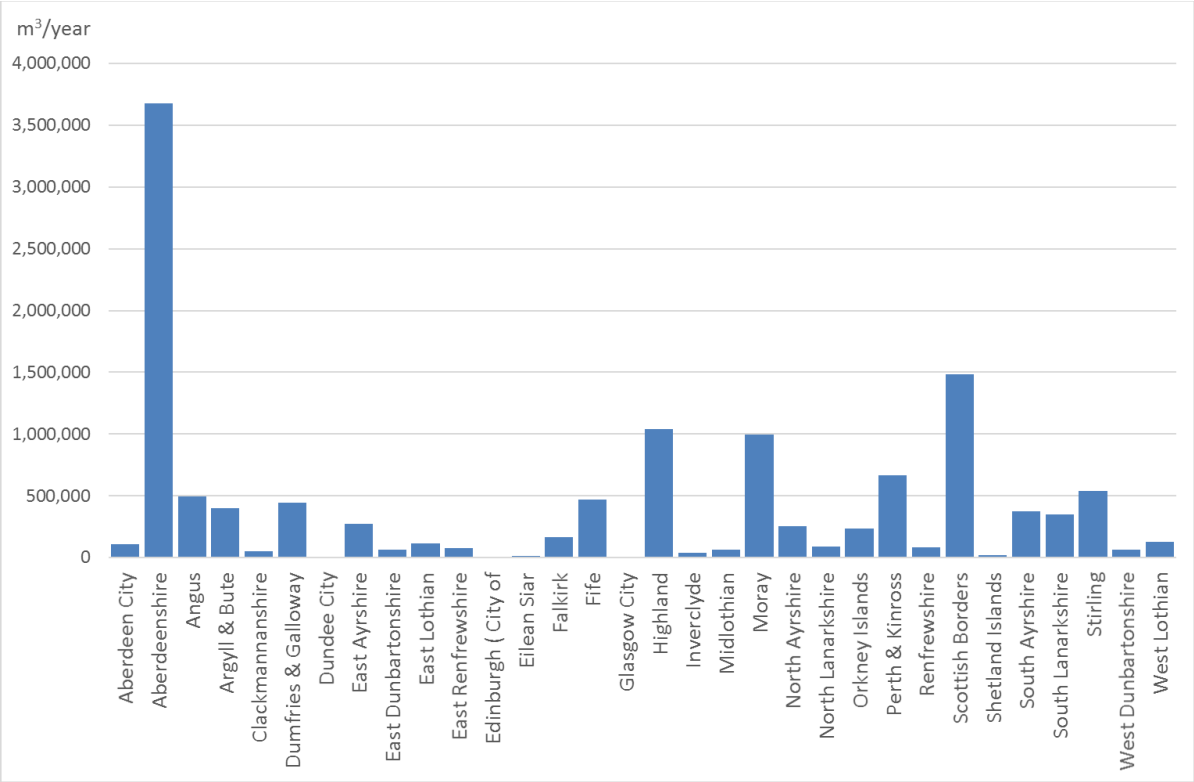
Slurry arising from beef cattle (2015)



FYM arising from dairy cattle (2015)



FYM arising from beef cattle (2015)



Appendix 4 – Data for 24 AD facilities

The farms listed in this appendix all appear on the AD Portal (http://www.biogas-info.co.uk/resources/biogas-map/) as slurry/FYM only and so we have researched them. In doing so we have reviewed multiple data sources (including some telephone calls direct to the farmers), some of which indicate that a number of the AD facilities are no longer in operation and some of which indicate that other feedstocks may also be being processed. Some of the data sources vary in the details provided. We have used what appears to be the most recent or relevant data, but cannot guarantee all information to be absolutely accurate.

KEY
Operational & slurry/FYM only
No longer operating
Other feedstocks confirmed/suspected

	Broadwigg Farm AD (Farm AD)	Crofthead Farm	Balmangan Farm (Balmangan AD)	Corsock Farm
Location	Newton Stewart, Dumfries & Galloway	Dumfries and Galloway	Dundrennan, Dumfries and Galloway	Dumfries and Galloway
Farm details	Dairy	Dairy (1,150 cows plus satellite unit nearby of 200 head and rearing heifers). Housed all year. One of Scotland's largest dairy farms.	Dairy and beef (300 head)	200 head, including 130 head dairy from nearby farms. Overwintered Oct -Apr.
Year of AD construction/commissioning	2014/2015	2015/2016	2015/2016	2004 (no longer operating- ceased in 2013)
Feedstock	Cattle slurry and poultry manure 28,000tpa (the largest slurry/FYM only facility in the UK)	Cattle slurry 3,000tpa	Cattle slurry 5,500tpa	Cattle slurry and manure
Energy use/capacity	500kWe	124kWe	124kWe (farm use and grid connection)	Heat only 20kWth (to heat digester only)
Technology			18m diameter digester with double skinned membrane dome gas collection on top. CHP circa 37 day retention time in digester	80m^3 glass coated steel tank.
Financial information	FiT accredited 23/12/2014		FiT accredited	£168k capital cost. No financial returns beyond reduced fertiliser purchase.
Benefits and issues				Scottish Government funded, including first 5 years of maintenance and parts. The operator noted the scheme would not have otherwise taken place due to his age and the payback times that would be involved. Was very pleased with the digestate produced. Enabled him to reduce his fertiliser bills by 2/3. However, biogas yield was much lower than expected such that there was only sufficient biogas to heat the digester. Sufferred boiler corrosion. Ongoing maintenance issues and farmer's age led to closure. Operator was very positive about the concept. However, he felt that the scale of his own scheme was too little to make it work.

