Department of Mechanical and Aerospace Engineering

# Sustainable Energy using Anaerobic Digestion of By-Products: Islay Whisky Industry Case Study

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Signed: Date: 31st August 2016

# Abstract

A study was conducted into the feasibility of centralised anaerobic digestion (AD) plants creating biogas from whisky by-products on the isle of Islay. It looked at pumping of the by-products from all 8 distilleries to the central location as an alternative to transporting via truck to the sea discharge point. A range of scenarios were considered, which involved a mixture of combined heat and power units and biogas boilers. Some scenarios consider the feasibility of complementing the biogas with biomass drying.

Distilleries have a high thermal demand and mostly use fossil fuels. The aim of the study was to investigate what proportion of this could be offset with energy derived from anaerobic digestion of their own by-products in order to reduce greenhouse gas emissions, as well as provide a renewable source of energy.

A literature review was conducted and experts consulted to gather the data required for the analyses. A range of scenarios were defined and modelled in Excel to analyse the potential for energy savings as well as environmental and financial feasibility.

It was found that around 30% of the whisky distilleries total energy requirements can be met with individual AD plants providing biogas for combustion in biogas boilers. However a central AD plant opens up further opportunities to include other available feedstocks for increase of biogas yield, as well as biomass drying which can then provide 100% of the distilleries thermal requirements. Biomass in this case is used as thermal energy 'storage' in the same way the electricity grid is used as electrical storage, which allows supply and demand matching. In every case it was shown that subsidies are required for financial feasibility. Without them, long payback periods result.

The results highlight the importance of designing for a technological solution rather than financial gain. In most if not all cases in the UK, AD plants use CHP systems as until now, FIT has yielded the highest profits. This provides very little renewable thermal energy, which is often what is highest in demand.

# Acknowledgements

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Especially Wendy.

# Table of Contents

# List of Figures

## List of tables

# Abbreviations

| | |
|---|---|
| AD | Anaerobic Digestion |
| ADBA | Anaerobic Digestion and Bioresources Association |
| CCL | Climate Change Levy |
| $CH_4$ | Methane |
| CHP | Combined Heat and Power |
| $CO_2$ | Carbon Dioxide |
| $CO_2e$ | Carbon Dioxide Equivalent |
| COD | Chemical Oxygen Demand |
| CSTR | Continuous-flow Stir Tank Reactor |
| DECC | Department of Energy and Climate Change |
| FIT | Feed-In Tariff |
| GHA | Glasgow Housing Association |
| GHG | Greenhouse Gas |
| HRT | Hydraulic Retention Time |
| IET | Islay Energy Trust |
| mc | Moisture Content |
| Ofgem | The Office of Gas and Electricity Markets |
| RHI | Renewable Heat Incentive |
| RO | Renewables Obligation |
| ROC | Renewables Obligation Certificate |
| RTFC | Renewable Transport Fuel Certificate |
| RTFO | Renewable Transport Fuel Obligation |
| TS | Total Solids |
| UASB | Upflow Anaerobic Sludge Blanket |
| VFA | Volatile Fatty Acid |

# 1.0 Project Introduction

## 1.1 Background

With the continued increase in energy demand and resulting depletion of fossil fuels, along with global commitments to reducing greenhouse gas (GHG) emissions comes an inherent interest in the development of low carbon technologies which utilise renewable resources such as solar, geothermal or tidal. Switching from fossil fuel to renewable energy sources has the desired effect of cutting down GHG emissions whilst also securing an infinite energy supply.

Energy can also be produced from waste or by-products which if left unused, may also contribute towards GHG emissions or cause other environmental issues. For example food waste sent to landfill decomposes and emits methane gas; this GHG is 21 times more potent than carbon dioxide. If collected and treated with anaerobic digestion (AD), biogas can be created for use in the same way as natural gas; to produce heat or power, or both. Through combustion, the methane is burnt and only the remaining carbon dioxide is therefore released to atmosphere, reducing GHG emissions, increasing energy supply and also reducing landfill.

Of particular interest is the whisky industry, which has by-products known to be suitable for AD, as well as intensive energy demands for whisky production. To what extent could this demand be met by using their own by-products for energy generation? Several distilleries currently already have operational AD plants; could energy generation be optimised with the use of larger centralised plants serving several distilleries? Financial subsidies are ever decreasing, could economic viability be increased with the use of such centralised plants?

The isle of Islay has an abundance of whisky distilleries as seen in *Figure 1*[1], which will serve particularly well as a case study location in an attempt to answer these questions.

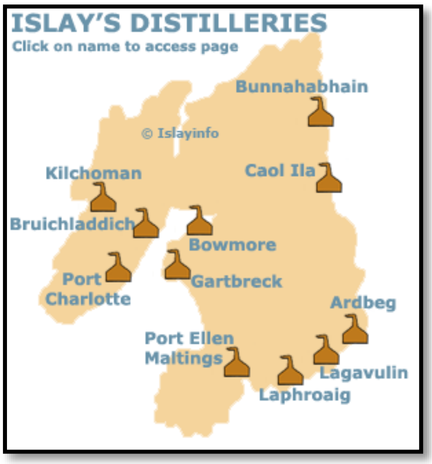


Figure 1 – Islay Distillery Map

[1] (Islay Info, 2016)

## 1.2 Aim and Objectives

### *Aim*

To investigate a range of scenarios for providing sustainable energy from a central AD plant to meet the energy demands of whisky distilleries on Islay by anaerobic digestion of their own by-products as a base feedstock.

### *Objectives*

To investigate

- The percentage of distillery energy demand which could be met with anaerobic digestion of their by-products;
- Optimisation of biogas production with additional available feedstocks;
- The potential to include a local supply of biomass as a complementary renewable energy supply as a demand matching solution;
- Environmental benefits of a range of scenarios;
- Financial feasibility of a range of scenarios;
- The implications of reduction in subsidies, i.e. the extent to which subsidies are relied upon in this field.

## 1.3 Approach

1. Literature review of the topic of anaerobic digestion.
2. Review of Islay to identify key details relevant to the study.
3. Scenario investigations as outlined in *Table 1*. To fulfil objectives, the following results will be analysed:
    - Percentage of energy provision;
    - GHG emissions reduction;
    - Percentage of land use change;
    - Capital investment required;
    - Payback period.
4. Discuss results individually as well as overall.
5. Draw conclusions in relation to the project aim.

| | **No On-Site CHP** | **On-Site CHP** |
|---|---|---|
| **Biogas for use at distilleries** | ***Scenario 1***<br>*Heat Only* | ***Scenario 2***<br>*CHP On-site, Heat at Distilleries* |
| **Biogas used to dry wood chip** | ***Scenario 3***<br>*Optimisation of Biomass Store On-site* | ***Scenario 4***<br>*Optimised Biomass with CHP On-site* |
| ***Scenario 5***<br>*Individual AD Plants at each Distillery* | | |

Table 1 – Outline of Scenarios

# 2.0 Literature Review

## 2.1 Anaerobic Digestion Background[2]

Anaerobic Digestion is a process which occurs naturally with the decaying of organic matter, for example in landfill sites or marshes, releasing gases to the atmosphere. However this process can also be carefully controlled and the resulting gases (biogas) contained in order to prevent the release to atmosphere, with the biogas being used to generate energy; both heat and power. This is an alternative to energy production from fossil fuels, with other benefits including landfill volume and greenhouse gas (GHG) reduction.

The technology has been in use for many years, with the variety of uses increasing over time as different issues become more prominent. This forces the implementation of legislation which drives the need to find solutions, with AD proving to be viable in many cases.

### *Benefits of AD*

- GHG reduction – Although there is still a release of carbon dioxide to the atmosphere, the methane is captured and can be converted to useful energy which results in an overall emissions reduction.
- Waste reduction – if suitable organic waste and by-products are treated through AD, then it will contribute towards landfill volume reduction.
- Less contamination of water/soil – for example in the case of agricultural slurry being applied directly to the land as fertiliser, this can cause contamination of nearby water sources and the soil if it is applied in great quantities. Additionally, this reduces unpleasant odours.
- Less reliance on the grid (electricity or gas) – if on-site AD is used to generate energy, then less energy needs to come from the grid. This has the double benefit of adding income in the form of reduced energy bills and also payments in the form of renewables subsidies.

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[2] Section 2.1 general references:
(O'Kiely, Korres, West, & Benzie, 2013)
(Williams, 2005)
(Wheatley, 1990)
(Van Brakel, 1980)
(Demuynck, 1984)

*AD Barriers*

- Food Vs fuel – as with many renewable energy systems, the issue of food versus fuel arises. If it is more financially beneficial to grow energy crops rather than food crops then farmers may switch, potentially putting a strain on food supplies.
- Reliance on long-term contracts – If feedstock is supplied by a 3rd party then it requires long-term contracts for security over the life of the system. This may be hard to secure, which adds risk to potential projects.
- Subsidy changes – Government subsidies change fairly regularly which introduces further risks to projects in the planning phase. It can take up to 18 months to plan, install and commission a project and it is only at the point after commissioning, when a physical grid connection is made, that the operator is securely tied into the subsidy scheme at the rate at which the financial analysis will have been made against.
- General issues for smaller plants – A meeting with Glasgow Housing Association (GHA) highlighted several other issues such as;
    - Site selection – this can be made difficult due to need for space for storage of feedstock, smells and noise.
    - Logistics – if relying on many small collections of waste, it is difficult to organise the collections and could be costly.
    - There may not be a use for heat on-site which reduced the potential benefits.

## *A Brief History of AD*

The history of anaerobic digestion sees improvements and changes occurring over time due to changes in global priorities. There are several key milestones or drivers which have progressed the development of AD:

1. General scientific discoveries regarding the chemical or microbiological processes;
2. Requirement for the treatment of sewage waste;
3. Requirement for the reduction of landfill volume;
4. Requirement for cheaper energy production (due to increase in oil price);
5. Requirement to reduce GHG emissions.

*Table 2* summarises some of the more definitive events throughout the history of the advancement in anaerobic digestion.

**Table 2 – Summary of Anaerobic Digestion History**

| **Year** | Key Milestone |
|---|---|
| **1776** | The scientific history of methane digestion began with the work of Alessandro Volta, when he correctly concluded that:<br>• The amount of gas produced is related to the amount of decaying vegetation (in marshland) and;<br>• Certain proportions of the gas produced forms an explosive mixture with air.<br>This led on to further scientific discoveries in the field over the coming years. |
| **1808** | Sir Humphry Davy successfully collected methane gas from cattle slurry which was stored in a sealed container. |
| **1850-1900** | Systematic investigations began in this time period, with research from many scientists contributing to an overall clear view as to the workings of the microbiological process of anaerobic digestion. |
| **1895** | Although sceptic tanks were incorporated into sewage systems in 1860, it wasn't until 1895 in England that a system was designed by Donald Cameron which allowed the gas to be collected. The drivers of this design were the need to reduce the suspended solid content of the effluent |

| Table 2 – Summary of Anaerobic Digestion History | |
|---|---|
| **Year** | Key Milestone |
| | and also to reduce severe odours. The resulting gas was used for street lighting. |
| **1897** | An anaerobic digester was installed in Bombay to treat waste from the Matinga Leper Asylum. The biogas here was also used for street lighting, as well as to run a motor. |
| **1905** | Most British and German sewage works were upgraded to the Cameron system (from 1895) and technological advancements increased rapidly from this point with the USA also following suit. |
| **1907-1925** | Many patents were issued in this time period for variations in plant designs to improve efficiencies. The systems evolved to heated digester systems, which utilised the resultant biogas to maintain the required digester temperature. |
| **1935-1942** | Ground up domestic solid waste was added to sewage plants in the USA, the driver here being to reduce landfill volume. During this period, many areas also carried out this practice until it ended in 1942 due to the intensive loading procedures required and contamination issues. |
| **1960** | Large scale animal waste disposal became a problem with the increase in size of farms. Tightening of environmental legislation caused increased difficulties in safe disposal of carcasses and odour reduction of excreta. At this time it was generally seen that anaerobic digestion was not an economically viable solution for energy production, but is technically viable as a waste treatment solution. |
| **1973** | Oil crisis caused increased interest in renewable energy generation. Focus on energy generation from AD rather than simply as a waste management solution. |
| **Present day** | Continued focus on climate change and reduction of GHG's, therefore further promotion of renewable and low carbon energy technologies with the support of a variety of subsidised incentive schemes. |

## 2.2 The Process of Anaerobic Digestion[3]

As *Figure 2* shows, organic material known as the feedstock is fed into the anaerobic digester which is air tight so as to prevent the presence of oxygen. Within the digester, a four stage chemical process occurs as summarised in *Table 3*.

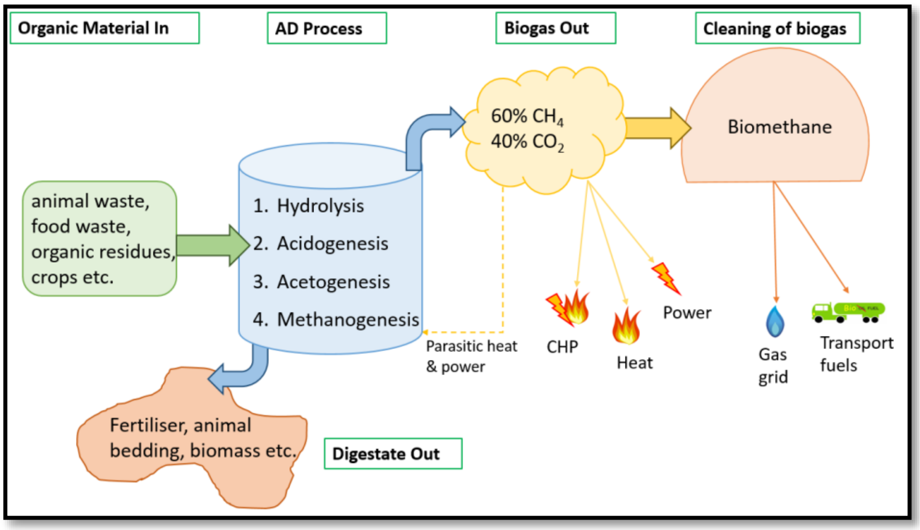


Figure 2 – Sketch of AD Process

| **Table 3 – Summary of AD Process** | | |
|---|---|---|
| **Stage** | Stage Name | Description |
| **1** | Hydrolysis | This first stage sees complex polymers such as proteins, fats, cellulose and carbohydrates broken down into solution. |
| **2** | Acidogenesis | At this stage, acidogenic bacteria further break down the simple monomers, creating volatile fatty acids (VFAs), ammonia, $CO_2$ and hydrogen sulphide. |
| **3** | Acetogenesis | Here, acetogens digest the products of stage two to produce acetic acid, which releases $CO_2$ and hydrogen. |
| **4** | Methanogenesis | In the final stage of the process, methanogenes or ‘methane formers’ convert the products of the previous three stages into biogas which is typically made up of around 60% methane and 40% carbon dioxide. |

[3] Section 2.2 general references:
(NNFCC, 2009)

The direct outputs of this process are biogas and digestate which both have uses as described in the following sections. It is also possible to further process biogas into biomethane, which has its own uses again.

## 2.3 Suitable Feedstocks[4]

Suitable feedstocks for AD include any biodegradable organic matter, either from plants or animals. However, ‘woody’ plant matter is not suitable as anaerobic micro-organisms are not capable of breaking down lignin. Therefore material with this property if added to the feedstock, will slow down the digester.

Suitable feedstocks:

- Animal/human waste – e.g. litter, urine and faeces.
- Food and drink industry waste – e.g. slaughterhouse waste, fish factory waste, distillery or brewery co-products. Increased quality regulations result in higher volumes of waste product.
- Agricultural waste – e.g. remains after harvesting and processing of crops; stalks, husks and foliage.
- Energy crops – these can be grown specifically for the purpose of co-digesting along with other feedstocks e.g. grass silage, maize or sugar beet.
- Seaweed – kelp and a variety of algae are suitable for treatment by AD.
- Domestic food waste – e.g. food scraps, garden waste such as grass cuttings or trimmings from bushes

Each source has a different potential for biogas yield depending on its individual properties.

[4] Section 2.3 general references:
(NNFCC, 2009)
(O'Kiely, Korres, West, & Benzie, 2013)

## 2.4 Biogas[5]

Biogas is mainly made up of methane at around 55-60% and carbon dioxide at 40-55%, with a few trace elements of other substrates. It is only methane which has an energy content, carbon dioxide has none.

### *Yields*

Biogas yields depend on the feedstock properties input to the system, namely the;

- Dry matter content
- Energy left after prolonged storage
- Time in the digester
- Type of AD plant and conditions within the digester
- Purity of the feedstock (level of contamination)

### *Uses*

Biogas used in its raw state, through combustion, can produce heat through a biogas boiler, power from an electricity generator or both with the installation of a combined heat and power (CHP) unit.

If used for heat only, some energy can be used to heat the digester (this is known as the parasitic heat) and the remainder can be used by a nearby source, perhaps a district heating scheme for example. This would attract support from the RHI scheme.

Producing electricity can be a more beneficial option if there is no requirement for heat in the vicinity of the plant since electricity is easily transported long distances compared with heat. Again electricity produced can be used to run the AD plant (parasitic electricity) with the rest being exported. However producing electricity alone has a low efficiency due to the high heat losses and it can be expensive to connect to the electricity network, however it would attract subsidy from the FIT scheme.

CHP may be the most financially viable option since the high proportions of heat generated during the production of electricity is recovered and made useful which

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[5] Section 2.4 general references:
(NNFCC, 2009)
(Zero Waste Scotland, 2010)
(Wheatley, 1990)
(ADBA, 2013)

brings the overall efficiency up to around 80% or above and attracts both FIT and RHI together. CHP is the most common use of biogas in AD plants in the UK.

