Feasibility report for the Bennamann-Atlantic fugitive methane green distillery solution

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Glossary

AD – Anaerobic Digestion/Digester

B/D – Brewery/Distillery

BBL – Brewer's Barrels

BEN – Bennamann Energy Network

BL – Beer Leachate

CFM – Compressed Fugitive Methane

CHP – Combined Heat and Power

COD – Chemical Oxygen Demand

GL – Gin Leachate

GWPxxx – Global Warming Potential, subscript denotes the time horizon being used

HL - Hectolitre

LFM – Liquid Fugitive Methane

LPG – Liquid Petroleum Gas

MBW – Macerated Beer Waste

NGG – Natural Gas from the national Grid

SBP – Specific Biogas Potential

SLAD – Slurry Lagoon Anaerobic Digester

SME – Small / Medium enterprise

WTT – Well To Tank

Traditional Generator – Generator with no CHP system

LC – Liquid Cooled

Executive summary

The need to decarbonise every carbon-emitting sector of the economy has been widely recognised for over twenty years. While significant progress has been made by replacing fossil fuels with renewables, several sectors of the economy still struggle to find affordable, reliable renewable energy solutions.

Bennamann is a renewable energy company based in Cornwall, that aims to address these hard to decarbonise segments by creating local energy networks that produce and consume one of the most flexible forms of renewable energy on the planet, fugitive methane. All organic matter emits methane as it decays, and if it is not captured and is emitted to atmosphere it is known as fugitive methane. Bennamann's goal is to capture fugitive methane that is produced by our target markets during their business-as-usual operations, and generate additional value for those organisations by capturing, processing, storing and distributing their fugitive methane. Bennamann's ambition is to create 'green power stations' on farms, grasslands and communities all over the world. Our green power stations will act as nodes in local renewable energy networks that match supply and demand of locally produced, better than net zero energy. Major targets include farm animal / livestock slurry, human sewage & waste, crop and food / drink manufacturing waste.

The purpose of this study was to examine the technical, economic and environmental benefits and barriers of adding distilleries to Bennamann's Energy Network (BEN). Bennamann has identified agriculture and transport as early adopter segments, as the economic and environmental gains are significant. Exploration of drink manufacturing waste in the supply-side of the network, as well as profitability of the distillery market on the demand-side of the network were explored to understand both the technical feasibility and economic attractiveness of the market.

Work has been completed alongside Atlantic Distillery and Brewery, a company at a key point of growth seeking to decarbonise its operations. The company served as a test case on which to base the modelling both in its existing form (considering a nano-distillery and micro-brewery) and its future larger form (considering a small distillery and small brewery).

The study has shown that a simple fuel switch presents the least barriers to decarbonising the distilling industry. For each kilogramme of fugitive methane combusted the equivalent carbon from 108kWh of grid electricity can be offset.

Improvement of distillery and brewery efficiency via the incorporation of combined heat and power and Stirling engine heat recovery has been investigated but in both cases its implementation was found to be not cost effective.

Whilst the profit margins achievable with gas consumer customers is low, co-digesting distillery waste in slurry lagoon anaerobic digesters allows distilleries to become gas producers and improves margins. Co-digestion has been shown to be possible and has demonstrated improved gas yields over limited time horizons though further work is needed to enhance these results.

Overview of the project

This feasibility study is delivered by two partners: Bennamann ltd and Atlantic Brewery and Distillery. The aim is to investigate whether it is possible to switch Atlantic's fuel source from LPG, electricity, and natural gas to fugitive methane delivered via the Bennamann Energy Network (BEN). In doing so, the study should indicate the potential for fuel switching for the wider distillery industry.

Atlantic Brewery is an organic micro-brewery established in 2005. It has had on-farm processing accreditation from the Soil Association since its inception. It started creating organic gins at the same location outside Newquay in Cornwall as Atlantic Distillery in 2017. They are committed to ethical and environmental production of high-quality beers and spirits.

With both the brewery and distillery growing beyond their existing capacity, a move is underway to new premises operating under Atlantic Distillery Ltd. The move will allow for an expansion of processing capacity, taking the brewery from micro to small scale (4-10 BBLs (6-10HL)) and the distillery from nano to micro and on to small scale (50-230-730 litres).

Inherent in the expansion is the transition from an electrically heated brewhouse to a gas-fired steam-heated brewhouse. The existing stills will remain as direct gas heated stills. The addition of a gas-fired steam-heated combination still will allow for increased gin production but also the creation of spirit from the brewhouse beer. Atlantic's commitment to sourcing a green solution to the new energy requirements has led to the collaboration with Bennamann and the potential for switching to fugitive methane as the gas used to power the processes.

With Atlantic at this key stage of growth and transitioning, there is an ideal opportunity to investigate the feasibility of switching to fugitive methane from both the brewhouse process of an existing electrical system and a proposed grid-gas system, and the stillhouse process of an existing propane gas system and a proposed grid-gas system.

As both brewhouse and stillhouse processes are inherent in the production of spirits, the study has investigated the benefits of fuel switching to both sets of processes.

Bennamann is a technology company working to exploit biomethane from fugitive sources. It does this by implementing innovative technology, such as covered slurry lagoons and mobile gas processing systems, to produce compressed and liquid methane at small scale, often in rural locations, that can be driven off-site to a local consumer. In this way, the technology does not require a grid connection and enables small scale AD to be cost effective. This concept is enabled by the Bennamann Energy Network (BEN), a network of 'nodes' comprising gas producers and gas consumers linked via distribution networks and controlled using an internet of things that allows Bennamann to remotely control and operate the system. To date, Bennamann has focused on slurry lagoon anaerobic digester (SLAD) gas supply nodes and transport sector gas consumer nodes. The partnership with

Atlantic offers an opportunity to investigate how brewery and distillery customers may become gas producers and consumers in the network.