KEY
Operational & slurry/FYM only
No longer operating
Other feedstocks confirmed/suspected

	Meikle Laught Farm	Lodge Farm AD Plant (Farm AD)	Tain Y Foel Farm	Hall Farm
Location	Saltcoats, Ayrshire	Wrexham, Clywd	Corwen, Conwy	Ludlow, Shropshire
Farm details	Dairy	Organic dairy (600 head)	90 suckler cows, 1,000 breeding ewes with lambs with 200 lambs kept for breeding. 540 acres in Nitrate vulnerable zone (NVZ).	Dairy (240 head housed for 5 months of the year)
Year of AD construction/commissioning	2005 (no longer operating)	2010	2014	Constructed between 2013 & 2015 & commissioned in 2016
Feedstock	Cattle slurry and manure	Cattle slurry, chicken litter and low category food waste (industrial). One source suggests silage may also be processed. 15,000tpa	Cattle and sheep slurry and broiler litter (broiler litter added as a feedstock at a later point than original construction) 1,400tpa	Cattle slurry and chicken litter 2,500tpa
Energy use/capacity	Heat only 20kWth (to heat digester only)	160kWe & 200kWth Approx. 30kWe used on site to power engineering business, office and large farmhouse. Approx. 60kWth is used to heat the digester and rest used to heat house and office. Surplus electrcity goes to national grid.	Heat only	Heat only (70kWth of which 40kWth required to heat tank)
Technology	190m^3 glass coated steel tank.	Fibreglass roof on tank- allows more headspace to reduce foaming risk and can be insulated. Sweeping arm in digester for grit removal (good for chicken manure which has high grit loading). Gas mixing (2kWe) which allows for heat exchangers to be placed further into tank to improve heat exchange. Digestate separator. 2 hours per day required for feeding and maintaining		147m^3 digester operated at 27°C with gas at 64% methane. Circular glass coated panel steel tank of 1600m^3 gross capacity with double membrane roof mounted gas holder. Internal heat exchanger (continuous heat requirement of 40 kWth needed) fitted near the tank floor. Gas mixing. Air injected to control hydrogen sulphide.
Financial information		c £750k capital cost c. £3k maintenance per annum Funded by 3 directors plus £45k innovation grant from the Welsh Assembly Government	Sustainable Production Grant from the Welsh Government	Originally projected at £270,000 captial cost but extra costs incurred relating to planning, permitting and extra mechanical and electrical works increased the cost.
Benefits and issues	Current owners took on the farm in 2015 and the AD facility was not in use and remains unused. The current owners no little about the facility but understood that the previous tenant had not used the facility either.	No artificial fertilisers used. Low odour when digestate spread.		Lower gas yield than expected due to rainwater diluting the slurry in the slurry pit. Marches Biogas (WRAP case study) note 'The slurry alone does not produce enough biogas all year around, therefore it is not feasible to produce electricity at this scale unless other high energy feedstocks are used'. Marches Biogas also note if the facility gets RHI it will be <£5k per year, giving a payback of over 50 years and the case study says 'despite the consistent interest in the Agri Digestore, due to the degression of FiTs and RHI for AD, it is now very unlikely that projects of this nature are going ahead to build unless small scale AD is supported by another means.

KEY
Operational & slurry/FYM only
No longer operating
Other feedstocks confirmed/suspected

	Edgeworthy Farm	Broadmeadows Farm	Y Energy Partnership AD (Manor Farm Dairy)	Skirwith Abbey Farm
Location	Tiverton, Devon	Penrith, Cumbria	Shepton Mallet, Somerset	Skirwith, Cumbria
Farm details		Dairy (450 head) 485ha (1,200 acres)	Dairy	
Year of AD construction/commissioning	2015 (no longer operating)	2015	2014	2015
Feedstock	Animal slurries/poultry manure & cattle manure (a planning submission was made to widen feedstocks, which referenced crop feedstock, but it is not known whether this occurred) 12,764tpa	Cow slurry and waste cattle feed 5,000tpa	Cattle slurry 5,000tpa	Cattle slurry (planning application also says silage- but not sure if this is processed) 3,000tpa
Energy use/capacity	200kWe	124kWe	124kWe	100kWe (farm use and grid connection)
Technology				
Financial information				
Benefits and issues				