## 2.5 Digestate[6]

The material which remains following the anaerobic digestion process is the digestate. It is composed of both a solid and liquid fraction which is nutrient rich and therefore suitable for use as a fertiliser as long as it meets environmental regulations.

If the solid proportion is dried then alternative uses could be for animal bedding or burning in biomass systems.

## 2.6 Biomethane from Biogas[7]

Biogas can be upgraded and converted to biomethane which has the same properties as natural gas and can therefore be injected into the gas grid. This is called gas to grid. The composition of biomethane is in the region of 97% methane and 3% carbon dioxide.

There are several advantages to this practice:

- Support from RHI scheme;
- Higher energy density than raw biogas;
- Biomethane is a more flexible fuel;
- Energy captured is used more efficiently.

However barriers also exist, such as:

- Large additional costs and parasitic energy to upgrade;
- Carbon savings can be reduced;
- No specific UK standard for biomethane;
- No incentive for grid operators to accept biomethane;

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[6] Section 2.5 general references:
(O'Kiely, Korres, West, & Benzie, 2013)
(Zero Waste Scotland, 2010)
[7] Section 2.6 general references:
(O'Kiely, Korres, West, & Benzie, 2013)
(NNFCC, 2009)

- Gas grid may be too far away for connection.

There are several processes which biogas can go through in order to remove the high $CO_2$ content such as membrane separation, chemical scrubbing, water scrubbing and pressure swing adsorption[8]. Rather than injecting the biomethane into the grid, in this form it is also suitable as a form of biofuel for transportation. Both of these options offer low carbon alternatives to fossil fuels.

## 2.7 Types of Digester[9]

There are 3 main types of digester in operation:

### *Batch*

In a batch digester, all feedstock is added at one time together with active anaerobic bacteria. Gas production is slow at first, eventually peaking before ceasing altogether. At this point the digester is mostly emptied; a small amount is left in which provides the required bacteria for the next batch.

The problem with this system is that biogas cannot be continuously supplied unless several digesters are operated together in stages. However it is a simple system to operate in that feedstock can be loaded with basic equipment such as tractor shovels, rather than having a need to be continuously loaded at a set rate with controlled equipment.

### *Continuous-flow Stirred Tank (CSTR)*

In a continuous flow digester, a wet slurry of fresh feedstock is continually (or frequently in smaller batches) added to the digester, with an equal proportion of biogas being produced at the same time. The waste is stirred by gassing and thermal convections. This is the most common type of digester found on farms.

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[8] (Ricardo-AEA, 2015)
[9] Section 2.7 general references:
(Wheatley, 1990)
(Demuynck, 1984)

*Upflow Anaerobic Sludge Blanket (UASB)*

Also known as a ‘high rate’ digester, these can be used for feedstocks with a very low percentage of total solids, for example waste water treatment or pot ale from a distillery. As there is a lack of solid matter for the bacteria to settle on, filters with a large surface area are used near the top of the tank for microbial attachment. The feedstock is passed through the filter and thus is digested by the bacteria.

This method achieves quicker production of biogas, which means a smaller tank is required. However the process is more temperamental so requires more control and fast reactions to issues. It also prevents the possibility to expand the range of feedstocks in the future.

## 2.8 Digester Operation[10]

The main factors affecting digester operation/design are as follows:

*Hydraulic Retention time (HRT)*

The hydraulic retention time is the average length of time which the feedstock remains in the digester to produce optimum levels of biogas. This value is important when deciding the digester volume. In general, a tank will be sized relating to the HRT to obtain around 85% of the biogas yield. This is because beyond this point, only a small amount more biogas could be gained with a much larger tank requirement due to the extended HRT. An example is shown in *Figure 3* which is a plot of biogas yield of draff over a 31 day period[11]. The three plots give biogas yields in litres per kg of total substrate weight (total starting weight of the draff sample), litres per kg of total solids and litres per kg of organic total solids.

[10] Section 2.8 general references:
(Wheatley, 1990)
(Demuynck, 1984)
[11] (Schmack Biogas, 2007)

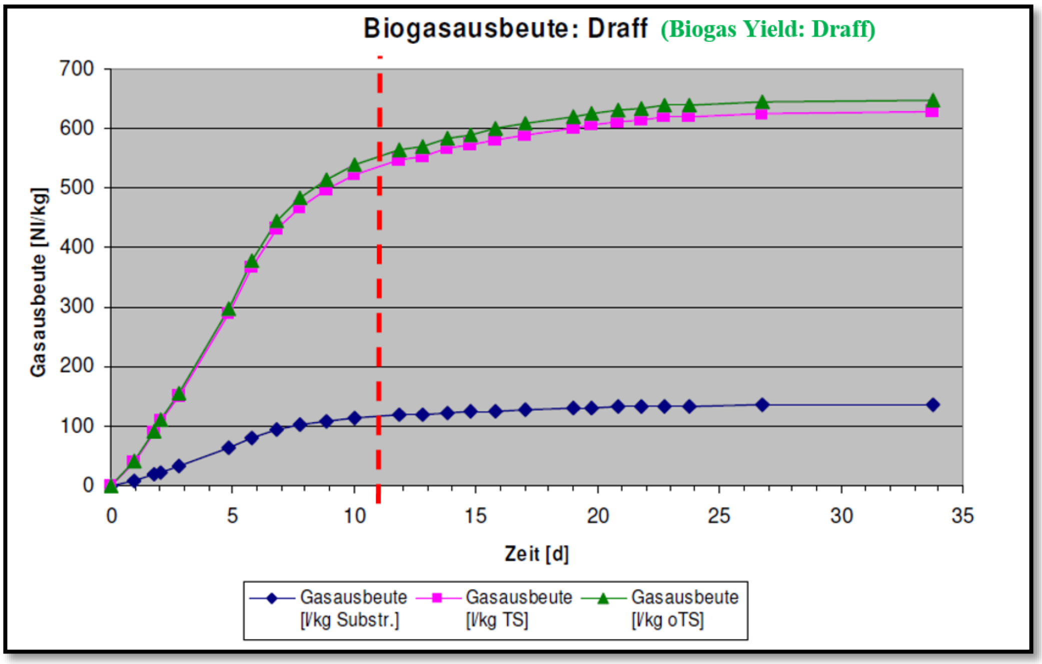


Figure 3 – Biogas Yield Vs HRT: Draff

The red line shows the 85% yield point at an HRT of 11 days, with the peak at around 28 days. This is almost 3 times the length of time for only 15% additional yield, which would require a digester of three times the volume.

If the HRT used to design the digester is too low, then aside from a less economical yield of biogas production, neither may it provide enough time to lower odours and pathogens etc.

### *Total Solids (TS)/Total Organic Solids (TOS) in the Feedstock*

The gas production depends on TS/TOS in the feedstock, therefore this characteristic must also be considered when designing the digester. *Figure 4* shows values which correspond to the previous HRT graph[12]. It shows that in a sample of draff, 21.7% of the original substance weight is dry matter, or total solids. It then shows that the gas yield is 628 litres/kg of total solids after 31 days.

[12] (Schmack Biogas, 2007)

| Untersuchungsparameter (Test Parameters) | | Wert | Einheit | Prüfverfahren |
|---|---|---|---|---|
| **Allgemeine Angaben (General Information)** | | | | |
| Trockensubstanz (Dry Matter) | TS | 21,7 | % (OS)* | DIN EN 12880 |
| Organ. Trockensubstanz | oTS | 21,0 | % (OS) | DIN EN 12879 |
| Glührückstand | GR | 0,66 | % (OS) | DIN EN 12879 |
| | | | | |
| **Biogas-Ausbeuten nach 31 Tagen (Mittelwerte) (Biogas Yield after 31 Days (Mean Value))** | | | | |
| Gasausbeute aus OS | | 136 | Nl/kg Frischsubstrat | DIN 38414-S8 |
| Gasausbeute aus TS (Gas Yield from TS) | | 628 | Nl/kg TS | DIN 38414-S8 |
| Gasausbeute aus oTS | | 648 | Nl/kg oTS | DIN 38414-S8 |

Figure 4 – Biogas Yield from TS Content: Draff

Depending on the type of system being employed, it will have an optimum load rate in kg of dry matter per day. This value, along with the characteristics from *Figure 4* above can be used to calculate the optimum digester size and biogas yields expected.

### *Temperature Range in the Digester*

The process of AD is successful, with useful biogas yields across a wide temperature range of around 15-65°C. This overall range can be split into two groups of optimum temperature ranges, the mesophilic range (around 25-40°C) and thermophilic range (around 50-65°C).

| | Temperature (°C) | | | | | |
|---|---|---|---|---|---|---|
| | 15[a] | 25 | 30 | 35 | 40 | 44 |
| Gas (litres/kg TS) | 0 | 260 | 300 | 300 | 360 | 420 |
| Solids degradation (%) | 0 | — | 33 | 36 | 37 | 38 |

Figure 5 – Example of Mesophilic Biogas Yields from Piggery Wastes

At lower digester temperatures, it is possible to optimise the biogas yield by increasing the HRT and as previously discussed, this means increasing the size of the digester. i.e. it is the rate of production which is affected by temperature as opposed to the total volume produced.

In a mesophilic digester, production will drop off above the 45°C mark, however if the temperature is increased further then thermophilic bacteria can become established above 50°C.

Thermophilic digestion produces gas at a higher rate due to the acceleration of the hydrolysis phase. The benefit of a thermophilic digester is therefore that the HRT is reduced and a smaller digester possible. The downside is that due to the increase in rate of activity, the whole process is more sensitive to change which requires more rigorous monitoring and control.

## 2.9 Typical Energy Outputs[13]

The energy output from biogas depends on the methane content and also the efficiency of the system employed (i.e. electricity generation, heat or CHP etc.).

The calorific value of methane[14] is typically 36MJ/$m^3$. 1kWh is the same as 3.6MJ, therefore 1$m^3$ of methane contains 10kWh of energy. So from this it is possible to calculate the total theoretical energy output from a given volume of biogas, depending on proportion of methane within it.

Supposing the biogas is being combusted in a CHP system, since this is the most common use, at 80% efficiency it would be expected that around 8kWh of energy will be output from each cubic metre of methane in the form of both heat and electricity. The specification of the CHP unit will determine the exact numbers, but typically it would be expected that around 35-40% is converted to electricity, with 40-45% as heat and the remainder lost to inefficiencies throughout the process.

### *Example calculations per cubic metre of biogas*

*Heat Only:*

**1$m^3$ biogas in** = 0.6$m^3$ methane (at 60% methane content)

= 6kWh energy potential (at 10kWh/$m^3$)

= **5.4kWhth (thermal) energy output** from boiler (at 90% efficiency)

[13] Section 2.9 general references:
(NNFCC, 2009)

[14] (Select Committe on Economic Affairs, 2008)

*Electricity Only:*

**1m³ biogas in** = 0.6m³ methane (at 60% methane content)

= 6kWh energy potential (at 10kWh/m³)

= **2.1kWhe electrical energy output** from generator (at 35% efficiency)

*CHP:*

**1m³ biogas in** = 0.6m³ methane (at 60% methane content)

= 6kWh energy potential (at 10kWh/m³)

= **4.8kWh useful energy output** from CHP (at 80% efficiency)

= 2.1kWhe and 2.7kWhth (at 35% and 45% efficiencies respectively)

## 2.10 Biomass to Complement AD

As previously discussed, biogas is not easily stored so if there is not a use for heating on site then it may not be a financially viable project. Upgrading to biomethane provides an option, but this is expensive and feasibility would have to be investigated on an individual basis.

An additional option could be to complement the AD system with a biomass drying unit which would provide a use for the heat generated and also another form of renewable energy supply which attracts RHI.

When biomass is first felled, it has around a 50% moisture content (mc), i.e. if it weighs 1000kg, then it will contain 500kg of wood and 500kg of water. To burn biomass with such a high moisture content is very inefficient as a proportion of the energy is being wasted in the act of evaporating the excess water. Therefore it is best practice to dry the timber before using as a fuel. The calorific value of the wood increases linearly with the decrease in moisture content[15] as per *Figure 6*.

[15] (Biomass Energy Centre, 2016)

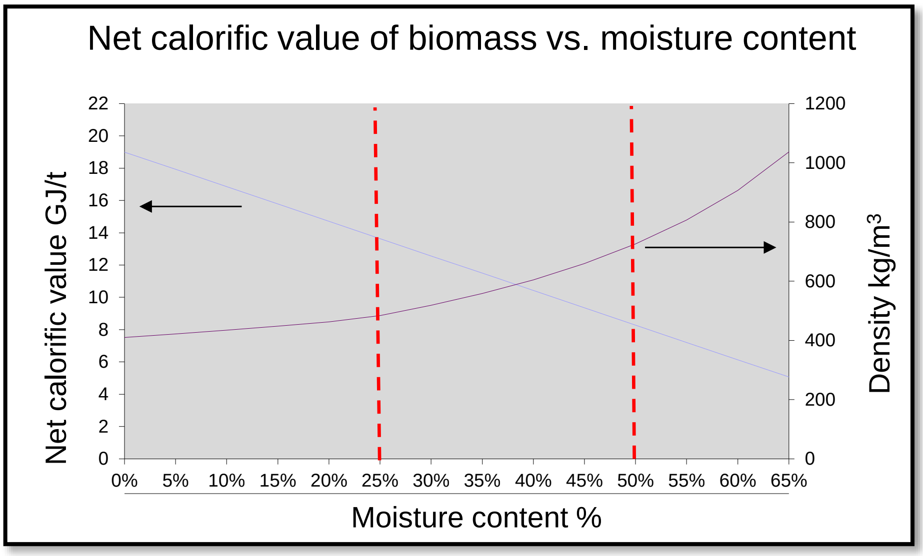


Figure 6 – Biomass Calorific Value & Density Vs Moisture Content

In general, a moisture content of 25% is what should be aimed for to use in a biomass boiler. It is an expensive practice to actively dry wood, therefore in the majority of cases it is left for a season or perhaps a year until adequately dried. However if there is a cheap source of heating then it can become profitable, for example in the case of an anaerobic digestion plant. If the available thermal energy supply is known, then it is possible to calculate the capacity of wood which can be dried and at what rate.

Biomass is more easily stored compared with biogas. It can also be brought on and offline as and when heating is a requirement in contrast with biogas having to be used as it is produced since it cannot be stored.

Short rotation coppicing is a sustainable way to produce biomass where fast growing tree species are cut to the stump to encourage numerous new stems to grow in the following season. It is a well-established practice in the UK, with both poplar and willow being the principal species used. Willow is the more commonly used of the two, due to the robustness of growth in harsh conditions as well as the dense growth per hectare.

Willow can be harvested into rods, billets or chips. Harvesting rods involves cutting the willow at the base, producing rods of up to 8m in length. Billet harvesting uses the same cutting method, but proceeds to cut the rods into shorter lengths. Direct chip harvesting uses a wood chipper which directly chips the willow rods once cut and blows it into a trailer. Problems occur with direct chip harvesting when the wood chip is left to naturally dry. Due to the higher density, less air can flow leading to high temperatures occurring within the pile which leads to decomposition and even combustion. Decomposition results in reduced calorific value, with the mould produced during this process presenting health hazards. Therefore direct chip harvesting should ideally be force dried rather than naturally dried over a season. Studies have shown that it is not economical in the majority of cases to actively dry woodchip unless there is an abundant source available[16].

## 2.11 Incentive Schemes

The following sections give a brief description of the schemes in the UK which serve the AD industry, including any changes which have been announced over the last year which could affect future growth.

### *Feed-In Tariff (FIT)*

The feed-in tariff scheme pays the producer of renewable and low-carbon energy a predefined price per kWh of energy generated. It was introduced by the government to encourage the installation of smaller scale projects due to the high capital costs required. It pays both a rate for electricity generated, as well as a separate rate for excess electricity which is exported back to the grid[17]. In addition to these two sources of income, energy bills are also reduced due to the lesser need to import from the grid.

*Table 4* shows the current rates[18] which apply to projects commissioned by 30th June 2016, as well as the proposed rates which will take effect from 2017. The proposed rates come as a result of a government consultation on revising the FIT scheme, proposing a cap on AD plant capacity of 500kW with degression rates for smaller plants of 27%[19].

This will have a negative impact on the growth of the industry and as ADBA state in their July 2016 Market Report, the pipeline of applications could fill the AD cap up to

[16] (Biomass Energy Centre, 2016)
[17] (Ofgem, 2016)
[18] (Ofgem e-serve, 2016)
[19] (DECC, 2016)

2019 which would mean that operators will not be able to apply FIT for pre-accreditation from 2018[20].

| Table 4 – FIT Rates | | |
|---|---|---|
| **System Size Category** | **Current Rate (p/kWh)** | **Proposed from 1st Jan 2017 (p/kWh)** |
| 0 – 250kW | 8.21 | 5.98 |
| 250 – 500kW | 7.58 | 5.52 |
| >500kW | 7.81 | 0.00 |
| Export Tariff | 4.91 | 4.91 |

### *Renewables Heat Incentive (RHI)*

The renewables heat incentive scheme is similar to the FIT but based on heat generated rather than electricity, and there is no (efficient) way to export heat therefore the tariff is for generation only. Eligible projects receive quarterly payments at a set rate for 20 years relative to the amount of heat generated[21].

The tariffs are set by the Department of Energy and Climate Change (DECC). *Table 5* lists the current rates for projects accredited on or after 1st July 2016[22].

These rates show a 15% degression from previous which is not nearly as high as the FIT scheme, however could still have an effect on whether a project is financially viable.

