Enablers For On-Farm Anaerobic Digestion, Methane Capture and Use

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Introduction

Methane is a significant greenhouse gas contributing to global atmospheric warming. It has become an increasing focus of international efforts to address climate change and in 2021 at the Glasgow COP Conference, a group of high-emitting countries, including the UK, signed the Global Methane Pledge to reduce methane emissions by at least 30% by 2030. In the UK, methane comprises around 14% of total greenhouse gas emissions. The main sources are the oil and gas industry, landfill sites and agriculture. Emissions in the UK from the first two sources have fallen significantly since 1990. However, methane emissions from agriculture are calculated to have remained relatively stable over the past decade. In 2019, the UK Government set a statutory target of reducing greenhouse gas emissions to achieve net zero by 2050 and this commitment has focused attention on how emissions from agriculture might be reduced. Most methane emissions from agriculture come from ruminant animals, especially cattle and sheep. These emissions are categorised as enteric emissions – directly from the animals themselves – and emissions from manure management.

Methane emissions per animal are highest for dairy cows. The UK's National Inventory, which is produced annually and reported to the United Nations under the Framework Convention on Climate Change, contains calculations of the contributions of different parts of the UK agricultural sector. For dairy cows, it estimates that 75% of methane emissions come from enteric fermentation and 25% come from manure management. However, recent research has questioned the assumptions in the calculations of emissions from manure management and measurements of methane emissions from the slurry stored on dairy farms suggests emissions could be four to five times greater than officially reported.[1]

Technology exists to capture methane emissions from slurry storage and process the gas to a useable form. Such technology has the potential to dramatically reduce methane emissions from dairy farming. The methane can be used to power farm machinery such as tractors and to heat and power farm buildings. It has been estimated[1] that the benefits to an average size British dairy farm could be tens of thousands of pounds and the benefit to the whole dairy sector of captured methane could be of the order of £400m to £500m. What then, are the technological and skills needs, and policy measures, required to help capitalise on this technology, save money for farmers and reduce emissions?

This report addresses these questions. It is the outcome of work led by the Net Zero Methane Hub, coordinated by International Fugitive Emissions Abatement Association (IFEAA) and supported by Cornwall Council SPF funding. This report was also supported by the Biotechnology and Biological Sciences Research Council's Environmental Biotechnology Network and UKRI's AFN (Agri-Food4NetZero) Network+.

The Net Zero Methane Hub held a workshop in Cornwall in May 2024 to share knowledge and expertise to help understand the technology development needs for small scale biogas and biomethane production, alongside policy enablers and skills requirements. The event was attended by representatives from Bennamann, IFEAA, British Compressed

Gas Association, Environmental Biotechnology Network, Agrifood 4 Net Zero Network and Duchy College. Subsequent interviews were carried out with QUBE Renewables and Biofactory.

The workshop examined five key questions:

- What does a biomethane supply chain look like?
- What are the key processes in the supply chain?
- What are the technology development needs within the supply chain?
- What are the policy enablers for this supply chain?
- What skills are needed to grow the sector?

The workshop focussed on small biomethane plant, where gas is used locally rather that transported via the gas grid with an output of less than 100kWe electrical, or approximately 830 m^3/day biomethane, processing slurry from up to 1000 dairy cows. The group considered a range of methods to generate biomethane, including passive digestion (e.g. covering slurry lagoons) and active anaerobic digestion (AD) (e.g. through conventional AD). This report details key workshop outputs.

The Biomethane Supply Chain

The biomethane supply chain includes feedstock preparation, digestion, transport and use, as shown in Figure 1.

Note that the term 'biogas' refers to the mixture of methane and CO2 that is produced by anaerobic digestion. The term 'biomethane' refers to the gas that is produced when CO2 and impurities are removed from biogas.