To investigate the feasibility of this concept, the study has been structured around the following primary and secondary aims. Each aim will be investigated for Atlantic brewery/distillery (B/D) at its current and future (larger) size. In this way the findings will be transferable to other B/Ds in the UK.

1. Understand how switching to fugitive methane can benefit B/Ds by reducing carbon emissions.
2. Investigate whether Atlantic B/D can be integrated into the BEN at its current and future size.
    a. Show whether Atlantic can become a consumer of fugitive methane on the BEN.
    b. Show whether Atlantic can become a producer of CH_4 on the BEN via co-digestion of its waste in a SLAD.
3. Investigate whether it is cost effective for Bennamann and Atlantic to include the B/D as a node on the network.
    a. Investigate means of improving the energy efficiency of the B/D process to reduce costs and carbon emissions.

The aims were achieved via the following activities:

1. Modelling of current and future energy consumption to determine the benefit of switching to fugitive methane.
2. An assessment of the technology required to achieve fuel switching including energy saving strategies such as employing a CHP (combined heat and power system), methane generator for supplying electricity at peak demand, and flue heat recovery via a Stirling engine.
3. Experiments to determine the potential for gas production from B/D waste via co-digestion with animal slurry in a SLAD.

Experimental/modelling results and conclusions

The role of fugitive methane in carbon reduction and energy switching

Methane is a powerful greenhouse gas, thought to be responsible for 20% of radiative forcing from greenhouse gases. One metric for comparing the warming power of a gas is the Greenhouse Warming Potential (GWP). This is defined as the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of CO_2. As some gases live longer than others there is more than one GWP figure per greenhouse gas, considering the gases impact over different periods of time, known as time horizons. For a solution to be truly effective in tackling the climate emergency both the short- and long-term implications for the climate must be reduced, ideally to zero or below.

Though methane's lifetime is considerably shorter than that of CO_2, 12.4 years versus 500 years, its effects are far more powerful than CO_2's over its lifetime as evidenced by its higher Greenhouse Warming Potential (GWP). See Table 1.

Table 1 - GWPs of 1kg CH4[1].

Gas	GWP_{20}	GWP_{100}	GWP_{500}	Molecule Life time
CH_4	84	28	7.6	12.4
CO_2	1	1	1	500

Traditional bio-methane is produced in Anaerobic Digesters (AD) using various waste streams and energy crops as feed stocks. Fugitive gases are those unintentionally lost from a process, for example as leaks from natural gas processing or from the decomposition of organic waste; Bennamann for example focusses on emissions from SLADs. By capturing gases emitted from these sources and processing them into a high purity fuel the SLAD's fugitive gases cannot reach the atmosphere and the impact they would have can be considered removed. As a result, there is a beneficial net-cooling effect over all time horizons, represented as a negative value of $kgCO_{2e}$.

Table 2 compares the GWP of fugitive methane to NGG and LPG. These negative GWP figures indicate that simply switching from traditional NGG to fugitive methane alone would have vast and positive implications for the climate emergency, accounting for a reduction of up to $28.23kgCO_{2e}$ per kg of fugitive methane (offset of the GWP for NGG added to the GWP of fugitive methane) burnt in place of traditional heating fuels over a 100-year time horizon on a mass for mass basis.

Note: For the purposes of this report, GWP_{100} figures are used when calculating fugitive methane emissions, in line with current international conventions.

Table 2 - Comparison of greenhouse warming potential over the 20, 100, 500-year time horizons for LPG, NGG, and fugitive methane stoichiometric burn presented for fugitive methane cases as well as combustion of fugitive methane with identical emissions as a typical NGG burn.

Fuel	GWP_{20} ($kgCO_{2e}$)	GWP_{100} ($kgCO_{2e}$)	GWP_{500} ($kgCO_{2e}$)
NGG	3.17	2.98	2.76
LPG	3.61	3.49	3.24
Fugitive methane, stoichiometric burn	-81.25	-25.25	-4.85
Fugitive methane, NGG combustion emissions	-78.09	-22.27	-2.09

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[1] GWP_{20} and GWP_{100} from Ch8 of IPCC 2013. GWP_{500} figures from the IPCC 2007 report.

Switching Atlantic’s operation to fugitive methane

Modelling activity has focused on understanding the power requirements of the current and future Atlantic operations alongside integration of the following technology:

- Use of fugitive methane as a direct heating fuel replacement - replacing LPG or NGG.
- Use of a CHP (combined heat and power) system to effectively take the entire operation off grid - supplying electricity and heating via a fugitive methane generator with associated heat recovery.
- Use of a small fugitive methane generator to provide peak electrical power with and without heat recovery. This may result in lower capital outlay than the larger CHP in the previous point.

Table 3 describes the technology associated with nano, micro and small versions of the brewery and distillery.

At present, Atlantic operates a LPG-fired nano-distillery and electrically-powered micro-brewery. Expansion will see this grow to a natural gas-fired micro-distillery and steam-powered small brewery.

Table 3 - Classification of nano, micro and small operations

Label	Still Sizes (L) and Heating Method	Brewery Size and Heating Method (Brewers barrel/Litres)
Nano	30 & 60 – Open Flame	4 / 650 - Electricity
Micro	2x 100 – Open Flame	4 / 650 – Electricity
Small	500 – Steam (Future)	10 / 1600 – Steam (Future)

Table 4 summarises the reduction in emissions by switching to fugitive methane for each of the size scenarios.

Table 4 - Overview of fuel swapped emissions and the counterfactual fossil fuel equivalent.