[20] (ADBA, 2016)
[21] (Ofgem, 2016(b))
[22] (Ofgem, 2016(c))

| Table 5 – RHI Rates | | |
|---|---|---|
| **Tariff Name** | **Eligible Sizes** | **Tariff (p/kWh)** |
| Biomethane injection | First 40,000MWh (tier 1) | 4.55 |
| | Next 40,000MWh (tier 2) | 2.67 |
| | Remaining biomethane | 2.06 |
| Small biogas | 0 – 200kW | 5.90 |
| Medium biogas | 200 – 600kW | 4.63 |
| Large biogas | >600kW | 1.73 |
| Small biomass | 0 – 200kW (tier 1) | 3.26 |
| | 0 – 200kW (tier 2) | 0.86 |
| Medium biomass | 200 – 1000kW (tier 1) | 5.24 |
| | 200 – 1000kW (tier 2) | 2.27 |
| Large biomass | >1MW | 2.05 |

### *Renewables Obligation (RO)*

This is a scheme aimed at large scale renewable energy which places an obligation on energy suppliers to supply more electricity from renewable sources.

The system is structured as so[23]:

- The energy supplier is given an annual obligation as to the percentage of their energy supply which must come from renewable sources.
- Eligible renewable electricity generators update their production levels monthly to Ofgem.
- Based on this figure, Ofgem issue renewable obligation certificates (ROCs) to the electricity generator.
- The electricity generator sells their ROCs to energy suppliers, which generates an additional income on top of the wholesale electricity price.
- At the end of the annual period, the energy suppliers present their ROCs to Ofgem and pay a penalty if their obligation has not been met.

[23] (DECC, 2016(b))

- The revenue generated from penalties is distributed to the other suppliers who met their obligations.

However this scheme will close to all new projects on the 31st March 2017. According to the ADBA, this creates further uncertainty for future AD projects as some developer's model for claiming the RO rather than FIT to serve as a worst case scenario in case FIT is not attained. Therefore, without the scheme there is more risk involved[24].

### *Renewable Transport Fuel Obligation (RTFO)*

The RTFO is a scheme similar to the RO, but aimed at supporting the government's commitment to reducing GHG emissions from vehicles. Under this scheme, suppliers of transport fuel (who supply at least 450,000 litres pa) are obliged to show that a percentage of the fuel they supply comes from renewable sources. Producers of biofuels of any size can register to claim Renewable Transport Fuel Certificates (RTFCs) which can either be used as evidence of meeting their own obligation, or sold to larger companies in order for them to meet their quota[25].

ADBA state that biomethane derived from wastes and residues are eligible for double the certificates as non-waste derived biomethane. However there is a lack of policy support which prevents the scheme from incentivising biomethane production at this time[24].

### *Climate Change Levy (CCL) Exemption*

This is a tax on non-domestic energy use which aims to incentivise the improvement of energy efficiency. Renewables derived energy used to have an exemption from this tax however this was removed on the 1st August 2015[26].

The ADBA state that this has cost AD electricity operators around £11m per year which is a further strain on finances[27]. However this only affects large scale plants.

[24] (ADBA, 2016)
[25] (UK Government, 2012)
[26] (Ofgem, 2016(e))
[27] (ADBA, 2016)

### *Scotland's Zero Waste Plan*

Scotland implemented the Zero Waste Plan in 2010 to encourage waste to be seen as a resource in order to reduce landfill volume. The current targets which apply to all waste are 70% must be recycled and a maximum of 5% sent to landfill by 2025[28].

This has led to the deployment of food separation schemes, where businesses who generate at least 5kg of waste per week must separate the food waste for collection. There are also food waste bins being rolled out across the domestic sector. This presents some opportunity for AD plants with food waste as a feedstock in the future, however as the ADBA point out, this service is rolling out at negligible levels which is restricting the market[29].

### *Manure Management Policy*

ADBA point out in their July 2016 Market Report that the government provide little incentive for agriculture to use manure for AD despite nearly 5 million tonnes of $CO_2e$ GHG emissions per year from livestock. With the degression of tariff rates for smaller scale AD plants, it is unlikely that there will be significant progression in manure management[29].

## 2.12 UK AD Industry Overview

As can be seen from the history of AD in *Table 2*, the process of producing biogas is well understood and utilised across a wide range of industries including waste water, agriculture and the food and drinks industries. The technology is well proven.

*Figure 7* shows the cumulative installed capacity of AD plants in the United Kingdom from 2010 until now[30]. April 2010 was when the Feed in Tariff (FIT) incentive scheme was introduced to encourage investment in renewable energy technologies to help the government meet their climate change targets.

[28] (Scottish Government, 2013)
[29] (ADBA, 2016)
[30] (DECC, 2016)

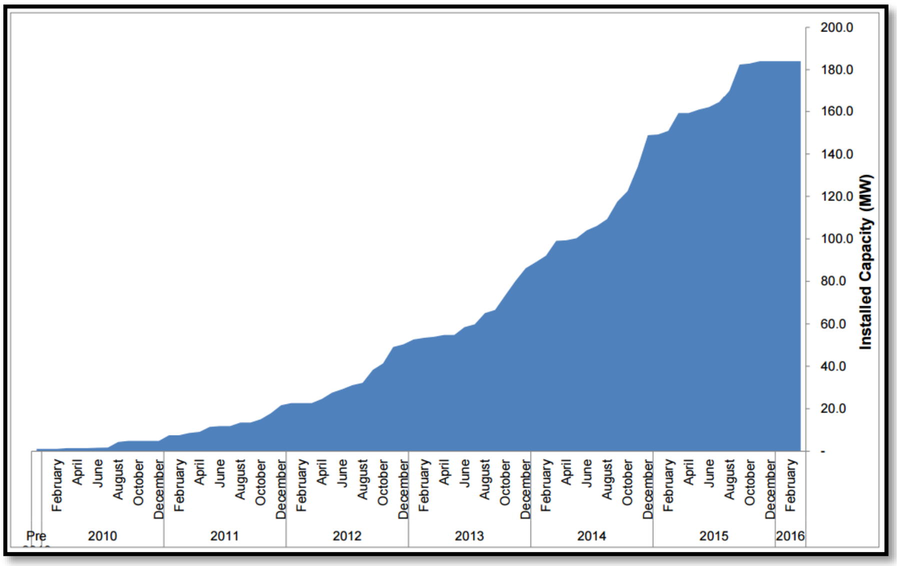


Figure 7 – Cumulative Commissioned Installed AD Capacity UK

Although this appears to show a high level of capacity, it is important to put this figure into perspective in terms of the annual electrical demand of the UK. In 2015, the total annual electrical demand of the UK was 360TWh[31]. With an installed capacity of 180MW, this provides 980GWh[32] with a load factor of 62.2%, which equates to under 0.3% of the total annual demand. This only considers electricity generation, however the biogas can also be used for thermal energy.

As of July 2016, there are a total of 327 AD sites in the UK (excluding sewage works). There are 486 sites including sewage works. A breakdown of sites by feedstock sector can be seen in *Figure 8*. It shows a steep increase in agricultural plants, which results in the overtaking of sewage plants in 2014. However it is expected that growth will slow across all sectors from 2017 onwards.

[31] (UK Government, 2016(d))
[32] (UK Government, 2016(e))

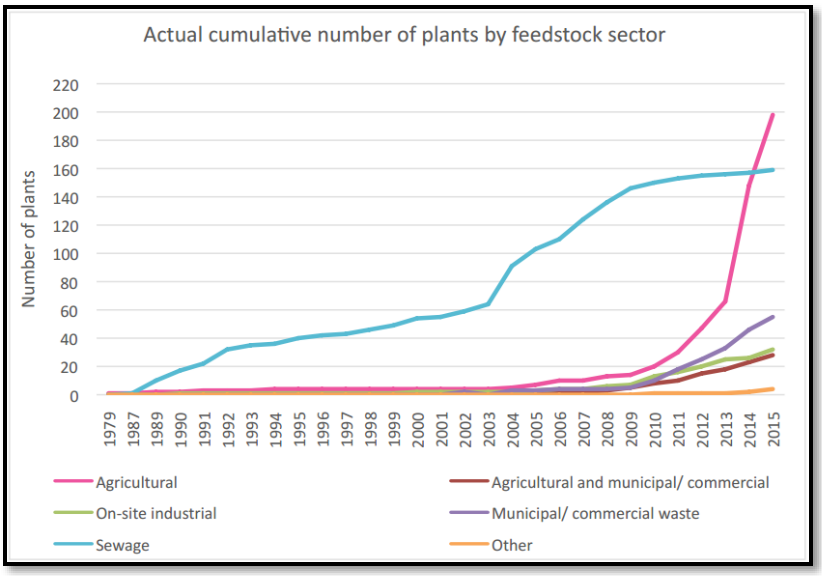


Figure 8 – UK AD Plants by Feedstock

Excluding extensions to existing plants, there is a total of 322 approved planning applications as well as 96 further planning applications pending approval. This could take the total number of plants in the UK up to 745 (excluding sewage works)[33].

## 2.13 AD use in the Whisky Industry

The by-products of whisky production are proven to be suitable for anaerobic digestion. Due to the energy intensive process of whisky distilling and the increasing need to lower carbon emissions, distilleries are beginning to incorporate efficiency improving and sustainable solutions into their processes, including anaerobic digestion of by-products. This is supported by the Scotch Whisky Association's (SWA) goals to source 20% of their primary energy requirement from non-fossil fuels by 2020, which is then to rise to 80% by 2050[34]. A progress report[35] highlights that in 2015 the whisky industry GHG emissions were 756,000 $tCO_2e$.

The following is a list of some examples of AD in distilleries in Scotland.

### *Roseisle*

Roseisle is a Diageo owned distillery in Morayshire which was built in 2010, producing around 11 million litres of whisky per year. It was the first new malt whisky distillery

[33] (ADBA, 2016)
[34] (Scotch Whisky Association, 2016)
[35] (Scotch Whisky Association, 2015)

to be built in Scotland in 30 years, as well as the first to include an on-site renewable energy plant. The plant uses the distillery's dried draff in biomass boilers and treats the pot ale and spent lees with AD for biogas, producing 50% of its energy demands from renewable energy. The project is said to have cost £17 million in capital.

### *Glenfiddich*

Again, a Diageo owned whisky distillery in Moray, with an AD plant in operation since 2015. Here, both the draff and liquid by-products are pumped away from the distillery to the AD site where they are converted to biogas. It is not clear how the biogas is being used, but the plans which were approved stated the options of either cleaning it to pump into the mains gas grid, or using in a CHP system where the electricity would mainly be exported to the grid and heat being used at the distillery. The residues from the digester were planned to be sold and used as fertiliser.

### *Dailuaine*

This is another Diageo distillery in Moray. In operation since 2013, they use high rate digestion to treat the liquid by-products. Producing 0.5MW of biogas, this facility provides 40% of the electrical demand through CHP and reduces the $CO_2$ emissions by around 250 tonnes per year. The digestate is used by farmers as a solid bio-fertiliser. The project is said to have cost around £6 million in capital.

### *Glendullan*

This AD plant was a follow on from the Dailuaine, using the same type of high rate digestion system using liquid by-products. It produces about 2,000,000$m^3$ of biogas per year, which provides 8,000MWh of thermal energy for use at the distillery.

### *North British*

Situated in Edinburgh, North British Distillery operate a £6 million high rate liquid by-product processing AD plant. 24,000MWh of biogas is produced which is used in a CHP system providing heat and power for the distillery. It has resulted in a 9000 tonne/year $CO_2$ reduction which is the equivalent of removing 3000 cars from the road.

### *Cameronbridge*

This is the largest distillery in Scotland, again owned by Diageo. It now incorporates a £65 million bio-energy facility which includes biomass, AD and water recovery. It is estimated to produce up to 30MW of energy which meets around 95% of the distillery's demands.

### *Girvan*

The Girvan distillery, situated in South Ayrshire, is owned by William Grant & Sons. With a £15 million capital investment, the project produces biogas from the distillery's liquid by-products, meeting the 4.8MW demand with a further 2MW being exported to the electricity grid. The heat recovered from the CHP system meets around 10% of the thermal demand. It is expected that the investment will be paid back after only 4 years.

In most of these cases, it is only the liquid by-products which are used for biogas production. This may be due to the location of the distilleries;

- First of all there may not be the space required for a larger digester which would be needed for the digestion of draff compared to the high rate digester which can be used for liquid feedstocks alone. Note that Glenfiddich is the only distillery mentioned above which treats both draff and pot ale with AD and they pump these by-products away from the distillery, to the location of the AD plant. This could be due to space available at the distillery itself.
- Another reason may also be due to the requirement for waste water treatment. If it is not possible to discharge the pot ale to sea due to distance, then it is often put through the energy intensive process of evaporation to convert it to pot ale syrup, which can then be used as animal feed. Anaerobic digestion of pot ale provides an alternative option, which creates energy rather than consuming, and has the desired effect of reducing the Chemical Oxygen Demand (COD) enough to allow the disposal of the resultant liquid straight into fresh water streams with no detriment to the environment.

These may be the reasons for the majority to choose high rate digestion systems over continuous stir digesters for both by-products. However draff also has the potential to create biogas and if the conditions are suitable then it could be worthwhile exploiting the additional energy.

# 3.0 Islay Study

## 3.1 Islay General Info

Islay is an island of the Inner Hebrides, off the West Coast of Scotland. It measures approximately 40km by 25km and has a land area of 619.6km$^2$.

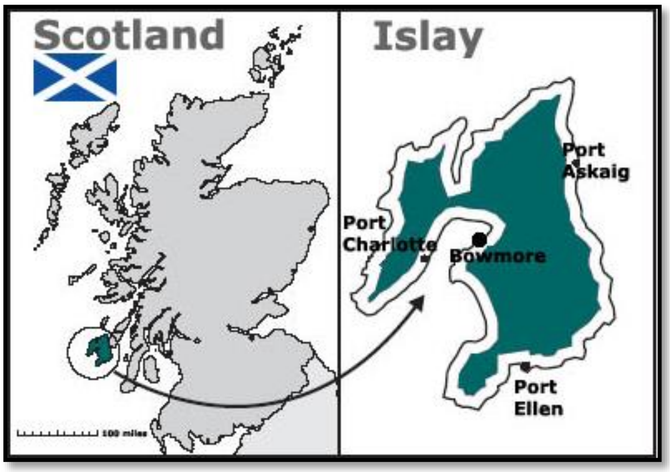


Figure 9 – Isle of Islay Location[36]

As per the last census taken in 2011[37], the total population of the island was 3,153 with 1,442 households. This gives a population density of 5.1 people per square kilometre.

As displayed in *Table 6*, the areas of highest population density are the villages of Port Ellen, Bowmore and Port Charlotte, with the rest of the population spread around the other areas of the island.

**Table 6 – Islay Population Distribution**

| Area | Population | No. of Households |
|---|---|---|
| Port Ellen | 846 | 390 |
| Bowmore | 797 | 355 |
| Port Charlotte | 103 | 45 |
| West Islay | 657 | 312 |
| North Islay | 417 | 196 |
| South Islay | 333 | 144 |

The main industries on Islay include whisky, tourism and agriculture. Whisky distilling is the predominant industry, with 8 single malt Scotch whisky distilleries on the island. This brings in a lot of tourism directly, and holiday homes are abundant as a result.

[36] (Islay Info, 2016)
[37] (Scottish Government, 2011)

Agriculture accounts for the main land use, including both crofting and more modern farming techniques. Dairy farming used to be common practice until the closure of the Islay Creamery in 2000. There is now only one dairy farming remaining which sells its products locally.

There is a mains electricity grid connection via neighbouring island Jura, which has a connection to the mainland. However there is no gas network connection.

### *Islay Energy Trust (IET):*

A community owned energy trust exists with the aim of developing renewable energy projects to serve the community whilst also reducing their carbon footprint. They operate small to medium renewable energy projects such as wind and biomass, as well as entering into partnerships with renewable energy developers for larger scale projects. They are currently working with ScottishPower Renewables (SPR) to develop the 10MW Sound of Islay Tidal Energy project. This is a demonstration project, which will consist of 10 off 1MW turbines submerged on the seabed between Islay and Jura. Other activities include carbon savings projects, which focus on energy efficiency with the aim of reducing fuel bills[38].

## 3.2 Islay Whisky

### *History*

It is said that distillation techniques were brought to Islay in the early fourteenth century by the Irish monks. The abundance of fresh water from lochs and rivers as well as peat made the island an ideal location for the production of whisky.

In the past, most of the whisky produced was for blends, but with the increase in global market for single malts this has seen a far greater percentage of single malt production in more recent years. To call the produced spirit ‘whisky’, it must be matured for a minimum of 3 years in oak casks. To call the whisky ‘Scotch whisky’, it must be made in Scotland. This means that the global demand for mature Scotch whisky is much higher than supply can withstand and thus increases the value considerably.

[38] (IET, 2012)

### *Production*

Today there are 8 operational distilleries on Islay and one maltings. Each of the distilleries were contacted to find out their annual whisky production levels in litres per year with the results displayed in *Table 7*. The total annual production on the island exceeds 16 million litres.

| Table 7 – Whisky Production | |
|---|---|
| **Distillery Name** | Annual Whisky Production (litres) |
| Ardbeg | 1250000 |
| Laphroaig | 2200000 |
| Lagavulin | 2400000 |
| Bruichladdich | 1350000 |
| Bunnahabhain | 1600000 |
| Bowmore | 1300000 |
| Caol Ila | 5800000 |
| Kilchoman | 175000 |
| **Total** | **16,075,000** |

### *Energy use*

Due to the intensive energy required during evaporation, whisky distilleries have very high thermal energy requirements.

When the distilleries were contacted, they were asked to provide annual energy use figures, however they declined to participate in this exercise. Last year, a study[39] was conducted which draws a correlation between annual whisky production and energy demand figures. In the absence of data specific to Islay distilleries, the results from this study have been used to aid this conceptual study with the view that results could be refined in the future with real data.

In last year's study, values were obtained for total energy demand as well as electrical demand for 9 distilleries of varying production levels. Here, the electrical demand was removed from the total value to obtain the remaining thermal energy required as this is the value of most interest here. The electrical energy has less of a dependence on annual

[39] (Meadows, 2015)

production levels as this can be attributed to size of offices or any other number of aspects. As fuel oils are used as the heating source, this is the energy which biogas will be offsetting.