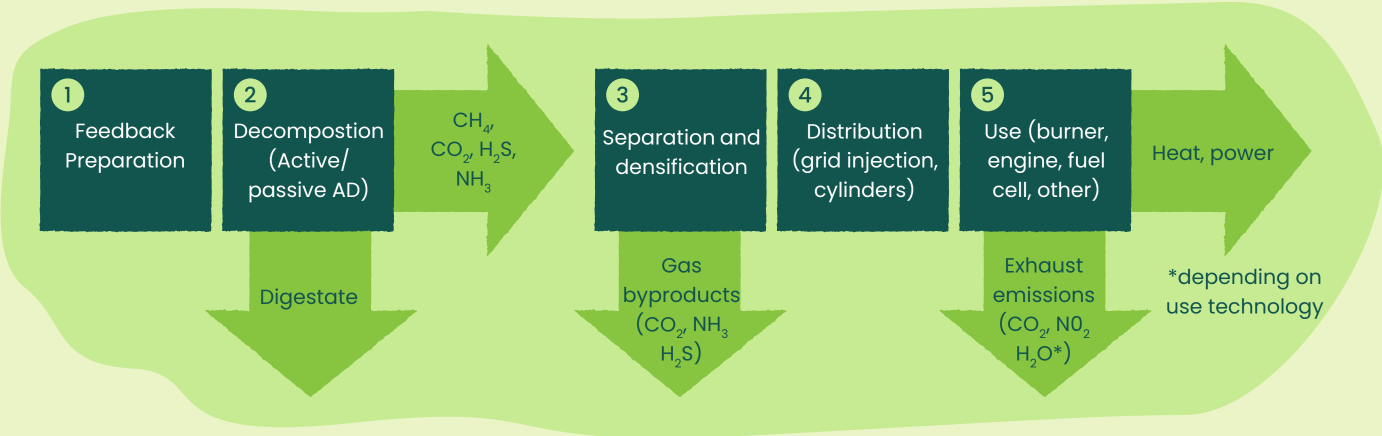

Figure 1 – Components of the biomethane supply chain

The processes involved in the supply chain are outlined below

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1. **Feedstock Preparation** – A wide range of organic materials can be used as a feedstock for biogas/biomethane production, including cattle slurry, food and feed waste, crops or crop residues and abattoir waste. Feedstock may need pretreatment (e.g. maceration) depending on its type and the digester engineering configuration.
2. **Decomposition** – Digestion of the feedstock can be active (in a conventional AD plant) or passive (such as gas captured from a slurry lagoon).
3. **Separation and Densification** – Biogas is processed to remove impurities such as hydrogen sulphide. This 'clean' biogas can be used in some combined heat and power plants (CHP) and boilers. CO_2 can then be removed to produce biomethane that meets vehicle fuel standards or, with further processing, standards for gas grid injection. Note that further processing for grid injection requires additional equipment and energy so, for example, in the UK to meet requirements for the calorific value of gas, propane is added to biomethane but this process is currently only commercially feasible at large scale. Densification is needed for many applications, increasing energy density by compressing or liquefying biomethane gas.
4. **Distribution** – Biomethane can be used on site or transported to the user in cylinders or tankers (known as a virtual pipeline) or via the gas grid. In a hybrid model, methane can also be transported to gas grid injection points.
5. **Use** – Biomethane can replace fossil fuels to produce heat and/or power from a gas boiler, generator, CHP, gas turbine or solid oxide fuel cell.

The supply chain can be organised over different physical locations and businesses. For larger-scale AD systems, while feedstock may be aggregated and stored off-site before being transported to the AD plant, biomethane is generally produced, processed and injected into the gas grid on the same site. Smaller-scale plant has adopted a range of different configurations, typically to reduce capital outlay for the farmer. The simplest configuration is to produce and use biogas on farm, e.g. capturing biogas from a slurry lagoon or using a small AD plant to process waste, and then using clean biogas in a generator or CHP system to produce electricity, and potentially heat, for the farm. Other configurations in use include the Hub & PoD (Point of Digestion) model, for food waste collection, where a centralised or mobile (e.g. vehicle with heat recovery) pasteurisation treatment for feedstock is used and the processed feedstock is then distributed to remote AD plant.[2]

Biomethane supply chains need not involve single farms operating independently but could also involve groups of farms working together. Multiple farms could supply a single gas processing unit. After centralised processing, gas can be returned to the participating farms for use. Where farms are located relatively close to each other, gas can be piped between them, thereby reducing transport costs. The Bennamann business model developed in Cornwall is a variant of this approach. There, the processing plant is mobile (mounted on a vehicle) and visits gas-producing farms periodically. Gas is processed and then compressed into cylinders for use on or off farm.