Operation Label	Counterfactual Emissions ($kgCO_{2e}$)	Fuel Switched Emissions ($kgCO_{2e}$)
Nano	352	-2693
Micro	3929	-35,061
Small	23,068	-205,491

The following paragraphs describe the relative benefits and drawbacks to swapping to fugitive methane as a directly burnt fuel and as a fuel in a generator to produce heat and power.

Replacing LPG and NGG with fugitive methane

Replacing heating fuel with fugitive methane appears to offer the simplest solution to de-carbonising the distilling industry. The industry norm for existing distillery plant (in particular at the mid to large scale) is for gas-fired steam-heated production. This means that direct switching from an existing LPG or NGG fuel supply to a fugitive methane fuel supply would be a non-invasive process and a more attractive solution to industry.

In addition, the carbon reduction gained by using fugitive methane in one process (such as for firing the stills), can offset the carbon used in another process (such as the use of fossil-fuel derived electricity from the grid). This is the case in the micro-scale scenario where the electrical emissions of the operation would be 9693 $kgCO_{2e}$ but the effective emissions of the stills would be -35,057 $kgCO_{2e}$. when fired with fugitive methane. The net emission for the entire operation would then be reduced to -25,364 $kgCO_{2e}$.

Use of generators

Using a fugitive methane fuelled generator to provide either the entire power requirements (off-grid scenario) or just the process peak power requirements is feasible, and due to the effective negative emissions of fugitive methane it initially appears a promising possibility. However, closer investigation of current off the shelf air cooled generators reveals that their inefficiency reduces the potential benefit. This can be overcome by using liquid cooled generators (greater heat exchange) but there is a lack of appropriately sized liquid-cooled generators at this scale. This is an area that is rapidly developing and so should not be ruled out in the future.

For the 20kW genset investigated in the micro and nano cases, 0.23 to 0.29 kg fugitive methane is required per kWh of electricity produced, corresponding to efficiencies of 22% to 28%. By comparison, a steam boiler's efficiency is typically 80-90%. Also, as the electricity grid draws more energy from renewable sources, it will make less sense to use relatively inefficient generators to provide power for processes; the limiting factor here being the poor conversion of chemical to mechanical energy in internal combustion engines. Additionally, the outlay for a generator is prohibitive – typically £1,000 to £10,000 for larger models and do not warrant investment.

Based on the efficiency of the generators relative to using the fuel in a steam boiler, their use is not recommended in a B/D application.

Distribution of gas within the Bennamann Energy Network

To integrate a customer into the BEN, gas will have to be supplied to the end-user. The gas could be delivered using existing infrastructure, where available, or delivered to site by vehicle. The delivery method has implications on the well to tank (WTT) emissions of the fugitive methane but Bennamann plans to use fugitive methane powered vehicles to ensure that end user processes retain negative CO_{2e} emissions.

There are several ways to further reduce the carbon emissions from gas distribution. Firstly, distribution in the future may be achieved via the national gas grid. An enabling factor for this would be low-cost gas injection points local to BEN fugitive methane sources. Alternatively, advances in storage methods could help to increase transport payloads and reduce logistical issues. Large quantities of fugitive methane used in relatively short timescales will be delivered in liquid form. This liquid is energy dense and provides an efficient means of transporting fugitive methane with minimal emissions from the distribution network itself. Smaller quantities are distributed in compressed cylinders, but these bottles are manufactured from thick steel which reduces transport efficiency. By reducing the ratio of payload (fugitive methane) to storage material (cylinder or liquid tank) the quantity moved per delivery can be increased and the logistics footprint can also be reduced.

Supplying larger quantities of fugitive methane to several customers as part of a local energy network would also reduce the number of delivery trips and reduce costs. This would be a good solution to sites on new rural industrial or housing estates, where the utility pipework can be installed at the start of the project and used to feed several operations in place of the national gas grid.

Stirling engine results and conclusions

Introduction

To investigate the potential for energy recovery and re-use, Stirling Works Global were sub-contracted to carry out a feasibility study into the use of Stirling engines to reclaim heat from hot flue gases.

A site survey was carried out to inspect the current (nano B/D) and collect live process data. This and projected data for the proposed equipment (the small B/D) was assessed.

Summary of results

For the distillery stills the heat reclaim was limited by the low temperature difference (the lower boiling point of alcohol resulting in a flue temperature of 84°C), the short length of down pipe available for heat reclaim and the standard diameter of the pipework to draw heat from externally (so as not to degrade the customer’s end product). Consequently, the output power predicted is negligible and not worth investigating further.

For the brewery boilers however there appears to be potential for heat reclaim. The delta T (temperature difference) is still low and to maximise this heat pipes are relied upon to get heat from a matrix in the boiler flue to the Stirling engine hot cylinder head. Likewise heat pipes are relied upon to reject heat from the cold cylinder head to atmosphere. Practically this could be achieved, although this would result in long lengths of heat pipe which could result in a detrimental increase in the delta T along their length to the hot cylinder head especially given the limitations of performance due to orientation (maintaining the evaporator below the condenser).

The study has shown that bespoke heat pipes are very expensive. Cost is based on the input power and even at high power outputs the prototype is £1.7/W. Hence for 4 prototypes the cost of the heat pipes alone would be circa £110k. Without using heat pipes the heat transfer to the Stirling engine would decrease significantly and output power would be further compromised. This is especially true on the cold cylinder head though water cooling could be provided.

In conclusion, the prohibitively high cost of the heat pipes required to make flue-gas heat recovery efficient indicates that it will not be worth pursuing the use of a Stirling engine at Atlantic B/D.