Not only will the offsetting of fuel oil benefit the environment, but it will protect the businesses from fuel supply issues. It has been reported on a number of occasions that there have been supply issues, with winter weather or extreme low tides causing problems for the supply vessels delivering the fuel to the pier resulting in the island supply running low and some of the distilleries being forced to halt production temporarily. Although this problem could be resolved by delivery of fuel oil by road tanker via ferry, it highlights the issues of a remote location relying on imports and the detrimental effect these kinds of problems can have.

See *Appendix A: Energy Values* for the background data which was used to determine Islay specific figures.

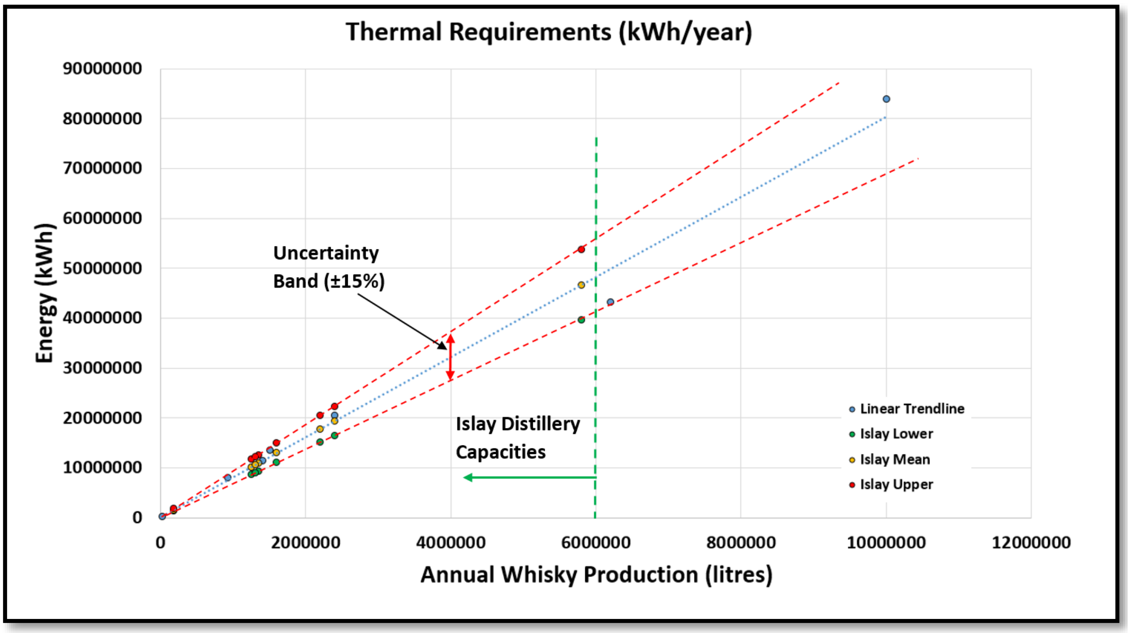


Figure 10 – Annual Whisky Production V Thermal Energy Requirements

*Figure 10* shows the linear relationship between volume of whisky produced in a distillery per year, and total thermal energy required per year (blue data points and trend line come from the past thesis[40]). The red dashed lines indicate uncertainty bands of +/-15% to supply an upper and lower value to cover both ends of the spectrum in lieu of

[40] (Meadows, 2015)

real data. To the left of the green dashed line is the area of the graph from which Islay distillery values will be taken. The orange data points are energy values corresponding to the whisky production levels of the 8 Islay distilleries which lie exactly on the dashed blue trend line, with green and red data points showing the lower and upper values respectively.

| **Thermal Requirements** | | Lower | Mean | Upper |
|---|---|---|---|---|
| Distillery | Whisky Production (l/year) | Heat (MWh/year) | Heat (MWh/year) | Heat (MWh/year) |
| Ardbeg | 1250000 | 8663 | 10191 | 11720 |
| Laphroaig | 2200000 | 15145 | 17818 | 20490 |
| Lagavulin | 2400000 | 16510 | 19423 | 22337 |
| Bruichladdich | 1350000 | 9345 | 10994 | 12643 |
| Bunnahabhain | 1600000 | 11051 | 13001 | 14951 |
| Bowmore | 1300000 | 9004 | 10593 | 12182 |
| Caol Ila | 5800000 | 39711 | 46718 | 53726 |
| Kilchoman | 175000 | 1327 | 1561 | 1795 |
| **Total** | 16075000 | 110755 | 130300 | 149845 |

Table 8 – Thermal Demand Estimations: Islay Distilleries

The capacity of boiler which would be required at each distillery can be calculated by assuming a 50% load factor. It is not known what the specific load factors of the Islay distilleries are, but information available regarding Balmenach distillery in Speyside shows that a 4MW capacity biomass boiler provides the full requirement of 18,000MWhth per year which works out at a 51.4% load factor[41].

Identifying the capacities allows the correct RHI tariff to be assigned based on the size of boiler which would be used. *Table 9* lists these results.

| **Distillery** | **Whisky Production (l/year)** | **Boiler Capacities (kWth)** | | | **Biogas RHI Category** | **Biomass RHI Category** |
|---|---|---|---|---|---|---|
| | | Lower | Mean | Upper | | |
| Ardbeg | 1250000 | 1978 | 2327 | 2676 | Large | Large |
| Laphroaig | 2200000 | 3458 | 4068 | 4678 | Large | Large |
| Lagavulin | 2400000 | 3769 | 4435 | 5100 | Large | Large |
| Bruichladdich | 1350000 | 2134 | 2510 | 2887 | Large | Large |
| Bunnahabhain | 1600000 | 2523 | 2968 | 3414 | Large | Large |
| Bowmore | 1300000 | 2056 | 2418 | 2781 | Large | Large |
| Caol Ila | 5800000 | 9066 | 10666 | 12266 | Large | Large |
| Kilchoman | 175000 | 303 | 356 | 410 | Medium | Medium |

Table 9 – Boiler Capacity Requirements

[41] (Scottish Energy News, 2013)

Electricity demands are estimated in the same way, shown in *Figure 11*, with upper and lower values taken from ±15% of the previous study results. The mean electrical energy demand has been used to identify which non-domestic electrical demand category each distillery falls under to determine costs per unit of electricity, as shown in *Table 10*. Each 'size' category of consumer has a different rate. This is required when assessing the financial feasibility of the scenarios as there may be additional electrical demands required depending on the setup. To simplify this aspect, only the mean values will be considered.

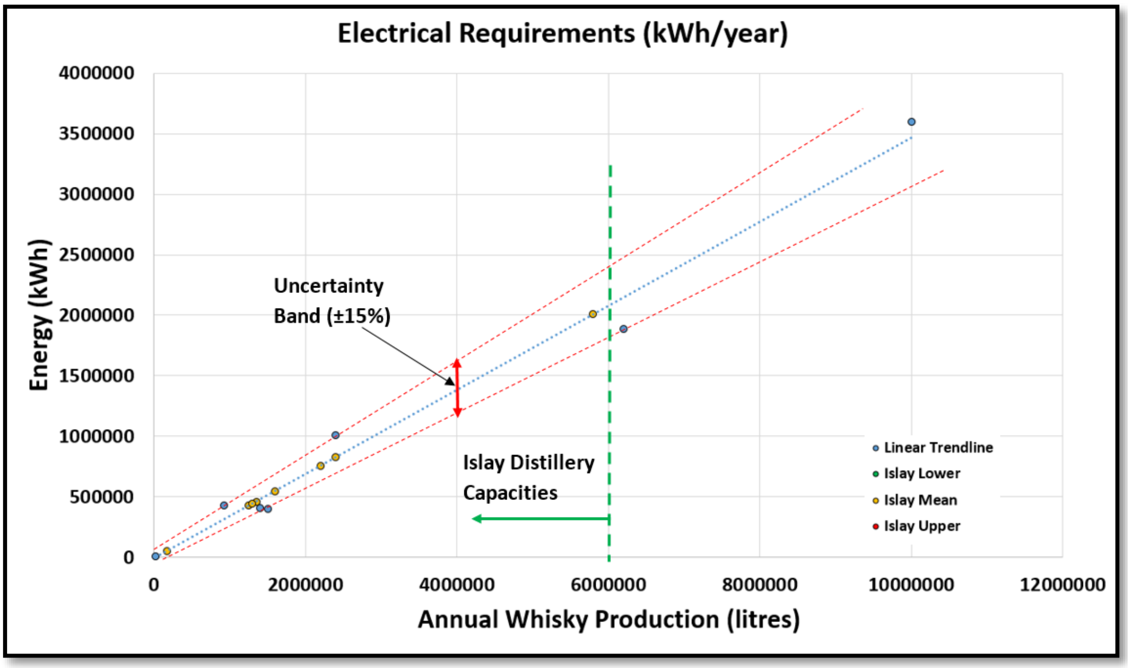


Figure 11 – Annual Whisky Production V Electrical Energy Requirements

By plotting points on the linear trend line which correspond to the annual whisky production of the distilleries on Islay, estimated mean electrical demands and therefore size categories[42] can be identified. These are shown in *Table 10*.

[42] (UK Government, 2016)

| Table 10 – DECC Size of Electrical Consumer | | |
|---|---|---|
| **Distillery** | **Mean Electrical Demand (MWh/year)** | **Size of Consumer** |
| Ardbeg | 427 | Small |
| Laphroaig | 757 | Small/Medium |
| Lagavulin | 827 | Small/Medium |
| Bruichladdich | 462 | Small |
| Bunnahabhain | 549 | Small/Medium |
| Bowmore | 445 | Small |
| Caol Ila | 2008 | Medium |
| Kilchoman | 54 | Small |

These category assignments will be referred back to in the financial analyses.

It should be noted here that the electrical demand only makes up around 4% of the total demand, as graphically represented in *Figure 12*. This further emphasises the benefit of focusing on offsetting the thermal energy supply rather than the electricity as a far greater overall benefit can be achieved by doing so.

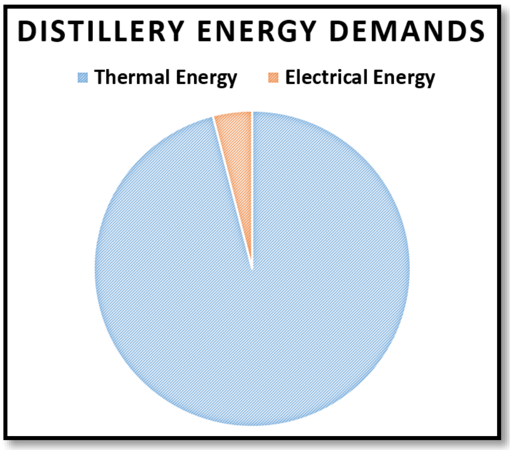


Figure 12 – Distillery Energy Demands

## *By-products*

The by-products from whisky production are draff, which is the spent grain and pot ale, which is the liquor left in the wash still after distillation. Using the same study as previously mentioned[43], quantities of draff and pot ale from each distillery were plotted

[43] (Meadows, 2015)

on a graph with +/- 15% uncertainty margins in order to obtain best and worst case scenario values for Islay. *Figure 13* displays the draff values obtained from this study as blue dots, with the blue dashed linear trend line forming the estimated mean values for the Islay distilleries, values listed in *Table 11*. The same method was applied for pot ale and shown in *Figure 14* and *Table 12*.

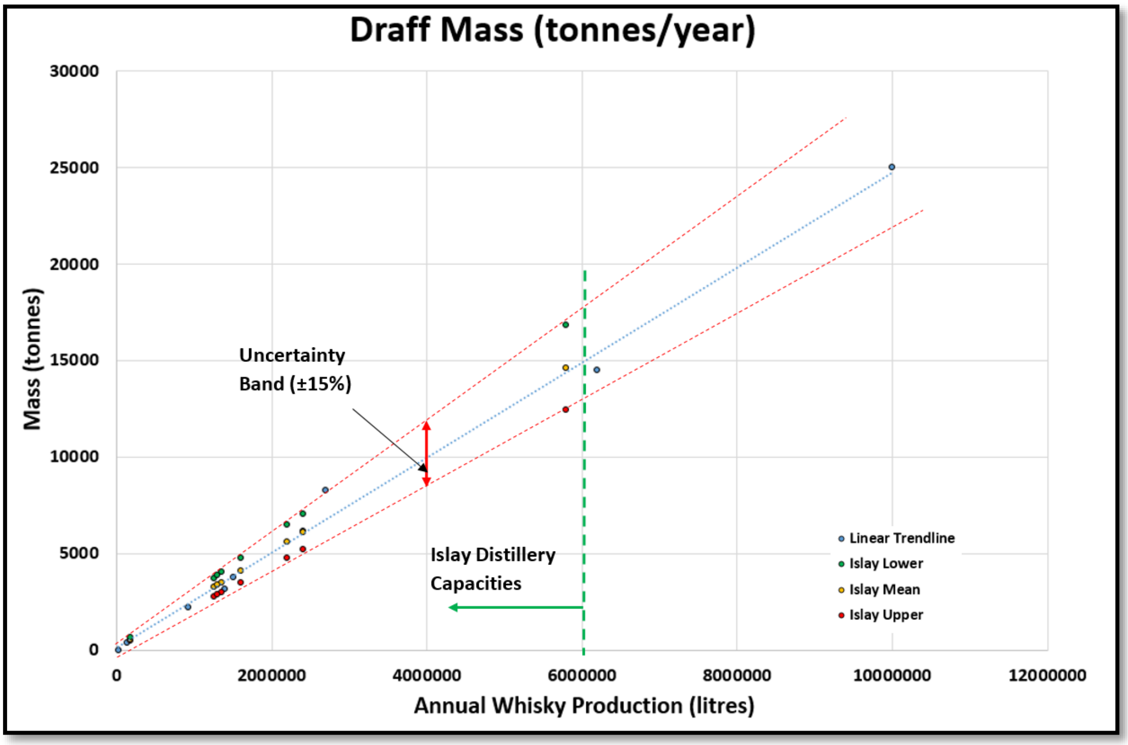


Figure 13 – Annual Draff Weight V Whisky Production

| Draff Mass | | Lower | Mean | Upper |
|---|---|---|---|---|
| Distillery | Whisky Production (l/year) | Draff (tonnes/year) | Draff (tonnes/year) | Draff (tonnes/year) |
| Ardbeg | 1250000 | 2762 | 3250 | 3737 |
| Laphroaig | 2200000 | 4781 | 5625 | 6468 |
| Lagavulin | 2400000 | 5206 | 6125 | 7043 |
| Bruichladdich | 1350000 | 2975 | 3500 | 4025 |
| Bunnahabhain | 1600000 | 3506 | 4125 | 4743 |
| Bowmore | 1300000 | 2869 | 3375 | 3881 |
| Caol Ila | 5800000 | 12431 | 14625 | 16818 |
| Kilchoman | 175000 | 478 | 562 | 647 |
| **Total** | 16075000 | 35008 | 41186 | 47363 |

Table 11 – Yearly Draff Weight Estimations for Islay Distilleries

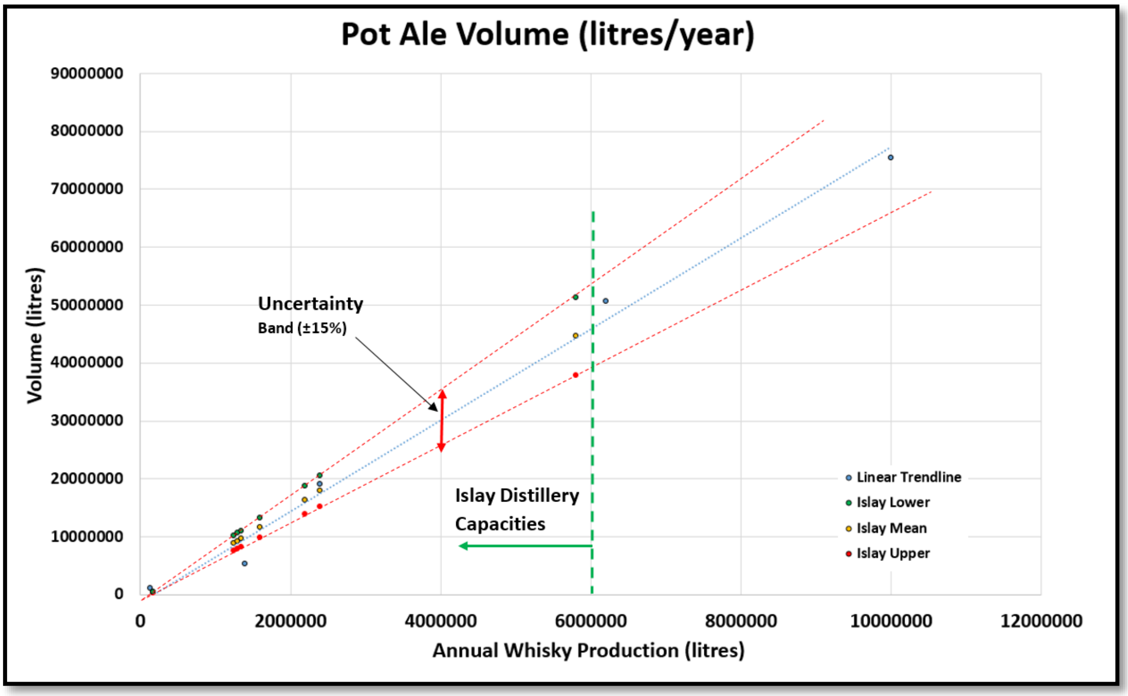


Figure 14 – Annual Pot Ale Volume V Whisky Production

| Pot Ale Volume | | Lower | Mean | Upper |
|---|---|---|---|---|
| Distillery | Whisky Production (l/year) | Pot Ale (litres/year) | Pot Ale (litres/year) | Pot Ale (litres/year) |
| Ardbeg | 1250000 | 7497744 | 8820875 | 10144006 |
| Laphroaig | 2200000 | 13842029 | 16284740 | 18727451 |
| Lagavulin | 2400000 | 15177668 | 17856080 | 20534492 |
| Bruichladdich | 1350000 | 8165563 | 9606545 | 11047527 |
| Bunnahabhain | 1600000 | 9835112 | 11570720 | 13306328 |
| Bowmore | 1300000 | 7831654 | 9213710 | 10595767 |
| Caol Ila | 5800000 | 37883531 | 44568860 | 51254189 |
| Kilchoman | 175000 | 318684 | 374923 | 431161 |
| **Total** | 16075000 | 100551985 | 118296453 | 136040920 |

Table 12 – Yearly Pot Ale Volume Estimations for Islay Distilleries

The equivalent mass of the pot ale can be calculated by assuming the density of pot ale is the same as that of water; $\rho = 1000$ kg/m$^3$.