KEY
Operational & slurry/FYM only
No longer operating
Other feedstocks confirmed/suspected

	Justicetown Farm	Crooklands AD	Castlesteads Farm	Aston Lower Hall Farm
Location	Carlisle, Cumbria	Wigton, Cumbria	Plumpton, Cumbria	Mondrum, Cheshire
Farm details	Dairy (300+ herd housed all year)	Dairy	Mixed	Dairy, sheep & arable 223ha (353 acres)
Year of AD construction/commissioning	2014	2015	2015	2015
Feedstock	Cow slurry and small amount of silage, maize or rolled barley 3,657tpa	Cattle slurry 2,000tpa	Cattle slurry 3,000tpa	Cow slurry farmyard manure and cattle feed (one published case study also said energy crops and brewing residues) 17,000tpa
Energy use/capacity	100kWe (farm use and grid connection)	124kWe	200kWe	500kWe / 790kWth
Technology				4,400m^3 semi plug flow
Financial information		FiT accredited 24/9/2015		
Benefits and issues				

KEY
Operational & slurry/FYM only
No longer operating
Other feedstocks confirmed/suspected

	Asgard Cardigan	Washfold Farm	Hill Farm	White House Farm
Location	Crugmore Farm, Cardigan, Dyfed	Leyburn, North Yorkshire	Lydney, Gloucestershire	Skegness, Lincolnshire
Farm details		Dairy (900 cows housed all year round)		
Year of AD construction/commissioning	2016	2014	2014/2015	2015
Feedstock	Animal slurry (a case study reviewed indicates that wider wastes including commercial food waste are also processed) 24,000tpa	Animal manure and vegetable matter (funders website says cattle slurry and grass silage) 16,000tpa	maize/grass silage, chicken litter and cattle slurry 5,000tpa	Cattle manure (some planning documents reviewed included silage clamps so may well take crop feedstocks) 6,500tpa
Energy use/capacity	499kWe (grid connection)	400kWe (on farm use & grid connection)	250kWe & 600kWth. Heat used in poultry houses.	200kWe (grid connection)
Technology		Main Digester Tank, Two Combined Heat and Power Containers, Flare Stack, Pump Room, Sub Station, Feed Hopper and Digestate Separator Together with Ancillary Hard Standing	Two digester, biogas CHP plant & two biogas boilers (2 x 300kWth)	One digester, 2 silage clamps, gas holder, process building and dryer
Financial information	£5.8m capital cost FiT accredited Funded by Downing LLP	FiT accredited Funded by Iona Capital	RHI accredited in 2015	FiT & RHI accredited
Benefits and issues				

KEY
Operational & slurry/FYM only
No longer operating
Other feedstocks confirmed/suspected

	Beaconfield Farm	Walford & North Shropshire College Farm	Agri-Food and Biosciences Institute (AFBI)	Croft Farm
Location	Hull, North Yorkshire	Shropshire	Hillsborough, County Down, Northern Ireland	Hampshire
Farm details		Mixed		Stud - 40 horses
Year of AD construction/commissioning	2015	1994 (no longer operational)	2008	2013
Feedstock	Pig slurry/ farmyard manure and grass silage 8,000tpa	Cattle slurry throughput winter period 6,000tpa	Dairy cow slurry, with capability of handling energy crops 5,000tpa	Horse manure and bedding straw 185tpa
Energy use/capacity	165kWe	100kWe	20kWe	10kWe
Technology		Chopper pump Gas mixed digester (330m^3 or 15 days slurry production when all cows housed) mesophilic (38°C) Digestate separator		Packaged AD
Financial information		c. £3k maintenane per annum c. £3k staff time per annum Electricity produced: £10,000 - £8,000 per annum Double ROCs £5,000 - £4,000 per annum Improved nutrient availability: £3,000 per year Compost sales £1,000 per year		Scheme funded by the developer as a trial. Site incurred costs for enabling works, services etc. owner noted they could not finance such a scheme without some form of external support. Payback would be too great to consider from regular borrowing.
Benefits and issues	Steep learing curve			Scheme was funded by the technology developer as part of a trial on horse manure. The packaged system kept the site reasonably clean. Site stopped using system about 2 years ago. The facility experienced handling issues with two types of bedding trialled and was only able to handle 1/10 of the site's production of manure. Outputs were significantly less than expected (e.g. only one tanker of digestate produced in two years). Digestate produced did not improve grass growth as intended (based on trials of strip spraying of grass)

Appendix 5 – Summary of published case studies

Issued as a separate electronic MS Excel file

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