Technology Development Needs

This section describes technology development needs for widespread adoption of small scale distributed biomethane production and use, highlighted by the workshop and subsequent supplier interviews. The technology development needs are reviewed for each part of the supply chain, and then overall system needs are considered.

1. **Feedstock preparation**
   Understanding the energy and emissions benefits of preprocessing feedstocks can help to optimise production methods, e.g. energy/carbon required for a specific pretreatment vs the additional biogas energy that is produced. Bioresource mapping is also needed to match demand for feedstocks with production locations.

2. **Decomposition**
   Challenges of decomposition depend on the technology:

   Anaerobic digestion is a mature technology, but challenges remain in improving digestion efficiency and increasing the range of feedstocks (e.g. to include woody feedstocks) to increase total feedstock available and gas yield. Challenges also remain for process emissions which require action to maximise environmental benefits:

   - Emissions from digestate storage can be significant and can be reduced, for example through the use of technology used for passive digestion (such as slurry lagoon covers).
   - Fugitive emissions from process equipment (e.g. venting or leakage) can be reduced through thorough monitoring and maintenance.

   Passive digestion (e.g. biogas capture from slurry lagoons) is commercialised at small volumes in the UK.

   - Development is needed to grow the flexibility of covering systems to deal with different source configurations (e.g. different slurry lagoon shapes).

   Sale of digestate for offsite use could improve the business case for on farm gas production by providing an additional income stream, though the costs of achieving ‘end of waste’, allowing digestate to be sold offsite, at these smaller scales is currently prohibitive.

   There are further considerations for digestate valorisation:

   - Transportation of digestate, which may contain as much as 90% water, is challenging due to volume/mass, which can limit AD implementation if it cannot be used on land near the digester.
   - Methods to reduce volume and mass of digestate can support more geographically distributed use (e.g. dewatering, drying using heat from on farm CHP).

- Cost-effectively removing nutrients or other products from digestate remains a key challenge to recycling nutrients and adding value to digestate. This is currently taking place for large digesters (e.g. at a large AD plant, current technology can recover CO_2 and ammonia and combine with digestate fibre to produce an organic fertiliser) but remains a challenge for smaller sites.
- Spatial mapping of nutrient production and use could support better distribution of digestate.

3. **Separation and Densification**

   To increase the energy density of biogas, CO_2 is removed to produce biomethane. This CO_2 can be captured rather than vented and then used (CCU) or stored (CCS) to increase overall process CO_2 benefit. Separation technology is mature for large industrial scale plant, but equipment at a suitable scale, efficiency and cost for smaller on-farm use is key to commercial viability.

   After separation, there are a range of potential uses for captured CO_2, including in the food and beverage sector, in greenhouses, for concrete manufacture, and in fire extinguishers. Purity requirements vary with use. Notably CO_2 for food use is subject to particularly strict regulations: it must conform to E290 standard, which includes the requirement that the CO_2 must be from a known feedstock and liquefied. Development of the business case and supply chain is needed to maximise CO_2 use. For small volume gas producers, capture and use/storage of CO_2 may remain uneconomic, so mandating CO_2 recovery for these producers without commensurate financial recompense may threaten commercial viability.

   Liquefaction and storage of methane is mature at large scale for oil and gas but needs development to improve cost effectiveness at small scale. This technology is historically produced by large industrial players (Air Liquide, Linde) who may not have an interest in transferring technology to small scale due to the relative size of their current market.

4. **Distribution**

   High gas storage pressure means that the mass of biomethane cylinders can increase cost and emissions of transporting the gas. Additionally, the cost of vehicle refuelling technology can act as a barrier to the use of biomethane for smaller operators.

5. **Use**

   Combustion engines, gas turbines or fuel cells can be used to generate power from biomethane or biogas. Methane engine technology is mature; the challenge for distributed generation is the supply of generators/CHP with suitable specification (single or 3 phase), power output, lifespan and price. Solid Oxide Fuel Cells (SOFC) can have higher efficiency than methane engines, although unlike hydrogen fuel cells they emit CO_2. Demonstration of SOFC at suitable power output in a relevant environment is needed. Methane could also be used for cooling, using, for example, conventional refrigeration technology. Integration of on-farm use, for heat, cooling and electricity generation, alongside electricity and/or heat storage, could improve overall farm energy efficiency.