Out of the eight distilleries, one did respond with by-product quantities. Bowmore gave annual by-product quantities which fall within the above estimated ranges. This gives an element of validation to the logic employed.

Other general waste water is also produced in abundance during the whisky distilling process as highlighted in last year's study[44].

Currently, the draff is sold to an animal feeds company who take responsibility of it from the door of the distilleries. It is transported off the island via ferry and processed into a marketable product for farmers' livestock. These are longstanding contracts which may cause a barrier when it comes to changing current practices to use draff as an anaerobic digestion feedstock.

The pot ale is discharged to sea from the discharge point at Caol Ila, which is transported to this point by road tanker from the other distilleries. The case used to be that the pot ale was discharged straight into the sea from each of the distilleries, however this changed due to the EU 'Urban Waste Water Treatment' Directive. Because of the use of copper stills, pot ale contains trace elements of copper. For this reason, it must be discharged in such a way that prevents the accumulation of pot ale in the sea, which is possible by making use of naturally fast flowing currents such as the sound of Islay. When discharged here, the water carries the pot ale far out to sea and disperses it which prevents a build-up in any specific areas and therefore reduces the risk of pollution. However, this is a fairly contentious point as it could be argued that the added pollution caused by the need for high levels of continual road transport may outweigh the benefits of this activity. Further to this, some studies suggest that the peat of the soil on Islay helps to neutralise the negative effect of the copper and even goes as far as to suggest that the pot ale could be environmentally beneficial. Either way, the pot ale is currently not put to use, and therefore would be available for use as a feedstock for anaerobic digestion.

## 3.3 Available Feedstocks on Islay

Whisky by-products are to be considered as the primary feedstock, with the potential for additional sources being added to optimise the system.

First of all, there is no food waste separation and collection system on Islay. Therefore food waste goes in the general waste bins and is sent to landfill (or composted). An estimation can be made as to the weight of domestic food waste based on the figure of

[44] (Meadows, 2015)

1,442 households. A study conducted by WRAP[45] estimates that the average food waste per household per year is 270kg. Of this, 170kg/year is 'avoidable' waste, i.e. food that could otherwise have been eaten if managed better, with 'unavoidable' waste being items such as meat bones and tea bags which could not be consumed. It is difficult to make an estimation for Islay without conducting a specific analysis of their waste, however for this study it is to be assumed that due to inflated prices because of the remoteness of the location, food may be better managed than the average household and therefore less avoidable waste will be experienced. This will also avoid overly optimistic calculations. So it is assumed that unavoidable waste remains at 100kg/household/year and a value of 50% of the national average for avoidable waste, equalling 85kg/household/year which gives a total of 185kg/household/year of food waste on Islay. Therefore the yearly quantity of food waste to be used for calculations is 267 tonnes based on there being 1442 households. This does not include any commercial food waste which gives further confidence that the figure is not higher than realistically expected. There are over 30 cafes, restaurants and take-aways on Islay[46], as well as 3 schools and a hospital which all contribute to food waste totals

Fishing industry waste was considered, however the vast majority is shellfish (crab, lobster and scallop fishing). Most of this is exported, leaving no waste on site as it is shipped live. Anything processed locally produces only shells which are used for drainage. So there does not appear to be any potential from fishing for AD feedstock.

Farming has been difficult to quantify due to lack of contacts, however given the area of land available, a backward calculation approach can be taken to identify the yield of crops required to produce a specific volume of biogas.

## 3.4 AD System Selection for Islay

Draff and pot ale could be treated in separate digesters, with pot ale being treated in an upflow anaerobic sludge blanket digester and the draff in a continuous flow stirred tank digester. This would speed up the digestion process for the pot ale, allowing for a

[45] (WRAP, 2008)
[46] (Islay Info, 2016)

smaller digester to be used. However it would require higher capital costs for 2 separate digesters and a UASB requires stricter control, with higher risk of problems occurring.

Therefore the selected digester type for Islay would be a single continuous flow stirred tank, with the draff and pot ale mixed as a slurry and pumped directly to the site from the distilleries. This is an additional benefit of this system, which removes the requirement to separately transport the draff by road. It should also be noted here that if a slurry mix has over ~8% TS, then pumping can become more difficult, therefore this characteristic must be evaluated.

The system can be sized for the primary feedstocks, and also sized to include other additional feedstocks as available as a comparison.

## 3.5 Location

The location of each distillery was mapped and a central location selected around the area of Bridgend. This results in 3 'clusters' of distilleries, where their by-products can be accumulated and pumped together through 3 single pipes.

Using Google Maps, the distances between each distillery and the central location were obtained, as well as the height differentials. Note that these are the distances via road i.e. they provide conservative values due to the high agricultural area on Islay which means shorter, more direct routes would most likely be possible. *Figure 15* shows the locations and general piping routes, with *Table 13* listing the distances.

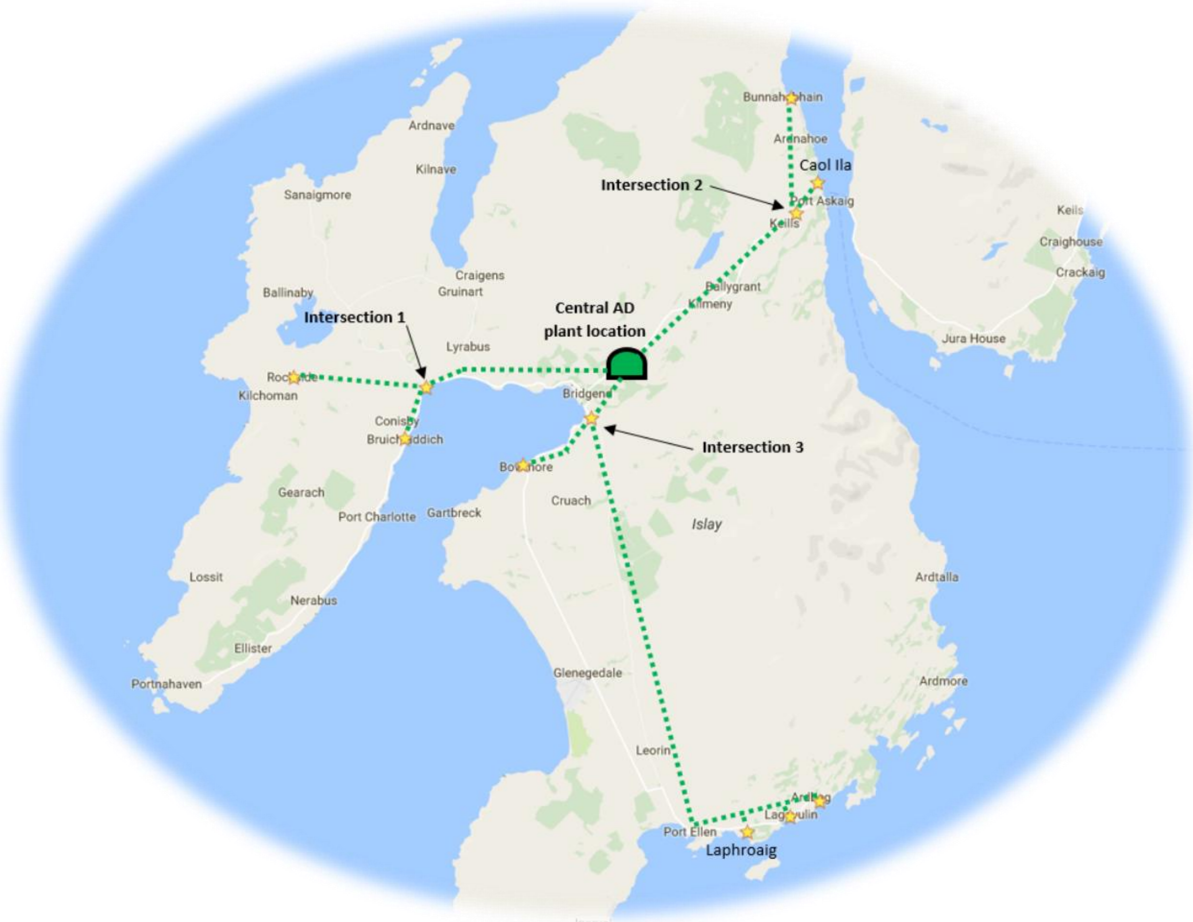


Figure 15 – Map of Distilleries and Pipe Routes

| Grouping | From | To | Distance (km) | Differential Height (m) |
|---|---|---|---|---|
| 1 | Kilchoman | Intersection 1 | 7.24 | -23.7744 |
| | Bruichladdich | " | 2.25 | 0 |
| | Intersection | Bridgend | 6.92 | 0 |
| 2 | Bunnahabhain | Intersection 2 | 5.79 | 53.0352 |
| | Caol Ila | Intersection 2 | 1.45 | 51.816 |
| | Intersection | Bridgend | 11.10 | -53.9496 |
| 3 | Ardbeg | Lagavulin | 1.77 | 0 |
| | Lagavulin | Laphroaig | 1.77 | 0 |
| | Laphroaig | Intersection 3 | 19.31 | -7.0104 |
| | Bowmore | Intersection 3 | 3.54 | 0 |
| | Intersection | Bridgend | 1.13 | 0 |
| | | **Total** | **62.28** | **20.12** |

Table 13 – Distances between Distilleries to Central Location

It has been calculated that the draff and pot ale can be pumped together as a single slurry. If the overall dry matter of the slurry mix is higher than 8%, then general waste water can be added to dilute it down.

*Table 14* shows the range of values which have been calculated for each distillery, covering best and worst case scenarios. The best case assumes highest value of pot ale and lowest value of draff, i.e. lowest percentage of dry matter overall. The worst case assumes lowest value of pot ale and highest value of draff, i.e. highest percentage of dry matter overall. The column on the end shows the maximum additional water which would be required to bring the overall percentage dry matter down to 8% based on worst case conditions occurring in order to make pumping of slurry easier.

| **Dry Matter** | Worst Case | Mean | Best Case | Max. additional water required (l) |
|---|---|---|---|---|
| Distillery | % DM (TS) | % DM (TS) | % DM (TS) | |
| Ardbeg | 10.14 | 9.04 | 8.09 | 3007267 |
| Laphroaig | 9.90 | 8.83 | 7.90 | 4813744 |
| Lagavulin | 9.87 | 8.80 | 7.88 | 5194054 |
| Bruichladdich | 10.10 | 9.00 | 8.05 | 3197422 |
| Bunnahabhain | 10.02 | 8.93 | 7.99 | 3672811 |
| Bowmore | 10.12 | 9.02 | 8.07 | 3102345 |
| Caol Ila | 9.71 | 8.66 | 7.76 | 11659339 |
| Kilchoman | 15.98 | 14.77 | 13.49 | 963096 |
| Total | 9.93 | 8.85 | 7.92 | 35610079 |

Table 14 – Dry Matter of Slurry from Each Distillery

## *Energy Required to Pump Feedstock*

To calculate the energy required to pump the mixture of pot ale and draff to the central plant, the volumetric flowrates (Q), overall mixture density (ρ) and differential heights (h) for each of the pipe sections are required. Pump ($\eta_p$) and motor ($\eta_m$) efficiencies are both also required.

First of all, head loss due to friction must be calculated. Using a frictional factor (f) of 0.0145 obtained from the Moody Diagram[47], a pipe diameter (d) of 70mm, and the relevant length (L) of pipe per section, the following equation can be used:

$$h_f = \frac{fLQ^2}{3.03d^5} \ (m)$$

[47] (University of Leeds, 2012)

This identified the head loss for each section of pipe due to friction, which when summed up comes to 353m, i.e. the friction in the pipes has the effect of having to raise the quantity of liquid a further 353m vertically. The majority of the routes are either flat of downhill, with only a couple of uphill sections which helps the case.

The hydraulic power ($P_h$) can then be calculated, which is the power absorbed by the slurry in order to move it from one location to another. The general equation used to calculate hydraulic power is as follows:

$$P_h = Q\rho g(h + h_f)\ (kW)$$

This was calculated individually for each section of the routes and totalled at the end.

Next, the shaft power ($P_s$) can be calculated. This is the power supplied by the motor to the pump shaft, and is the sum of the hydraulic power and the losses due to inefficiencies from the shaft to the feedstock. This can be calculated as follows:

$$P_s = \frac{P_h}{\eta_p}\,(kW)$$

Finally, the motor power ($P_m$) can be calculated. This is the power consumed by the motor to turn the pump shaft and the sum of the shaft power and losses due to inefficiencies in converting electricity to kinetic energy. This can be calculated as follows:

$$P_m = \frac{P_s}{\eta_m}\,(kW)$$

Centrifugal pumps are commonly used for pumping of slurry and have an overall efficiency ($\eta_p * \eta_m$) in the range of 60-85%. Assuming mid-range efficiency centrifugal pumps were to be employed in this case, an overall efficiency of 72.5% has been used.

The results of these calculations can be seen in *Table 15* which gives lower, mean and upper values which relate to the range of estimated values of distillery by-product quantities. The energy required per year shows the amount of electricity which will be required to run the pumps, either from the grid or from biogas produced electricity.

| Table 15 – Power and Energy Requirements for Pumping Feedstock. | |
|---|---|
| Total Head Loss | 354m |
| Total Hydraulic Power | 8.1kW |
| Total Motor Power | 11.1kW |
| Total Energy Required | 98MWh/year |

This is a highly complex and sensitive calculation, relying on many specific pieces of data which are only estimated here. Exact properties are vital for accuracy as results will differ depending on whether the calculations are modelled for a settling or non-settling slurry and also for newtonian or non-newtonian fluids.

Not only are the properties of the slurry estimated, but the actual pipe design plays a large role in the results also. In reality, the design of the pipe would be specified in such a way that the frictional forces are kept to a minimum. A balance needs to be met between achieving the required velocities to obtain the high Reynold's number which would keep the slurry suitably mixed with turbulent flow, as well as selecting the most suitable pipe diameter to reduce friction. Pipe routes can also be chosen to avoid particularly hilly sections which may increase the length of pipe etc.

So although there is a wide range of potential energy requirements for this activity, it is assumed that the careful design of the piping system would achieve the lowest result possible.

It is accepted that this is a weakness in the overall study, which is far more complex to investigate than time allows for. However as a minimum, it is known that it is possible to pump a slurry of draff and pot ale as this is already carried out at the Glenfiddich distillery as previously mentioned.

# 4.0 Analysis

## 4.1 Energy Analysis Values

### *Energy from Biogas*

Based on the estimated best and worst case feedstock quantities, it is possible to calculate total potential biogas yields from anaerobic digestion of the feedstock. Refer to *Appendix C: Energy Analysis Calculations* for MathCAD working. The following tables provide the results from these calculations.

For food waste, this has been estimated in a more general sense due to the lack of data specific to Islay food waste. Without this data it is not possible to perform more detailed calculations, therefore biogas yield data tables were consulted and a value of 110m$^3$ of biogas per tonne of fresh food waste has been assumed[48], giving a total of 29,370m$^3$ of biogas per year. At 55% methane content, this results in 16,154m$^3$ per year.

| **Biogas Yield (m^3/year)** | Lower | Mean | Upper |
|---|---|---|---|
| Pot ale only | **2620486** | **3082912** | **3545365** |
| Draff only | **4055138** | **4770764** | **5486274** |
| Pot ale and draff total | **6675623** | **7853676** | **9031639** |
| Including Food Waste | **6704993** | **7883046** | **9061009** |

Table 16 – Biogas Yield Summary

| **Energy (MWh/year)** | Lower | Mean | Upper |
|---|---|---|---|
| Pot ale only | **14413** | **16956** | **19500** |
| Draff only | **22303** | **26239** | **30175** |
| Pot ale and draff total | **36716** | **43195** | **49674** |
| Including Food Waste | **36877** | **43357** | **49836** |

Table 17 – Energy Available Summary

| **Digestate Output (tonnes/year)** | Lower | Mean | Upper |
|---|---|---|---|
| Pot ale only | **90497** | **106467** | **122437** |
| Draff only | **31507** | **37067** | **42627** |
| Pot ale and draff total | **122004** | **143534** | **165064** |
| Including Food Waste | **122244** | **143774** | **165304** |

Table 18 – Digestate Yields Summary

48 (SEAI, 2016)

Note that these values do not yet account for energy required to run the AD plant. They only represent the total theoretical energy/power yields from the quantity of feedstock available.

### *Biogas and Biomass Boilers*

Efficiencies of 90% and 85% are used when calculating the energy output from biogas and biomass boilers respectively. These are general figures provided by a biogas plant owner and biomass specialist, and are used in the analyses for all capacities of boiler.

### *CHP System*

The FIT scheme is changing, with a cap at 500kWe capacity. Therefore no CHP system larger than this will be considered in this study.

The biogas required to run a 500kWhe CHP unit has been calculated, along with the expected electrical and thermal outputs. The datasheet for a 500kWe CHP unit[49] has been consulted for the purpose of using realistic efficiencies. The figures quoted have been graphically displayed in *Figure 16*.