Fugitive methane production and co-digestion

For a B/D to become a gas supplying node in the BEN, its waste must be able to generate gas. For this reason, the feasibility study investigated the benefit of co-digesting B/D waste with slurry to determine whether there is any benefit to doing so, through uplift in methane production. The practical application of this would be the removal of waste from a B/D site for transfer to a local SLAD, potentially as part of the return journey of a gas delivery. The waste may undergo some pre-processing before being added to the lagoon to enhance gas output.

The digestion of B/D waste in a slurry lagoon is dependent on many parameters, including: the waste's chemical oxygen demand (COD), its form (macerated or leached), the digestion temperature (which varies seasonally) and the slurry quantity in the lagoon for the waste to react with (which also varies seasonally). The scope and time available for this study has not been sufficient to fully investigate each of these parameters though each has been considered in plans for further study. For the purposes of this report results have been limited to the success, or otherwise, of digesting brewery and distillery waste alone (mono-digestion), and with slurry (co-digestion), and has taken a limited look at the impact of COD, slurry to waste ratio, and temperature on gas production.

Due to the relatively short time scales and need for AD at ambient temperatures to acclimatise, (a process that can take many months), experiments were conducted in pairs at mesophilic temperatures, 37.5°C (higher than those seen in a traditional SLAD) and ambient, to achieve results within the period of the study whilst at the same time providing a baseline.

The feasibility study aimed to demonstrate digestion at lab- and field-scale but due to time constraints the results of the field-scale experiments could not be concluded.

Biogas production from brewery and distillery waste

This experiment sought to investigate the potential of beer and gin wastes to produce biomethane.

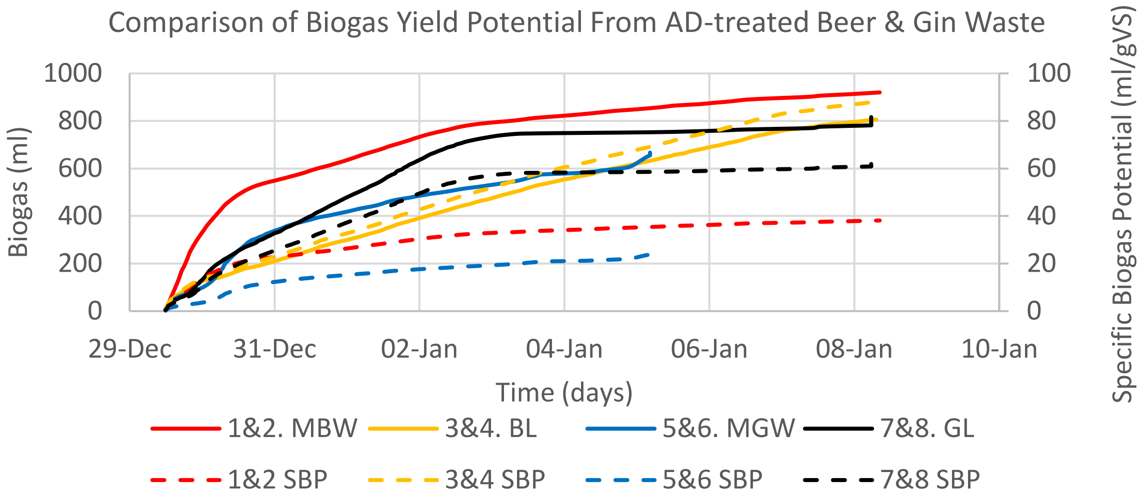

Figure 1 - Comparison of biogas yield potential from AD-treated mono-digested beer and gin waste at 37.5°C

Referring to Figure 1, solid lines refer to the left-hand axis, Biogas, and dotted lines to the right-hand axis, Specific Biogas Potential. The figure shows that beer waste produced similar biogas yields whether presented as macerate (MBW) (solid red) or leachate (BL) (solid amber) although the cumulative yield trends differed. Metabolism of MBW was more immediate than BL which demonstrated a more linear biodegradation and rate of biogas production. By Day 10 both waste streams had converged to ~ 15% of each other's cumulative biogas yield.

Conversely, gin waste streams (blue and black line) started on a similar linear biodegradation pathway before diverging around Day 2. Biogas yield from leachate (GL) (solid black) continued to rise before levelling off on Day 5 whereas the rate of biogas production from macerated gin waste (MGW) (solid blue) reduced around Day 2 and continued on a similar pathway until Day 7. Final cumulative biogas yields were again within 15% of either waste stream.

The ability of anaerobic bacteria to produce biogas from waste in either form was clearly demonstrated although the reasons for the differing rates of production are currently unclear. Obvious potential reasons to explore are:

- Acidity/alkalinity levels achieved throughout the biodegradation process and its effect on the process.
- Effectiveness of leaching in terms of nutrient removal for later anaerobic digestion.

Co-digestion of distillery waste and slurry

Co-digestion under slurry lagoon conditions at both mesophilic and typical lagoon temperatures (Figure 2) demonstrates the importance of temperature to the rate of biogas production. (As before, the solid lines refer to the left-hand axis for Biogas and the dotted lines refer to the right-hand axis for Specific Biogas Potential). Although the nutrient availability for methane production within both systems is the same, biodegradation occurs much faster at warmer temperatures as demonstrated by the change in the gradient of the cumulative biogas yield curves (solid profiles) when heat is added or removed.