Early-stage research is investigating alternative uses of methane (e.g. to make proteins for food or graphene), avoiding combustion. These technologies are expected to be industrial in scale so, when mature, gas transport to a central processing location is likely to be needed.

System level enablers

The vital importance of data in distributed biomethane systems was highlighted for different purposes:

Commercial – Credible data is key to supporting the commercial case for on farm gas production. To produce a business case for farmers, investors or financiers, data on expected costs and returns is needed. To generate this information, reliable evidence of methane output and also the wider implications of the system are needed, for example effects on water and fertiliser use and farm operations. Currently data on the effect of digestion on the properties of slurry as a soil improver over a long period is sparse.

Operational - A distributed network of methane producers and users is a disruption of the current supply chain, centred around gas grid distribution. Development of data systems and AI is key to reliable operation, for example using of Internet of Things (IoT) technology to monitor gas volumes at different locations combined with gas mapping tools for users will encourage local production and use.

On farm, energy systems integration is needed to make the most efficient use of methane which is produced; for example, coordinating on farm energy storage as gas, electricity or heat and optimising export to the electricity grid.

On a regional level, system level analysis of the efficiency of different supply chain configurations is needed to maximise environmental and financial benefits. Considering a supply chain of local producers and users (Figure 2), analysis of system well-to-wheel (WTW) and lifecycle greenhouse gas (GHG) emissions or operating and capital costs (OPEX and CAPEX, respectively) could enable optimisation of this supply chain. For example, supporting decisions on the numbers and locations of refuelling stations or gas processing units.