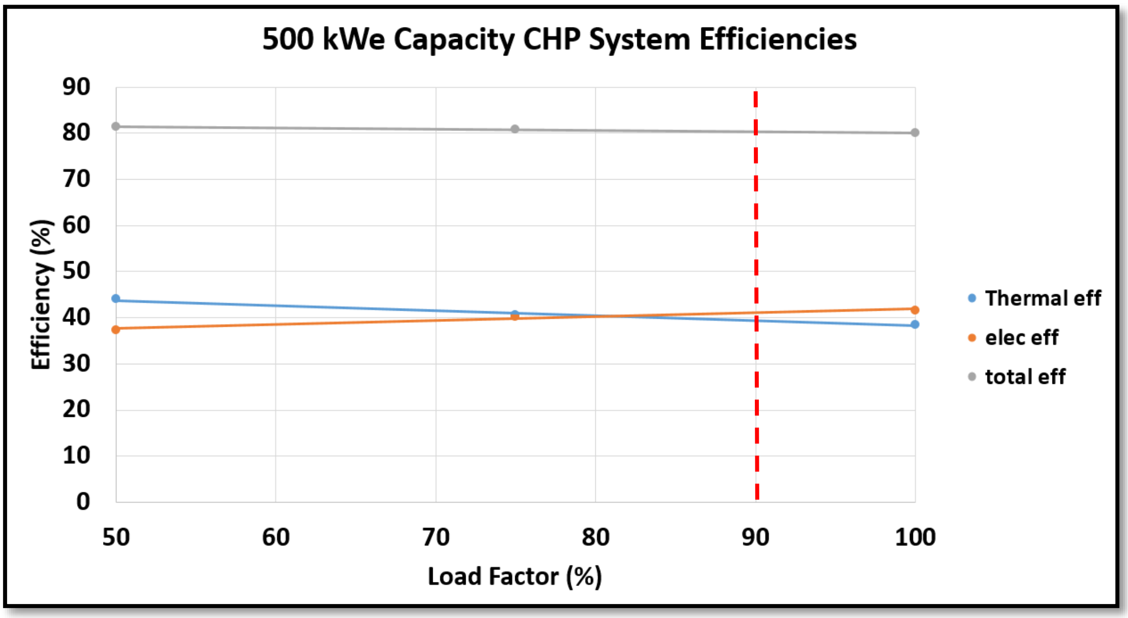


Figure 16 – Efficiencies of Edina CHP Unit

With a 90% load factor, the system will see 39.4% thermal and 41% electrical efficiencies, giving an overall efficiency of 80.4%.

[49] (Edina UK Ltd., 2013)

*Figure 17* summarises the energy outputs from the CHP unit.

The energy content of the biogas input to the system can therefore be calculated as the sum of each of the three outputs which is 9608 MWh.

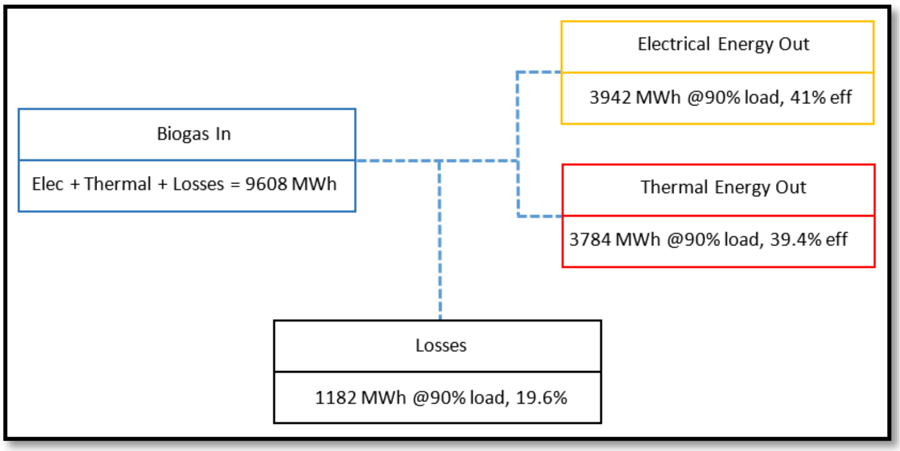


Figure 17 – Biogas Required for 500kWe CHP Unit

The electrical and thermal energy output from the CHP unit will not all be available for other uses as some of it will be required to run the AD plant. Discussions with an AD plant operator highlighted some of the difficulties in predicting these values due to the variations with location (weather most importantly) and insulation of system etc. However as a rule of thumb, it can be assumed that 5% of the electricity generated and 20% of the heat generated goes back into the running of the plant. The useful thermal and electrical energy generated from a 500kWe capacity CHP unit is stated in *Table 19*.

The same method and efficiencies are used for all other capacities of CHP unit.

| **CHP Unit** | | | |
|---|---|---|---|
| **Energy (MWh)** | Generated | Used in Plant | **Useful Output** |
| Thermal | 3784 | 757 | **3027** |
| Electrical | 3942 | 197 | **3745** |

Table 19 – Scenario 2 Summary (CHP outputs)

### *Running of AD Plant*

As detailed in the previous section *CHP System*, the thermal and electrical energy demands of an AD plant have been estimated based on percentages of CHP system outputs for simplicity.

### *Woodchip*

Discussions with a biomass specialist identified that 1 MWh of thermal energy produces 1 tonne of dried woodchip at 25% mc (from the original 'wet' state of 50% mc), with 1 tonne of dried woodchip containing 3.6 MWh of energy.

The source also disclosed that it is usual for a woodchip dryer system to operate for 8000 hours per year. Given that there are 8760 hours per year, this means that they will operate with a 91.3% load factor, which is the value used in this analysis.

### *Sugar Beet*

Due to concerns regarding the food V fuel issue, studies have been conducted to assess energy crop methane yield per hectare. With this information, it is possible to select higher yielding crops per area of land, rather than per weight of crop, so as to minimise the impact on land use change or even simply to keep land use to a minimum. One such study[50] compares the methane yields of 6 energy crops; hemp, sugar beet, maize, triticale, grass/clover ley and winter wheat. The resulting energy yields per hectare are displayed in *Figure 18* with sugar beet giving the best result (for both the root and top) at 160GJ per hectare (44.44MWh/ha). For this study, sugar beet is the selected energy crop.

[50] (Gissen, et al., 2014)

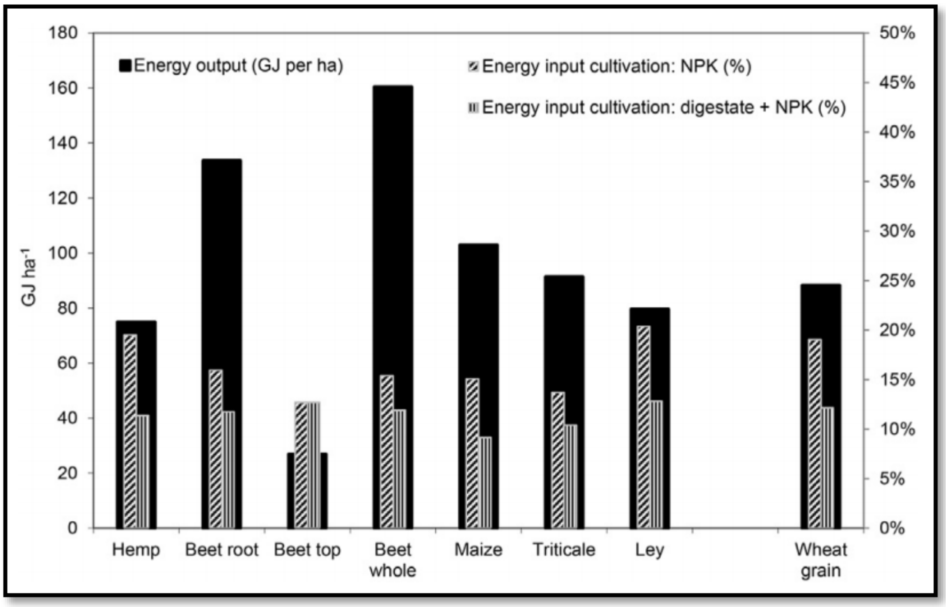


Figure 18 – Energy Crop Energy Yield per Hectare

## 4.2 Financial and Environmental Analysis Values

This section lays out the values which are used across all scenarios for the analysis of both costs and emissions.

### *Cost of Consumables*

**Table 20 – Consumables Costs**

| Item | Value | Unit | Notes |
|---|---|---|---|
| Fuel Oil | 46.02 | p/litre | Note 1 |
| Grid Electricity (small consumer) | 12.18 | p/kWh | Note 2 |
| Grid Electricity (sml/med consumer) | 10.87 | p/kWh | Note 2 |
| Grid Electricity (medium consumer) | 10.01 | p/kWh | Note 2 |
| Sugar Beet | 2,304 | £/hectare | Note 3 |
| Wood Chip (50% mc) | 30.00 | £/tonne | Note 4 |
| Food Waste | 20.00 | £/tonne | Note 5 |
| Transport | 2.50 | £/mile | Note 6 |
| Draff/Digestate | N/A | N/A | Note 7 |

Notes:

1. This is the average cost of standard grade burning oil from 2005 – 2015[51] (see *Figure 19*). Due to the volatility of oil fuel prices, a longer term average was taken rather than a single month or year average.

   Also note that to obtain estimates of fuel volume in litres, an energy conversion factor of 11.35kWh/litre was used, which is the midpoint value between medium and heavy fuel[52].

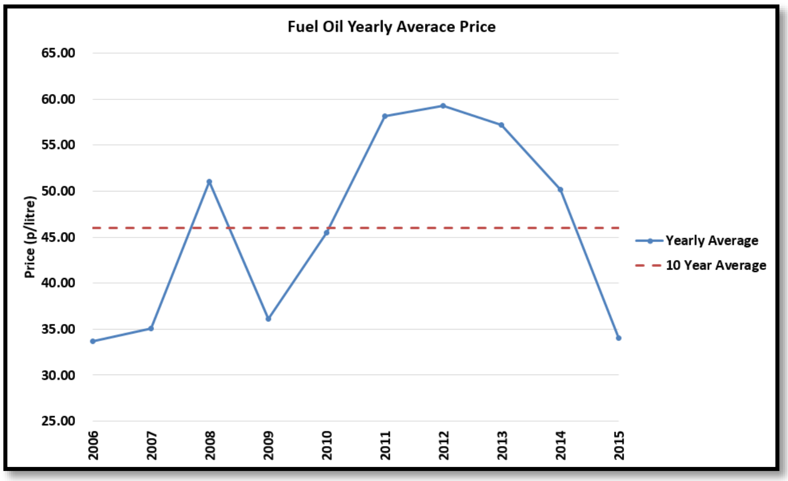


Figure 19 – Fuel Oil Prices 2006 - 2015

2. The grid electricity costs are for non-domestic consumers, defined as follows[53]:
   - Small consumer: 20 – 499 MWh/year
   - Small/Medium consumer: 50 – 1,999 MWh/year
   - Medium consumer: 2,000 – 19,999 MWh/year
3. The cost of sugar beet as a feedstock for biogas takes into account production and supply costs and results in a total cost per energy output from anaerobic digestion[54]. This value has been converted to a cost per hectare of land for this analysis.
4. Wood chip cost per tonne was supplied by a biomass professional. The cost assumes that short rotation coppice willow is chipped on harvest and supplied directly in 'green' state (50% mc).

51 (UK Government, 2016(b))
52 (Jacobs, 2008)
53 (UK Government, 2016)
54 (Gissen, et al., 2014)

5. The current standard rate for landfill tax in Scotland is £84.40[55]. The cost used in this analysis is a nominal gate fee which is low enough to encourage the council to collect the segregated food waste rather than sending it to landfill. This would save the council £17,200 per year based on the 267 tonnes of food waste estimated.
6. Discussions with an AD plant owner identified that £2.50/mile was a typical road tanker cost to the customer.
7. The loss of income from selling draff has been assumed to be offset by the income generated from the sale of digestate as fertiliser. The value of draff as a product for animal feed varies greatly, as does the value of biofertiliser, both within similar ranges. Therefore it was decided to keep the resulting cost neutral rather than to choose a relative profit or loss.

The cost saving due to no longer transporting pot ale uses the previously calculated number of miles required to make the required number of trips from each distillery, multiplied by the hire cost of £2.50/mile of a road tanker. This results in an estimated annual saving of £282,500 for each scenario.

The income from gate fees of the food waste comes to £5,340 which is relevant to scenarios 1 to 4.

All other consumable costs are calculated on a case by case basis.

### *Cost of Equipment*

**Table 21 – AD Plant Costs**

| Size | Where Used | CAPEX | OPEX | Notes |
|---|---|---|---|---|
| 0.5 GWh/yr | Kilchoman | £500,000 | £47,827 | |
| 3.8 GWh/yr | Ardbeg | £939,884 | £126,479 | |
| 4 GWh/yr | Bowmore | £986,784 | £130,137 | |
| 4.1 GWh/yr | Bruichladdich | £1,033,685 | £133,795 | Note 1 |
| 4.9 GWh/yr | Bunnahabhain | £1,268,187 | £152,086 | |
| 6.8 GWh/yr | Laphroaig | £1,830,993 | £195,985 | |
| 7.4 GWh/yr | Lagavulin | £2,018,595 | £210,618 | |

[55] (Revenue Scotland, 2016)

| Table 21 – AD Plant Costs | | | | |
|---|---|---|---|---|
| **Size** | **Where Used** | **CAPEX** | **OPEX** | **Notes** |
| 18 GWh/yr | Caol Ila | £5,207,829 | £459,378 | |
| 50 GWh/yr | Scenarios 1 & 2 | £14,740,141 | £1,202,899 | |
| 66 GWh/yr | Scenario 3 | £19,580,752 | £1,580,466 | |
| 71 GWh/yr | Scenario 4 | £21,086,386 | £1,697,906 | |

Note:

1. AD Plant costs have been taken from financial information provided by the ADBA. Capital and operating costs of anaerobic digestion plants of various sizes (based on energy value output from biogas production) were provided, which were plotted on graphs to check for relationships, see *Figure 20*. In both cases, relatively linear relationships were found and therefore was used for estimated figures in this study.

   The capital costs include feasibility studies, planning applications (including impact assessments), land costs, civil works, feedstock pretreatment/storage equipment, AD plant equipment such as feedstock feeding equipment, digestion tanks and gas holders. Operational costs include staff costs (training and salaries), plant maintenance and insurance.

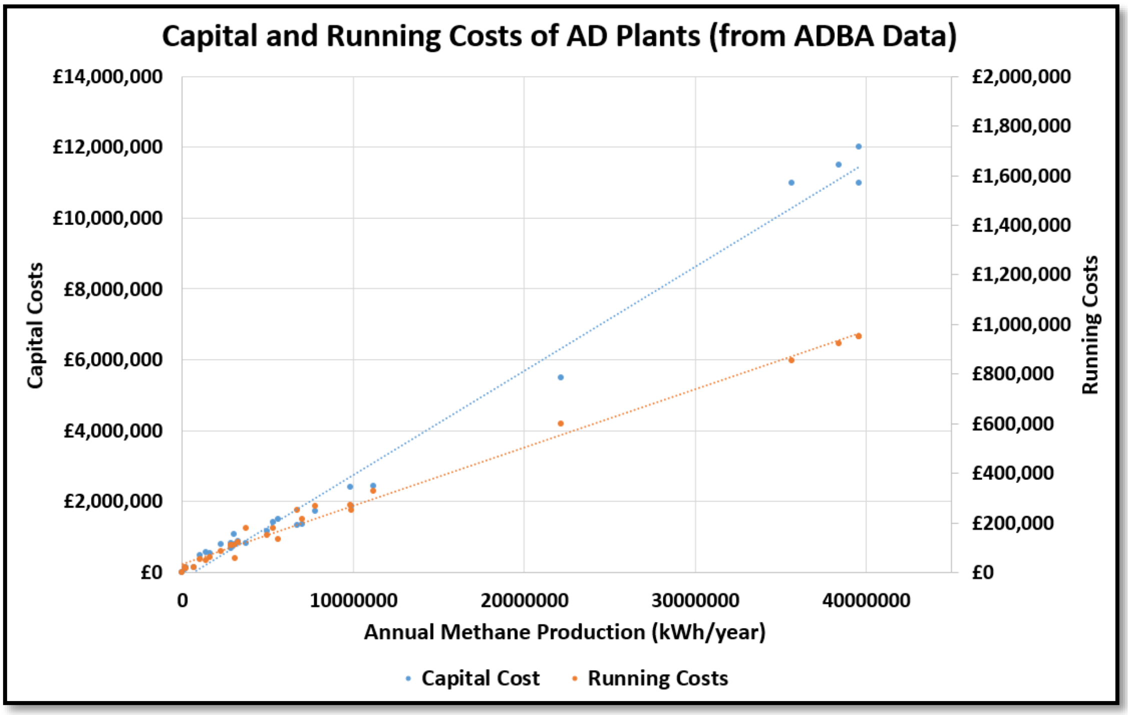


Figure 20 – AD Plant Capital and Running Costs

| Table 22 – Biogas Boiler Costs | | | | |
|---|---|---|---|---|
| **Size** | **Where Used** | **CAPEX** | **OPEX** | **Notes** |
| 100 kW | Kilchoman | £58,881 | £2,944 | |
| 150 kW | AD plant (scenarios 1 & 2) | £59,580 | £2,979 | |
| 800 kW | Ardbeg | £68,660 | £3,433 | |
| 850 kW | Bruichladdich & Bowmore | £69,359 | £3,468 | |
| 1050 kW | Bunnahabhain | £72,153 | £3,608 | |
| 1400 kW | Laphroaig | £77,042 | £3,852 | |
| 1550 kW | Lagavulin | £79,138 | £3,957 | Note 2 |
| 1750 kW | Caol Ila | £81,932 | £4,097 | |
| 3000 kW | Ardbeg (scenario 2) | £99,394 | £4,970 | |
| 3750 kW | Caol Ila | £109,872 | £5,494 | |
| 5500 kW | Laphroaig (scenario 1) | £134,319 | £6,716 | |
| 6000 kW | Lagavulin (scenarios 1 & 2) | £141,304 | £7,065 | |
| 7000 kW | Wood Chip Drying (scenario 4) | £155,274 | £7,764 | |
| 7150 kW | Wood Chip Drying and AD Plant (scenario 3) | £157,370 | £7,868 | |