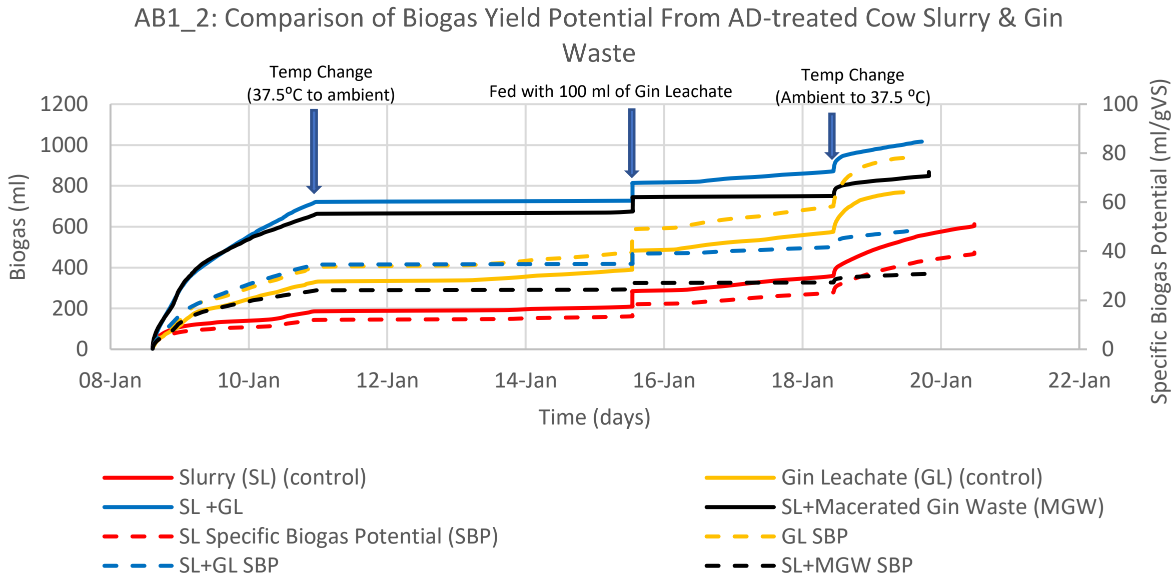

Figure 2 - Comparison of biogas yield potential from AD-treated cow slurry and gin waste when continuously mixed at ambient temperature and at 37.5°C

The benefits of co-digestion are more clearly shown in Figure 3. By comparing the sum of gas produced by slurry and gin leachate mono-digested (blue dashed line) with gas produced by co-digested slurry (SL) and gin leachate (GL) (orange line) and gas produced by co-digested slurry and macerated gin waste (MGW) (grey line), data shows that over the first 7 days of the experiment nearly twice as much gas was produced via co-digestion than mono-digestion. The difference in gas production reduced after this and by the 11th day of the experiment the sum of the mono-digestates exceeded the co-digestates. This indicates that co-digestion can produce biogas more rapidly than mono-digestion at the start of the AD process, highlighting the potential for farmers to use distillery waste to rapidly up-lift gas production of a slurry lagoon. As mentioned previously, the parameters affecting the creation of biogas must be more thoroughly investigated to better understand why mono- and co-digested wastes behave differently over time and what affect this may have on cumulative gas production.

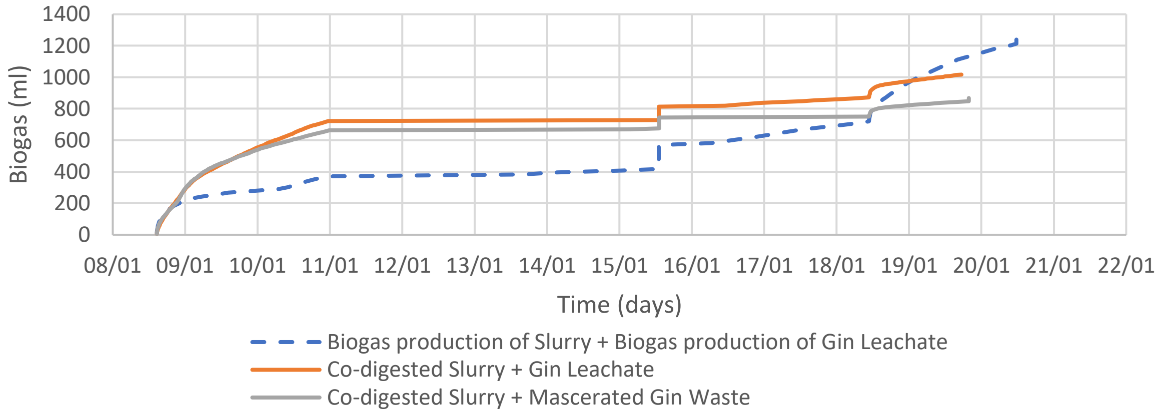

Figure 3 – Benefits of co-digestion: Dashed blue line, sum of gas produced by slurry and gin leachate mono-digested. Orange line, gas produced by slurry (SL) and gin leachate (GL) co-digested. Grey line, gas produced by slurry and macerated gin waste (MGW)

Note: The levelling out of production and process efficiency around 11 Mar was caused by a power failure resulting in the process temperature dropping to 20°C for about 36 hours. The rapid rise in both metrics on 13 Mar coincided with a return to mesophilic conditions. This demonstrates the important of heat when anaerobically digesting waste.

Discussion

The relatively short period of time available for carrying out microbial based experiments aimed at mimicking the activities and potential activities within a slurry lagoon limited the extent of the results that were possible. However, the experiments have been established in such a way as to afford good longer-term investigation while still providing some short-term data.

Results show that methane is extracted from brewery and slurry waste when mono- and co-digested. The increased microbial diversity that results in the co-digestate mix leads to a healthier microbial population and is expected to increase gas production from both the distillery waste (non-fugitive methane) and the cow slurry (fugitive methane). Research to optimise the ratio of the mix and the effecting parameters will lead to best practice for lagoon management and maximising fugitive gas yield.