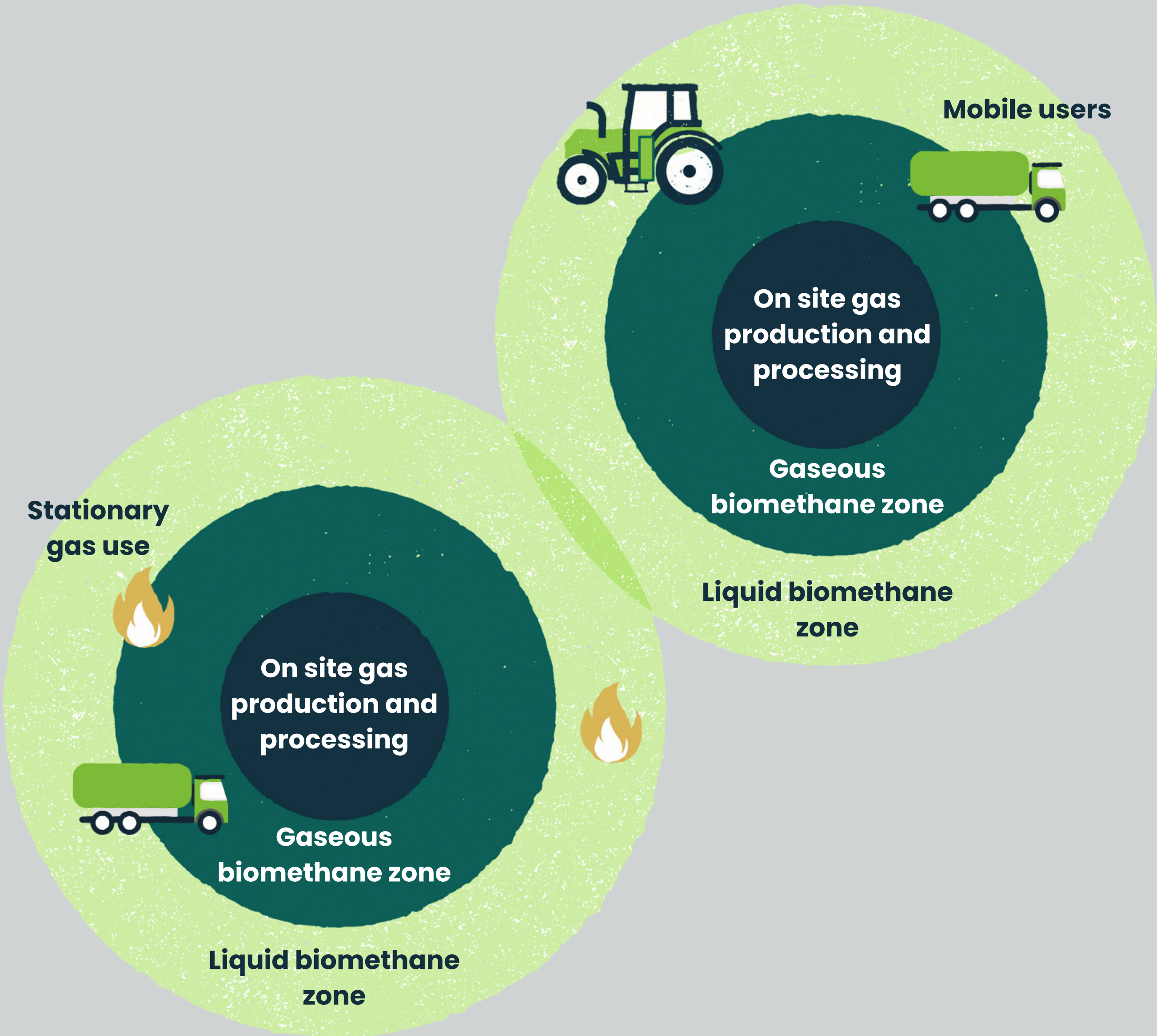

Figure 2 – Representation of biomethane supply chain. A distributed supply network consists of a number of producers, with mobile users such as trucks and stationary users such as dairy processors. Biomethane can be transported as a gas or a liquid, with liquid biomethane leading to a larger vehicle range due to higher energy density.

Enablers for Adoption and Scale Up

Policy

The policy environment is known to affect the scale of investment in biomethane production, particularly the financial support for plant.

Measures to encourage uptake in the UK could include:

- Grants or favourable loans for plant installation, e.g. increased subsidy for lagoon covers or inclusion of gas processing equipment and AD in the slurry infrastructure grant.
- Subsidies for gas produced, e.g. for gas the Green Gas Support Scheme (GGSS), for heat, the Renewable Heat Incentive (RHI) and electricity, the Feed in Tariff (FiT)
- A robust carbon market, noting the need to clarify ownership of carbon credits within the supply chain (farmer, processor, retailer).
- Tax breaks for supply chain investment in biomethane production.
- Floor prices for green energy produced; currently the Renewable Transport Fuel Certificate (RTFC) prices are low, reducing investor confidence.
- Taxation on livestock emissions and/or support for avoiding fugitive emissions.
- Measures which recognise the wider benefits of biomethane production: preventing methane, ammonia and hydrogen sulphide emissions, treating waste and producing useful byproducts such as fertiliser and CO_2.

Planning and permitting remain significant obstacles for biogas/biomethane production plant; activities to streamline these processes would support uptake, e.g. planning templates for biomethane plant, regulation and permitting requirements relevant to size of plant, fast track planning for carbon reduction schemes.

Some policy areas are of particular concern for small scale biomethane production and use:

- Currently UK subsidies (namely the GGSS) only apply to gas which is injected into the gas grid, so does not provide support for small producers where gas is used on farm or locally.
- Costs and effort of planning and permitting can be disproportionately large for small producers, so a streamlined, lower cost process could be a particular enabler in this sector.
- Regulations on the sale of digestate require that the digestate meets end of waste standards PAS110. Processing is required before off-site use is permitted, e.g. maceration and pasteurisation, which can be feasible for on farm systems. However, the administrative and cost burden of meeting PAS110 is challenging for small scale producers. The inclusion of a low-risk position for some wastes and uses, or the potential to aggregate accreditation between small producers could make the digestate market accessible for these businesses.

Where farms are operated under tenancy agreements, a number of issues may arise:

- The length of the tenancy may not provide sufficient time for payback on the investment made.
- Clarification on liability for any issues on the site would be needed – for example, if a water pollution event was related to the anaerobic digestion equipment, would the liability lie with the landowner or the tenant.
- Ownership of any carbon credits would also require confirmation.