Note:

2. Biogas boiler costs have been taken from an economic tool developed by an MSc group from the University of Strathclyde[56]. The tool uses costs which were obtained from biogas boiler suppliers.

| Table 23 – Biomass Boiler Costs | | | | |
|---|---|---|---|---|
| **Size** | **Where Used** | **CAPEX** | **OPEX** | **Notes** |
| 500 kW | Kilchoman (scenario 3) | £95,000 | £4,750 | |
| 3000 kW | Bowmore (scenario 2) | £570,000 | £28,500 | |
| 3500 kW | Bowmore, Ardbeg & Bruichladdich (scenarios 3 &4) | £665,000 | £33,250 | Note 3 |

[56] (Allardyce, Baster, Kirk, & Lamond, 2011)

| Table 23 – Biomass Boiler Costs | | | | |
|---|---|---|---|---|
| **Size** | **Where Used** | **CAPEX** | **OPEX** | **Notes** |
| 4000 kW | Bunnahabhain (scenarios 3 & 4) | £760,000 | £38,000 | |
| 5500 kW | Laphroaig (scenarios 3 & 4) | £1,045,000 | £52,250 | |
| 6000 kW | Lagavulin (scenarios 3 & 4) | £1,140,000 | £57,000 | |
| 14500 kW | Caol Ila (scenarios 3 & 4) | £2,755,000 | £137,750 | |

Note:

3. Biomass boiler capital costs were assumed to be £190 per kW capacity. This is the average value as quoted by the biomass energy centre[57] which states that above 500kW capacity, capital costs are in the range of £150-230/kW as a general guide. The operational costs have been calculated at 5% the capital costs, in-line with that of the biogas boiler operational cost estimates.

| Table 24 – CHP System Costs | | | | |
|---|---|---|---|---|
| **Size** | **Where Used** | **CAPEX** | **OPEX** | **Notes** |
| 50 kWe | Kilchoman | £430,000 | £2,160 | |
| 200 kWe | Ardbeg | £173,000 | £8,650 | |
| 250 kWe | Bruichladdich & Bowmore | £216,000 | £10,800 | |
| 300 kWe | Bunnahabhain | £260,000 | £13,000 | Note 4 |
| 400 kWe | Laphroaig & Lagavulin | £346,000 | £17,300 | |
| 500 kWe | AD Plant (scenarios 2 & 4) and Caol Ila | £430,000 | £21,500 | |

Note:

4. General CHP costs were obtained from an AD plant owner. It was stated that in general, capital costs are around €1,000/kWe capacity, which has been converted to pounds sterling here. Again, operational costs have been estimated at 5% of the capital cost.

[57] (Biomass Energy Centre, 2004)

| Table 25 – Rising Main Pump System Costs | | | | |
|---|---|---|---|---|
| **Size** | **Where Used** | **CAPEX** | **OPEX** | **Notes** |
| 62,280m | Feedstock system (scenarios 1 - 4) | £1,555,000 | £77,850 | Note 5 |
| 22,209m | Biogas system (scenario 1) | £555,222 | £27,761 | |
| 23,979m | Biogas system (scenario 2) | £599,479 | £29,974 | |

Note:

5. Ring main pump system costs came from an industrial source who stated that £20/m was a general cost for hardware (including pumps) and installation of this type of system. Due to the uncertainty of this figure, 25% has been added, with £25/m being used for the estimated costs. Again, 5% of capital costs are used for operational costs per year.

Scenario costs have been calculated on an overall basis. There are many options as to how the systems could be financially set up which is outwith the scope of this study. Here, total capital, operation and maintenance costs are offset against all cost savings from income generated and energy saved etc. This provides an initial review of the options, which can provide a basis for more detailed feasibility studies in the future.

Selling of existing equipment has not been considered in the cost calculations. For example where a new boiler is to be installed, the calculations have not accounted for the possible income from the sale of the existing fuel oil boiler.

Payback period method is used as a comparator between scenarios of time taken for each project to pay for itself. Time value of money is not considered in this method.

### *CO2 Values*

| Table 26 – $CO_2$ Values used in Calculations | | | |
|---|---|---|---|
| **Item** | **Value** | **Unit** | **Notes** |
| Fuel Oil | 3.18058 | $kgCO_2e$/litre | Note 1 |
| Diesel | 2.61163 | $kgCO_2e$/litre | Note 1 |
| Grid Electricity | 0.41205 | $kgCO_2e$/litre | Note 1 |
| Sugar Beet | 1295.9 | $kgCO_2e$/tonne | Note 2 |

| Table 26 – $CO_2$ Values used in Calculations | | | |
|---|---|---|---|
| **Item** | **Value** | **Unit** | **Notes** |
| Woodchip | 19.6432 | $kgCO_2e$/tonne wet woodchip | Note 2 |
| Food Waste | 45.4545 | kgCO2e/tonne | Note 3 |
| Whisky by-products | N/A | N/A | Note 4 |

Notes:

1. Values taken from DECC research and analysis documents[58].
2. The emissions stated take into account the primary input energy required during transportation, storage, cultivation and harvesting of sugar beet[59] and wood chip[60].
3. Food waste emissions show the quantity which could be saved if the food is treated with anaerobic digestion as opposed to going to land fill[61].
4. Pot ale and draff are not given individual values. The savings in emissions from pot ale are counted from the elimination of road transporting it to the sea discharge point. Draff did have a previous use (as animal feed) so emissions savings are omitted here.

All scenarios eliminate the transporting of pot ale to the discharge point at Caol Ila and therefore every scenario benefits from the same reduction in $CO_2$ emissions associated with this activity. To calculate this, the round trip mileage from each distillery to Caol Ila was noted along with the yearly pot ale volumes at each distillery (excluding Caol Ila). An assumption was made that medium tankers would be used, as larger tankers may have access difficulties on the smaller roads on the island. These have a capacity of 18,000 litres.

The number of loads required and therefore the number of miles required to be travelled was calculated. Assuming that the fuel used would be diesel, the GHG emissions were calculated at 150,500 kgCO2e/year. Note that the emissions associated with the delivery of fuel oil to the island (either by ship or road, or both) is not considered here.

58 (UK Government, 2016(c))
59 (Gissen, et al., 2014)
60 (Coppice Resources Ltd., 2009)
61 (Friends of the Earth, 2007)

In scenarios 1 to 4 where it is assumed that food waste will be added to the feedstock, the same carbon saving is seen by all. This comes to 12,100 kgCO2e/year based on the 267 tonnes of food waste per year estimated.

All other carbon emissions are calculated on a case by case basis.

### *Land Use*

| **Table 27 – Land Area Requirement** | | |
|---|---|---|
| **Item** | **Value** | **Notes** |
| Short rotation coppice willow | 15 hectares/wet tonne | Note 1 |
| Sugar beet | 0.0225 hectares/MWh | Note 2 |
| AD Plant | Negligible | Note 3 |

Notes:

1. This value was provided by a biomass specialist and backed up by information from the Biomass Energy Centre[62].
2. Derived from the previously detailed sugar beet energy yield of 44.44MWh per hectare.
3. The AD plant area required is assumed negligible as it will either be on distillery land or for the central plant, take up land in the region of several hectares as opposed to hundreds or thousands of hectares.

[62] (Biomass Energy Centre, 2016)

## 4.3 Scenario 1 – Heat Only

### Technical Configuration

The first scenario comprises a central AD plant which pumps produced biogas to the distilleries for use in biogas boilers. CHP is not utilised. AD plant parasitic loads and electricity to run pumps comes from on-site biogas boiler and electricity imported from the grid. *Figure 21* shows the concept idea in schematic form.

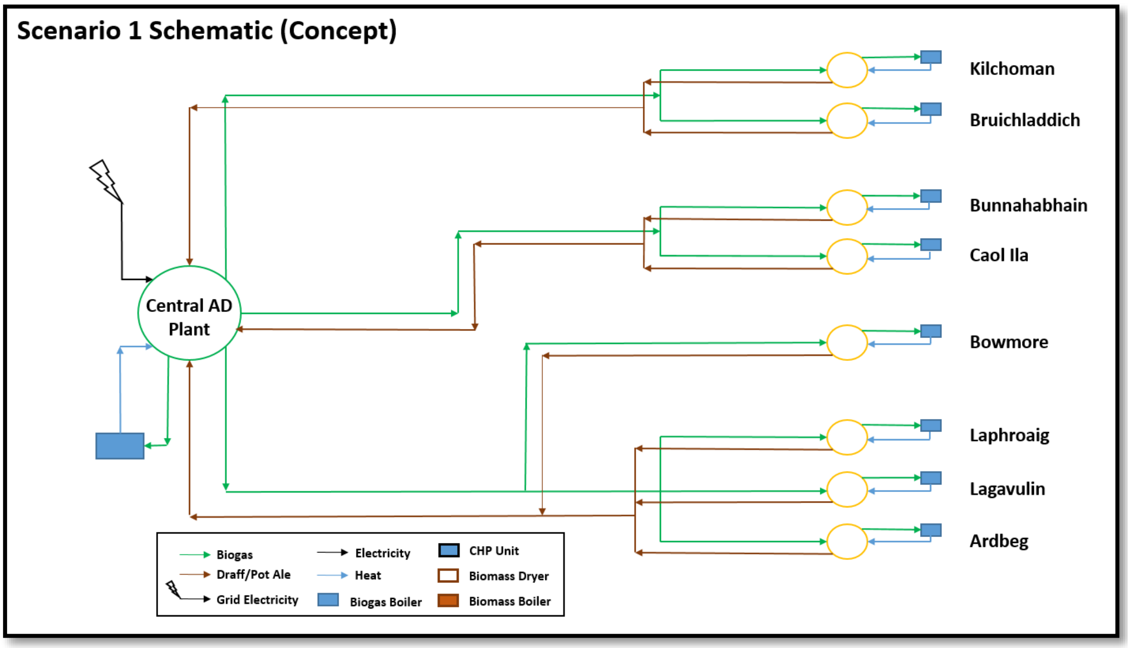


Figure 21 – Scenario 1 Concept Schematic

### Energy Analysis and Results

Using values discussed in *Energy Analysis Values*, energy analysis calculations were performed in Excel with the resulting thermal energy outputs shown in *Table 28*. *Figure 22* displays these results graphically, with each bar representing the range of estimation from lower to upper values.

| SCENARIO 1 OUTPUT | Energy Output from Biogas Boilers (MWh/year) | | | Percentage of thermal requirements met | | |
|---|---|---|---|---|---|---|
| | Lower | Mean | Upper | Worst Case | Mean | Best Case |
| Pot Ale Only | 12290 | 14579 | 16868 | 8.2% | 11.2% | 15.2% |
| Draff Only | 19392 | 22934 | 26476 | 12.9% | 17.6% | 23.9% |
| Pot ale and draff | 32363 | 38194 | 44026 | 21.6% | 29.3% | 39.8% |
| plus food waste | 32508 | 38340 | 44171 | 21.7% | 29.4% | 39.9% |

Table 28 – Scenario 1 Energy Output Summary

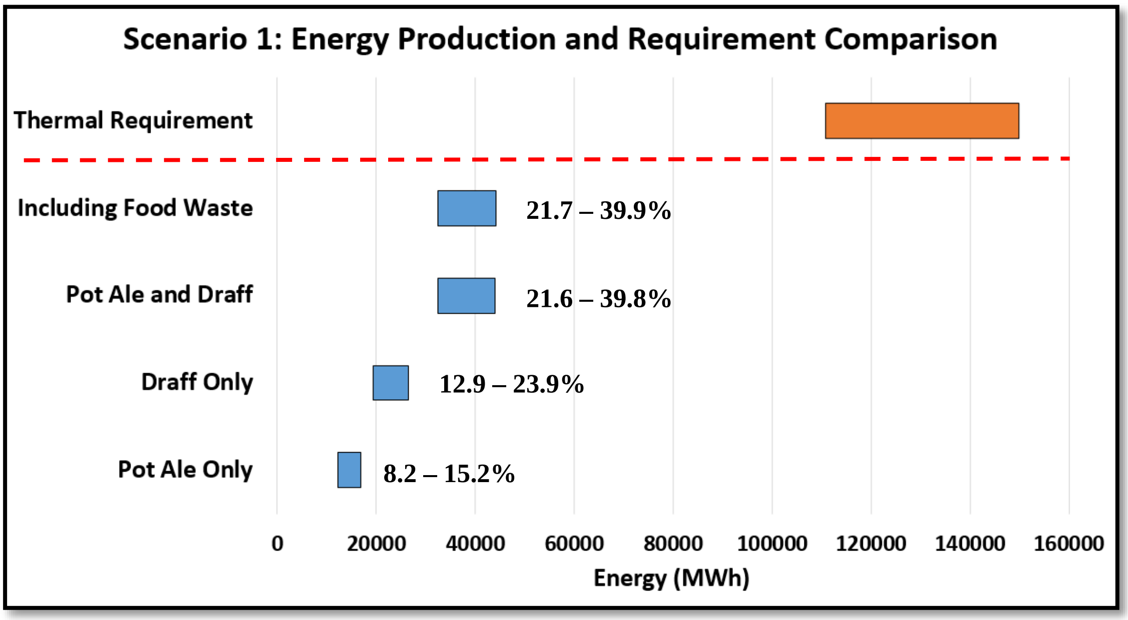


Figure 22 – Scenario 1 Energy Outputs V Requirements

The distilleries thermal energy requirements would be met within the range of 8-40% depending on feedstocks used. Assuming that both pot ale and draff were to be utilised, then a 29.3% reduction in distillery thermal energy would be seen as per calculations based on mean values. If draff was to continue to be used as animal feed and only pot ale used for biogas, then this results in an 11.2% reduction. Including food waste as a feedstock increases the available energy very slightly, by around 0.1%.

When comparing the various outputs against required input, it becomes clear that the addition of draff as a feedstock provides the most significant contribution.

If the biogas was split evenly between the distilleries, it would mean that they would have to operate dual fuel boilers, as another fuel would have to make up the shortfall. This system could be difficult to operate. Another option would be to supply 2 or 3 distilleries with all of the biogas which could meet 100% of their heating requirements, leaving the others to continue with their current systems but spreading cost savings out between all. This solution is preferred in this case as it also cuts down on the gas piping and number of new boilers which would need to be installed.

Prior to performing any financial or environmental analyses, refinement of the scenario configuration is required.

Reviewing *Table 8* (Distillery Thermal Requirements) and *Table 28* (Biogas Boiler Thermal Output) allows the selection of distilleries to receive biogas for heating. By also bearing in mind *Figure 15* (Map of Islay Distilleries) and the three distinct groupings of distilleries, a solution can be selected which keeps the gas piping requirement to a minimum. In this case, only mean values are used for simplicity and it is assumed that the maximum available feedstock is utilised, i.e. pot ale, draff and food waste.

With an available thermal output from combustion of biogas in boilers of 38,340 MWh, a group of distilleries were assessed to find a closely matching requirement. One possibility is Laphroaig & Lagavulin, which have a joint thermal requirement of 37,241 MWh. This leaves an additional 1099 MWh of biogas as a deficit. For the purpose of these calculations, it will be assumed that this deficit is also absorbed by the distilleries needs, i.e. the assumed thermal energy used by the two distilleries equals that of which is available; 38,340 MWh.

*Figure 23* shows an updated schematic which represents this idea, with biogas pipes leading to these two distilleries and original fuel oil boilers remaining at the others. Following the same methodology as calculating the energy to pump the feedstock slurry, the energy to pump biogas was calculated as 41 MWh/year.