Typical farming practices see a slurry lagoon emptied in the spring. This summer 'down-time' of the lagoon has two impacting effects: firstly, that gas production is reduced and secondly that the potential for adding distillery waste is reduced. Two solutions are under development by Bennamann. Firstly, ongoing research into optimising the lagoon mix and its effecting parameters including the need to retain a certain amount of capacity in the lagoon over the summer. This would allow for distillery waste to continue to be added, for gas production to continue, and for gas production to utilise the higher temperatures of the summer to increase yields. Secondly, an alternative anaerobic digestion gas production method is being developed alongside the lagoon system which would maintain gas production and the use of the distillery waste all year round. This is based on an up-flow anaerobic sludge blanket (UASB) design as used in the water treatment industry.

Gas production and distribution costs

Currently Bennamann produces compressed fugitive methane for transportation and storage in high pressure cylinders. However, to achieve more efficient distribution, the company plans to deliver liquid fugitive methane in large mobile storage tanks from 2023.

At present the costs of producing LFM are higher than producing CFM but distribution costs are significantly lower resulting in a lower overall cost per unit energy.

Cost comparison to fossil fuels

Grid Source Natural Gas

The average unit price and standing charges for 5 sizes of business were used to draw a comparison of costs between traditional NGG and Bennamann fugitive methane. The effective price includes the standing charge paid by the end user and generates a minimum unit price.

Table 5 - Data of gas prices and standing charges for small to medium enterprises (SMEs)[2].

Business size	Max Energy use	Unit Price		Standing Charge	Minimum effective grid price	
	kWh	Pence/kWh	Pence/kg	Pence/day	Pence/kWh	Pence/kg
Micro	5000	4.3	59.8	20.0	4.3	60.0
Small	15000	4.2	58.4	10.0	4.2	58.5
Medium	35000	4.2	58.3	10.0	4.2	58.3
Large	75000	3.5	49.5	120.0	3.6	49.6
Industrial	500000	3.4	47.3	600.0	3.4	47.3

Comparing Bennamann's production and distribution costs to Table 5, this information shows that Bennamann could provide liquid gas to most sectors, though with a very small profit margin.

When selling gas to the transport sector, the renewable transport fuel certificate (RTFC) can give a far larger margin on fugitive methane, of the order of pounds per kg, vs pence per kg. Therefore, it currently makes more business sense for Bennamann to sell its fuel into this segment. However, if similar incentive schemes became available in the heating sector this would become an attractive market for Bennamann. Furthermore, Bennamann is still quite early in its production optimisation processes so a further reduction in production costs is expected over the next few years, helping to yield a higher profit in this sector.

Bottled fuels

The price of bottled fuels depends on the quantity, frequency of ordering and supplier as shown in Table 6.

Table 6 - Cost of bottled LPG, sources for 5&6 kg from Calor gas website, 19kg price from Atlantic purchase history and 47kg from Calor customer.

Bottle size	Bottle Price (GBP)	Fuel Price per mass (GBP/kg)
5kg	20.50	4.10
6kg	23.45	3.91
19kg	41.40	2.18
47kg	85.00	1.81

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[2] https://www.businessenergy.com/business-gas/sme-prices

These prices offer a far greater opportunity for profit per kilogram of fugitive methane than end users supplied by the grid, though potentially with a lower revenue as customers may consume less gas. Bulk prices were not available, so no comparison was made.

Description of the demonstration project

The phase 2 project will demonstrate how fugitive methane can be used to provide carbon negative energy to the Atlantic distillery and brewery. It will do this by integrating the distillery into the Bennamann Energy Network, making it a receiver of fugitive methane from local farms, captured from their slurry lagoons. By the end of the project the distillery will become a supplier of gas on the network too via digestion of its waste.

The project will validate the model developed in phase 1 so that other distilleries can be assessed for inclusion in the BEN and to facilitate wider-scale industry switching to fugitive methane.