Policy measures - International examples

A range of measures have been implemented internationally to encourage uptake of anaerobic digestion to produce biogas and biomethane which could provide a model for UK policy. Examples of these measures include:

China: Subsidies for domestic scale AD have been granted historically to provide fuel for cooking and lighting in rural areas, and to dispose of waste, resulting in very large numbers of domestic digesters

France: Tariffs for biogas were increased in 2023 and are dependent on the energy efficiency of the plant. If the energy consumption of the plant is greater than 15% of production, the tariff is reduced; if the plant consumes 25% of production energy, the tariff is halved. Feed in tariffs are provided for 15 years. Plants can also claim 40% of costs of connecting biogas plant to the gas grid. In France, commercial organisations are also supporting AD: for example, Sodiaal have made a commitment to roll out on farm AD for 100 farms within 4-5 years, with financial support from Nestle.

Italy: Biomethane plants receive a grant for 40% of construction cost and a feed in tariff for gas produced for 15 years of 62-115 Euros/MWh.

Germany: Historically, Germany has provided subsidies for biogas production but has recently announced an intention to move away from subsidising production to supporting capital investment, aiming to reduce dependence on government support.

USA: The Inflation Reduction Act (2022) provides a range of support for biogas production, including tax credits on investment in biogas plant. RINs (similar to RTFCs in the UK) can also be earned for biomethane fuel, which can be traded.

Denmark: A plan has been announced to tax livestock farmers from 2030 at 40 Euros per TCO_{2e} in 2030, rising to 100 Euros by 2035 (still to be approved by parliament). New Zealand passed similar legislation in 2022 but it was scrapped following pressure from the agricultural sector.

Skills

A wide range of disciplines are needed for both equipment design, installation and maintenance. Skills that were highlighted at the workshop are shown in Table 1 below.

Engineering	**Agriculture**
Electrical power systems	Regenerative farming
Gas handling	**Manufacture**
Cryogenic engineering	Metal and composite fabrication
Bioenergy engineering	**Installation**
Civil engineering (e.g. lagoon design)	Health and safety (incl. HAZOP, DSEAR assessment)
Systems engineering	Permitting
	Quality assurance

Table 1 – Biomethane supply chain skills requirements

The wide range of skills required means that cross domain working is needed for efficient technology design and implementation, which requires good general knowledge and cross discipline working skills. Additionally, graduate engineers with both practical and theoretical skills are needed, alongside experience within an agricultural environment, both of which are not common for current graduates. The value of an apprenticeship to provide relevant training at both further and higher education levels was highlighted. However, currently the scale of the industry mean that it is not expected to be cost effective to have dedicated courses for biogas, so the ability to develop a biogas/AD qualification combining modules from other disciplines could meet the training requirements in the sector in the short/medium term.

For large scale roll out, skills and infrastructure for fabrication of equipment at scale are also a key challenge. The production and use of methane on farm introduces new Health and Safety requirements into agriculture and user businesses. It is therefore important to ensure that training at a relevant level is available for these stakeholders.

Conclusions

Key enablers for development of a distributed biomethane supply chain have been identified as:

Technology development

- Data is vital for a distributed supply chain, including data to support investment (methane emissions potential of slurry, effect of digestate on soil) and operation (IoT data on gas availability and gas and feedstock resource mapping for users).
- Gas processing technology at small scale requires development to improve efficiency and cost effectiveness (gas separation and liquefaction).
- Development of digestion technology is needed to improve efficiency and commercial viability and reduce emissions: Anaerobic digestion – improve digestion efficiency and feedstock range, reduce emissions from digestate; Passive digestion – improve range of covers to match variety of slurry store configurations. For both types of technology, emissions monitoring and reduction of emissions from leaks is key to maximising environmental benefit
- Supporting valorisation of byproducts (notably CO_2 and digestate) could improve commercial returns and therefore increase adoption.
- System analysis is needed to understand overall environmental impact (through LCA) and improve farm energy efficiency (through energy systems integration).

Policy

- Supportive long-term policy is vital, encouraging methane production and use at all scales, financially and through an appropriate planning and permitting framework.

Skills

- Alongside manufacturing capability, theoretical and practical skills and certification are needed; electrical engineering skills were seen as particularly scarce.

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