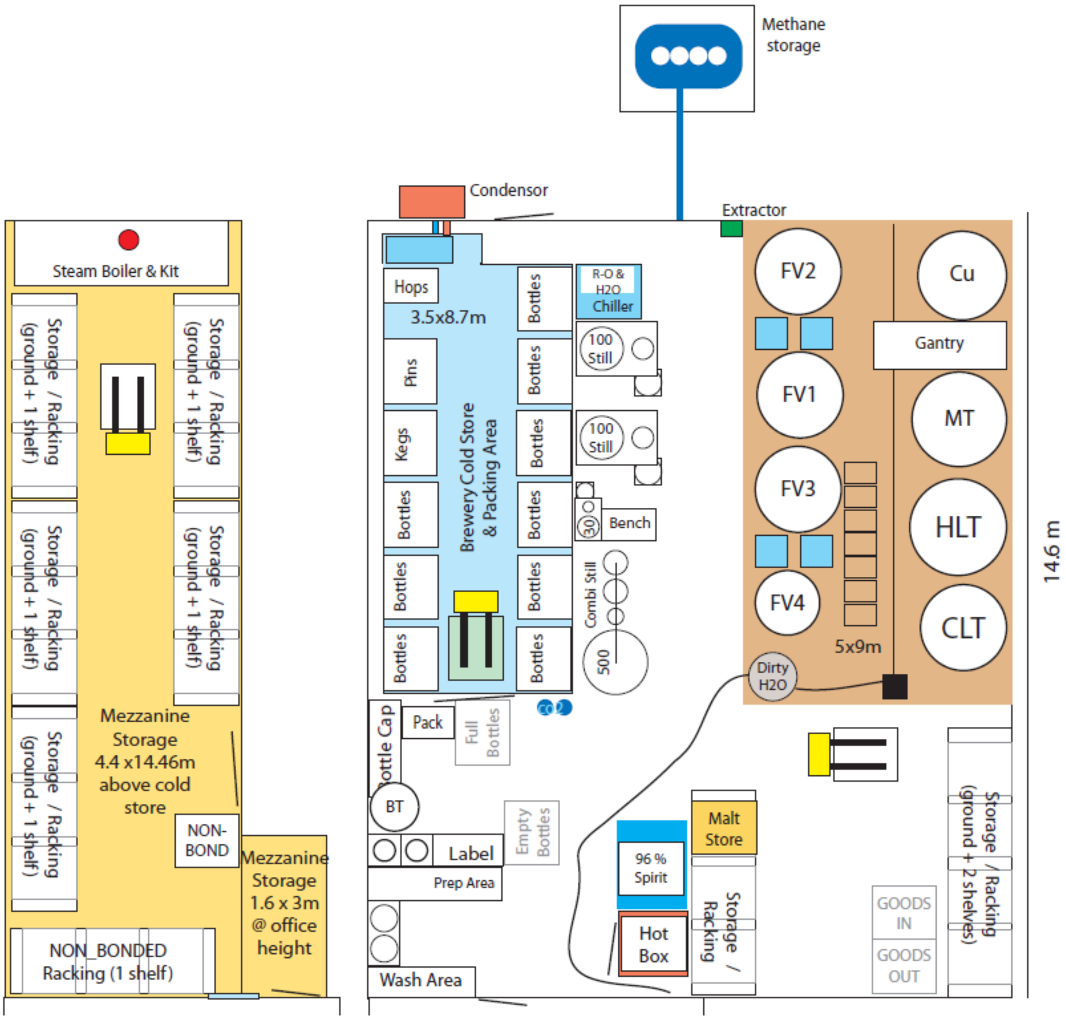
The phase 2 project aligns with Bennamann's corporate strategy to identify, assess, and integrate new nodes into the BEN. Every aspect of switching will be considered, addressed and solved through the actual installation, commissioning and running of a small-scale distillery on a fugitive methane fuel supply. This will expose all the potential barriers to fulfilling an energy switch and its ongoing supply, covering those obstacles particular to a new distillery and an existing distillery in one project. A resulting 'roadmap' document will be produced to facilitate the ease of roll-out at the end of Phase 2.

Phase 2 aligns with Atlantic's corporate strategy by enhancing the company's core values by providing a better-than-carbon-neutral fuel source. Atlantic sees their future market depending on environmental provenance and the opportunity to switch to fugitive methane as a solution long waited for. The project also provides a use for any waste material which may otherwise incur a disposal charge which will become a greater problem as the B/D grows.

Design of the demonstration

The diagram in Figure 4 shows the proposed layout of the up-scaled Atlantic distillery and brewery with fugitive methane gas supply. The switch to fugitive methane is facilitated via installation of a gas storage area at the rear of the building which is designed to meet all necessary regulations and provide access for delivery and collection of gas. Phase 2 will identify the equipment required to store and possibly process waste materials prior to collection so this is not shown on the plan. The layout will also be used to determine pipe routes within the building and when applying regulations such as DSEAR (Dangerous Substances and Explosive Atmospheres Regulations) which require zoning of the plant dependent on the risk from gas use.

Figure 4 - Detailed view of process locations



Benefits and barriers

The environmental benefits of switching to fugitive methane are significant; fugitive methane provides decarbonisation opportunities with minimal disruption to existing production processes. It is economically feasible for Bennamann to service this segment, matching existing energy prices of the marketplace, albeit with lower profit margins than other segments such as transport.

Capital & Production Costs

Capital costs vary and depend on the size of the distillery/brewery and the type of customer (whether they are producer-consumer customers or just consumers of fugitive methane).

Scenarios have been modelled for the consumer customer type, deriving a price of 79p/kg that Bennamann would need to charge the customer so that a 5-year payback is possible on their capital expenditure. This expenditure is assumed to be that required to set up a gas store and minor modification to the supply system.

Phase 2 will focus on understanding the increased yields and additional profitability of producer-consumer customers. This will be used to develop a pricing strategy that provides a discount to a gas producer such that the becoming a producer-consumer customer in the BEN is attractive to both parties.

Scaling the Process

One of the main barriers to scaling the use of fugitive methane in the sector is the availability of fugitive methane. At present, the UK is fulfilling less than 20% of its biomethane potential, with just 375 on-farm anaerobic digesters in the UK[3]. Bennamann's business model focuses on micro-scale producers, which is a largely unaddressed segment of the agricultural market. An early adopter segment is multi-farm owners, such as Local Authorities, who have many farms within a region. This approach means that Bennamann's energy network can scale across a region quickly, but the opportunity to extend the network to distillery/brewery customers is constrained by the growth of the supply-side of the network.

Other barriers include the lack of subsidies to stimulate renewable energy providers selling into the off-grid market.

Costed development plan

The total cost to deliver phase 2 is £329,983.00.

Work is scheduled to take 21 months with 6 months spent demonstrating and validating the model and 12 months spent acclimatising and generating results from co-digestion in a SLAD. During this time Atlantic would serve as a demonstration of the technology to showcase the benefits to other B/Ds.

Business plan for future development

On completion of the phase 2 demonstration Bennamann will continue to supply gas to Atlantic distillery and will continuously aim to streamline the service via new technology innovation. R&D is at the heart of the Bennamann business model, and the partnership developed with Atlantic will allow both parties to benefit from this innovation.

Depending on the results of the long-term waste co-digestion trial Bennamann will also continue to accept waste for processing into methane. The overall aim is for Atlantic distillery to become a blueprint for future distilleries to join the Bennamann Energy Network. The results of the project will be disseminated throughout the industry and Bennamann will seek to produce guidance to make fuel switching easy for distillery businesses to do. Bennamann will approach distilleries within the growing BEN as new locations are brought into the network.

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[3] https://adbioresources.org/2020-an-unprecedented-year-of-opportunity-for-biogas-in-the-uk/

Rollout potential

Market size and segmentation

The number of distilleries in the UK has increased significantly over the past five years and has continued to increase despite COVID. The total number registered in the UK in 2020 grew to over 560, up from 440 in 2019[4]. An extension to this market is the brewery market, as many of the same processes are used. Brewery numbers have remained stagnant over the past three years; there are currently 2,274 registered breweries[5]. This gives Bennamann a UK total addressable market (TAM) of 2,834. The market is segmented into small independent distilleries/breweries, who make up a significant portion of both markets (+80%) and large-scale operators. The serviceable addressable market (SAM) focuses on smaller independent distilleries/breweries and has been modelled as 2,267 (80% of the TAM); the serviceable obtainable market (SOM) is currently limited to distilleries/breweries in Cornwall (33), as this is the location of our pilot energy network. Bennamann intends to deploy networks all over the UK in the next five years, which will result in SOM figures that are aligned with the SAM numbers.

When developing customers who are both suppliers (waste) and consumers (fugitive methane), proximity to supply-side nodes will be key. The business model will be developed further to include energy pricing for supplier-consumers from this segment. Discounted energy pricing will be developed that accounts for the increase in methane yields brought about by the addition of distillery/brewery waste to supply-side ADs.

Route to market assessment

The route to market will be via a direct sales channel. Bennamann will be building a customer base on both the supply and demand side; the distillery market will be a target market to both. Initial target market will be the UK and the next phase of the project will help to further define early adopter segments within the market. Bennamann's business model is underpinned by local production and consumption of fugitive methane; the distillery market will increase and diversify the nodes in our local energy network model.

Steps to commercialisation

Bennamann has begun deploying its first Energy Network in Cornwall. Our core portfolio of technology on the supply-side is being demonstrated as part of a 6-farm pilot in Cornwall. We expect the portfolio to be fully commercialised by 2023.

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[4] https://www.wsta.co.uk/archives/press-releases/statistics

[5] https://www.statista.com/topics/6456/craft-beer-in-the-uk/#:~:text=The%20number%20of%20breweries%20has,in%202018%2C%201%2C978%20were%20microbreweries.

Barriers and risks

The main barrier to addressing this market is the growth of the Energy Network itself, which in the short-term, acts as a constraint to widespread adoption in the distillery market. At present 33 producer/consumer distilleries/breweries are obtainable, due to the geographical constraints. It is possible to reach many more demand-side customers via gas grid injection, but the opportunities for local, closed-loop customers will not scale until the Energy Network scales.

Benefit to other sectors

The Energy Network model that Bennamann has developed has enormous benefits to other sectors. The flexibility of fugitive methane coupled with its powerful environmental credentials, means that it can decarbonise any sector that uses it. Bennamann's value proposition rests on our ability to solve energy problems that traditional renewables cannot easily solve, so our initial target markets include agriculture and transport.

Our focus on capturing fugitive methane from slurry lagoon ADs (SLADs), dramatically reduces agricultural emissions; a 150-cow dairy farm can reduce its annual CO_2e emissions by 1,621 tonnes and remove 11 tonnes of ammonia per annum. There are over five million dairy cows in the UK, which could deliver 56m tonnes of CO_2e benefit annually for the UK.

Bennamann's fugitive methane sold into the transport sector can be used to solve some of its greatest challenges. Decarbonising heavy duty vehicles is a challenge due to lack of appropriate infrastructure/high costs associated with electrification/hydrogen. Powering gas trucks with fugitive methane is economically viable solution (payback ~ 2 years). A fugitive-methane powered heavy goods vehicle (HGV) will realise a 129,000kg CO2e benefit over a diesel-powered truck per annum.

Dissemination

Dissemination at this stage will be limited to Bennamann and Atlantic. Dissemination in phase 2 will follow a plan of work and include press releases, open days, and production of a 'road map' document for distilleries interested in fuel switching to fugitive methane.

Conclusions

Energy modelling work has shown that switching to fugitive methane transforms the carbon footprint for any sized B/D; in all cases the process footprint is made carbon negative. It is a well-matched solution for companies within the industry where the standard heating model is either direct combustion or gas-fired steam-power. Here, energy switching would incur minimal commercial interruption as there is no process or production interference.

Initial experiments have confirmed biogas generation from mono- and co-digestion of slurry and distillery waste. The increase in fugitive methane from slurry in a co-digested system should be further confirmed via the continuation of these experiments. This will also determine the limits of key parameters and look at solutions for the inter-seasonal fluctuation in lagoon usage and potential alternative methane gas production methods from distillery waste during lagoon downtime (i.e. via an UASB).

Cost modelling has shown that there are slim margins for profit in a gas consumer scenario based on the low cost of NGG supply and current costs of production and distribution. Integrating producer-consumer nodes provides the potential for greater margins and affords customers a discount on gas price and means of dealing with waste products at zero cost. Phase 2 will further investigate the pricing scenarios for integrating producer-consumer customers.

In summary, the study has shown that B/Ds such as Atlantic can become viable nodes within the BEN, creating a mutually beneficial, local, circular economy for gas production and waste use. B/D power requirements can be met via fugitive methane whilst at the same time drastically reducing carbon footprints. There is also the potential to co-digest B/D waste in SLADs to enhance methane production, making B/Ds a gas production node in the BEN and further enhancing the margins for both businesses.