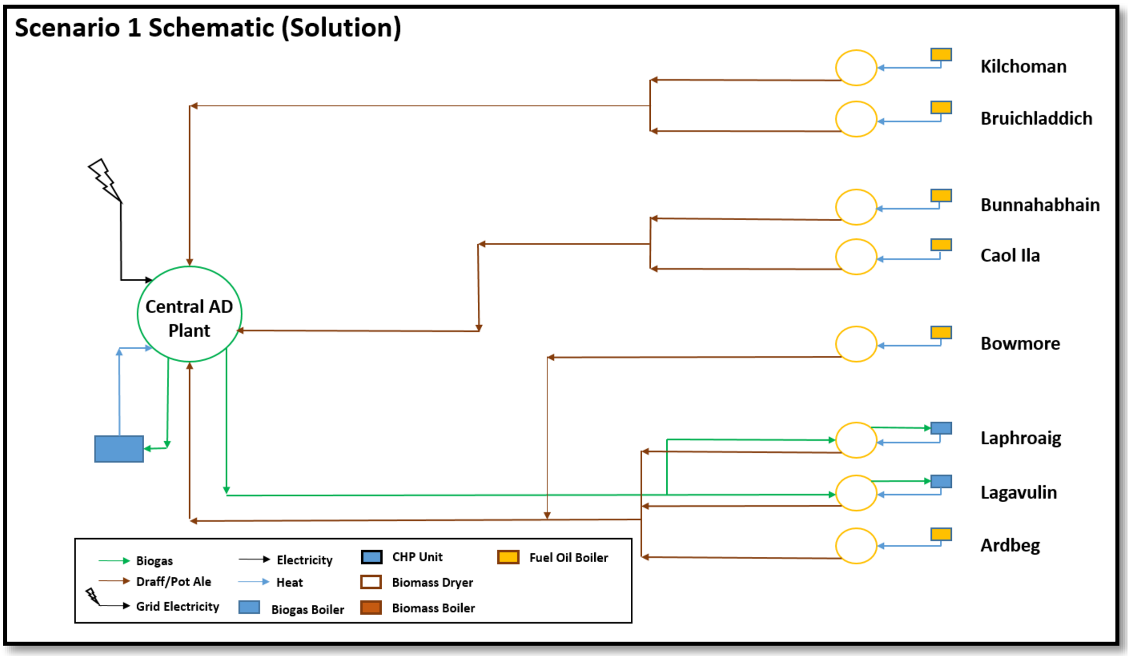


Figure 23 – Scenario 1 Proposed Solution Schematic

### Financial and Environmental Analysis Results

Using data supplied in *Financial and Environmental Analysis Values*, costs for scenario 1 were calculated as shown in *Table 29*.

| Table 29 – Scenario 1 Financial and Environmental Analysis Results | | |
|---|---|---|
| **Equipment** | CAPEX | OPEX |
| AD plant | -£14,740,141 | -£1,202,899 |
| On-site biogas boiler | -£59,580 | -£2,979 |
| Feedstock and biogas rising main pump systems | -£2,112,222 | -£105,611 |
| 2 off distillery biogas boilers | -£275,623 | -£13,781 |
| **Additional Fuel** | | **Cost** |
| Electricity imported for AD plant | | -£29,009 |
| Electricity imported for feedstock pumps | | -£11,878 |
| Income from food waste gate fees | | £5,340 |
| **Fuel Saving** | | **Cost** |
| Fuel oil reduction of 3.4 million litres per year | | £1,554,534 |
| **Subsidies Income** | | **Cost** |
| RHI from AD plant biogas boiler | | £44,652 |
| RHI from two distillery biogas boilers | | £736,976 |
| **Others** | | **Cost** |
| Saving from transportation of pot ale | | £282,534 |
| **GHG Emission Reduction** | | **Value** |
| Saving from pot ale transportation | | 151 $tCO_2e$ |
| Saving from fuel oil reduction | | 10,744 $tCO_2e$ |
| Increase from importing of electricity | | -138 $tCO_2e$ |
| Saving from the AD of food waste | | 12 $tCO_2e$ |

*Summary of Scenario 1 Results*

| Table 30 – Scenario 1 Results Summary | |
|---|---|
| **Total Capital Investment Required** | -£17,187,566 |
| **Percentage of Fuel Oil Reduction** | 29.4% |
| **Net Energy Reduction (electricity and fuel oil)** | 28.0% |
| **Yearly GHG Emissions Saving** | 10,768 tCO2e |

| **Land Use Change** | | 0% |
|---|---|---|
| | **With Subsidies** | **Without Subsidies** |
| **Total Yearly Income** | £1,263,218 | £481,591 |
| **Payback Period** | 14 years | 36 years |
| **Profit/Loss at end of 20 years** | £8,076,788 | -£7,555,756 |

## Discussion

The maximum calculated energy reduction in scenario 1 is 39.9% which requires both pot ale and draff, as well as the relatively small addition of available additional feedstock; food waste. Taking the mean value as a more realistic result, it could be expected that a 29.4% energy supply could be realised. This would all be in the form of thermal energy, as no electricity is produced in scenario 1. Due to this fact, more electricity is required to be imported for additional activities which brings the net energy reduction down to 28%. This only has a small effect due to the relatively low electrical requirement in comparison with thermal demand.

The calculated GHG emissions saving is just under 11,000 tonnes$CO_2$e/year, which equates to a 1.4% reduction on the scotch whisky industry emission total from 2015. The vast majority of this saving is due to the reduced use of fuel oil. Another environmental benefit is that no land would be required to change use, as in this scenario biomass and energy crops are not considered.

With an estimated required capital of £17.2m, the payback period would be 14 years with the currently available subsidies, increasing to 36 years without. It could therefore be concluded that presently, it is a financially viable project as the capital required would be offset within the subsidy provision period of 20 years. However, investors may see this payback period as too long and choose not to invest. This raises the question of whether subsidies should be increased for a shorter period of time so as to decrease the payback period, encouraging more projects to go ahead. It is clear that without the subsidies, the project would not be feasible.

## 4.4 Scenario 2 – CHP On-Site, Heat at Distilleries

### Technical Configuration

This scenario considers the addition of a 500kWe CHP unit on-site at the central plant, with the remaining biogas being used at distilleries in biogas boilers. The aim of this scenario is to investigate whether the produced electricity can offset the additional requirement to import from the grid as well as increase the financial income from FIT. The effect on available biogas for use at the distilleries will be analysed.

There is likely to be an excess of heat available on-site due to the set thermal output from the 500kWhe CHP unit. A use for this thermal energy in the form of biomass drying will also be considered, which could be used as fuel at some of the distilleries to supplement the biogas supply as illustrated in *Figure 24*.

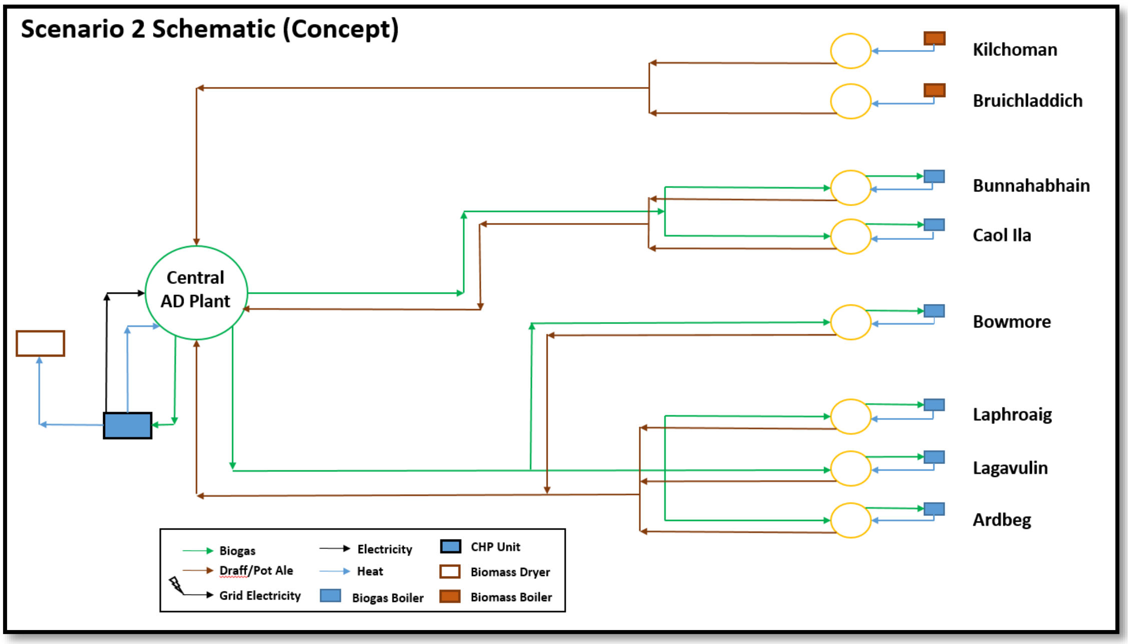


Figure 24 – Scenario 2 Concept Schematic

### Energy Analysis and Results

As there will be a grid connection the electricity can be easily exported and distributed to wherever required. However there is no thermal requirement at the site location (other than parasitic load), therefore the creation of a requirement in the form of biomass drying has been investigated. There is 3027 MWh of thermal energy available for drying biomass which can then be used in biomass boilers to further supplement the distilleries heating requirements.

This available energy would produce 3027 tonnes of dried woodchip, resulting in a useful thermal output of 9263MWh from biomass boilers. To supply this mass of woodchip, 303 hectares of land would be required.

*Table 31* below summarises the resulting thermal energy outputs for scenario 2.

| SCENARIO 2 OUTPUT | Energy Output from Biogas Boilers (MWh/year) | | | Percentage of Thermal Requirement | | |
|---|---|---|---|---|---|---|
| | Lower | Mean | Upper | Worst Case | Mean | Best Case |
| Pot Ale Only | 4324 | 6613 | 8902 | 2.9% | 5.1% | 8.0% |
| Draff Only | 11425 | 14968 | 18510 | 7.6% | 11.5% | 16.7% |
| Pot ale and draff | 24397 | 30228 | 36059 | 16.3% | 23.2% | 32.6% |
| plus food waste | 24542 | 30373 | 36205 | 16.4% | 23.3% | 32.7% |
| Including Biomass Output | 33805 | 39636 | 45467 | 22.6% | 30.4% | 41.1% |

Table 31 – Scenario 2 Energy Output Summary

This shows the thermal outputs available from the variety of options for feedstocks using biogas only, with the bottom line adding on the contribution from biomass to the biogas output from draff, pot ale and food waste. These results are displayed graphically in *Figure 25*.

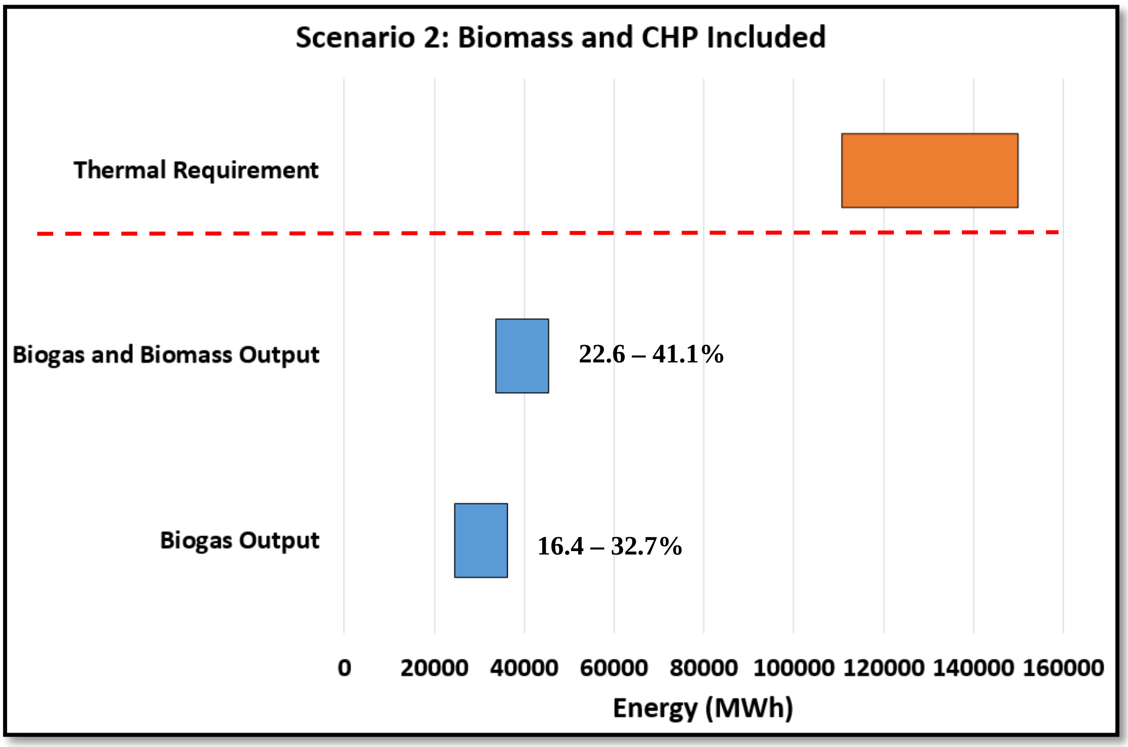


Figure 25 – Scenario 2: Energy Outputs V Requirements

The effect on output from biogas boilers with the addition of the CHP unit compared with scenario 1 is a reduction of 6% on the mean value (29.4% to 23.3%), but with a total increase of around 1% with the inclusion of the biomass boiler output (29.4% to 30.4%).

Again, there is a requirement to further refine the concept idea in order to identify the number of boilers required and the locations prior to financial analysis. Using the same approach as in scenario 1, the locations and thermal requirements of each distillery was assessed to select the ones to receive biogas or biomass to cover 100% of their energy needs. In this case, with a combined mean thermal requirement of 29,615 MWh, Ardbeg and Lagavulin are selected as this closely matches the available mean output of 30,373 MWh with a deficit of 758 MWh. Again, for the purpose of simplifying the assessment, it will be assumed that the available output exactly matches their requirement, so calculations will be based on 30,373 MWh being used by the distilleries.

The thermal output from biomass is 9263 MWh and the closest match on a mean requirement basis is that of Bowmore, which requires 10,593 MWh. Assumption again is that the demand and supply match at the available 9263 MWh value in order not to inflate the financial analysis results. An illustration of the proposal can be seen in *Figure 26*.

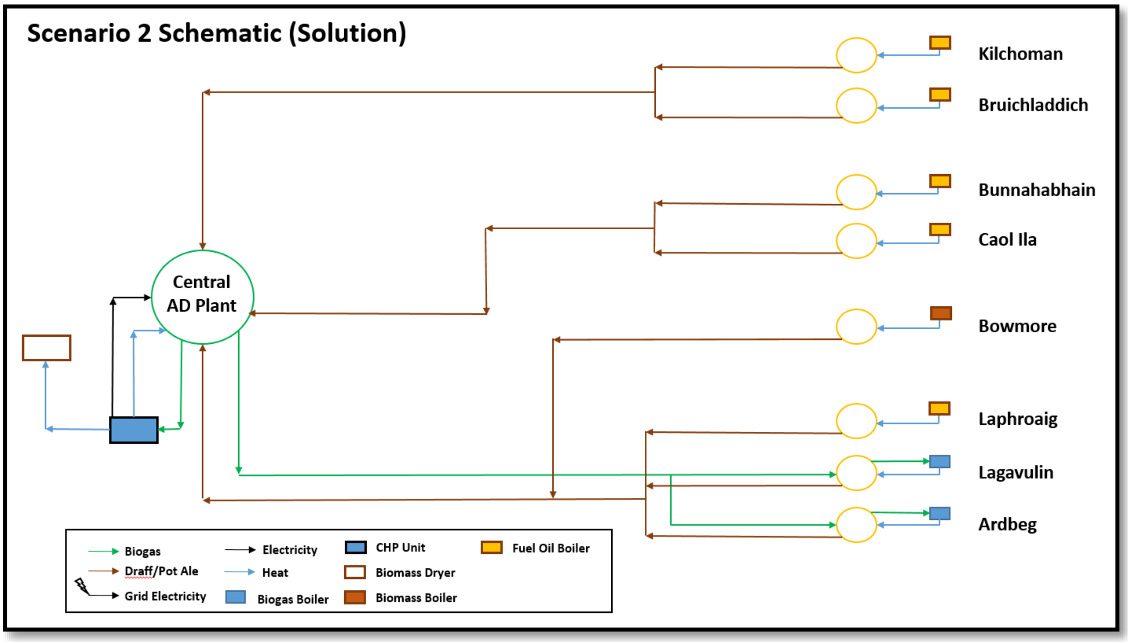


Figure 26 – Scenario 2 Proposed Solution Schematic

### Financial and Environmental Analysis Results

Using data supplied in *Financial and Environmental Analysis Values*, costs for scenario 1 were calculated as shown in *Table 32*.

| Table 32 – Scenario 2 Financial and Environmental Analysis Results | | |
|---|---|---|
| **Equipment** | CAPEX | OPEX |
| AD plant | -£14,740,141 | -£1,202,899 |
| On-site CHP system | -£430,000 | -£21,500 |
| Feedstock and biogas rising main pump systems | -£2,156,479 | -£107,824 |
| 2 off distillery biogas boilers | -£240,698 | -£12,035 |
| 1 off distillery biomass boiler | -£570,000 | -£28,500 |
| **Additional Fuel** | | **Cost** |
| Electricity imported for feedstock pumps | | -£11,878 |
| Purchase of wet woodchip | | -£136,215 |
| Income from food waste gate fees | | £5,340 |
| **Fuel Saving** | | **Cost** |

| Table 32 – Scenario 2 Financial and Environmental Analysis Results | |
|---|---|
| Fuel oil reduction of 3.5 million litres per year | £1,607,093 |
| **Subsidies Income** | **Cost** |
| RHI from AD plant CHP system | £65,464 |
| RHI from 3 distillery boilers | £773,728 |
| FIT from CHP system | £194,889 |
| **Others** | **Cost** |
| Saving from transportation of pot ale | £282,534 |
| **GHG Emission Reduction** | **Value** |
| Saving from pot ale transportation | 151 $tCO_2e$ |
| Saving from fuel oil reduction | 11,107 $tCO_2e$ |
| Net effect of importing/exporting electricity | 1,494 $tCO_2e$ |
| Saving from the AD of food waste | 12 $tCO_2e$ |
| Increase due to harvesting of wood chip | -89 $tCO_2e$ |
| **Land Use Change** | **Value** |
| Short rotation coppice willow | 303 hectares |

*Summary of Scenario 2 Results*

| Table 33 – Scenario 2 Results Summary | | |
|---|---|---|
| **Total Capital Investment Required** | | -£18,137,318 |
| **Percentage of Fuel Oil Reduction** | | 30.4% |
| **Net Energy Reduction (electricity and fuel oil)** | | 32.0% |
| **Yearly GHG Emissions Saving** | | 12,674 $tCO_2e$ |
| **Land Use Change** | | 0.5% |
| | **With Subsidies** | **Without Subsidies** |
| **Total Yearly Income** | £1,413,537 | £379,456 |
| **Payback Period** | 13 years | 48 years |
| **Profit/Loss at end of 20 years** | £10,133,426 | -£10,548,199 |

## Discussion

The percentage of fuel oil reduction is estimated to be 30.4% which is only a 1% increase on scenario 1, however there is the added benefit that electricity is produced from the CHP unit, bringing the total energy reduction up to 32% (from 28% in scenario 1).

GHG emissions are slightly higher at 12.6k $tCO_2e$, which would provide a 1.7% decrease for the whisky industry based on the 2015 total. Again, this is largely due to the reduced use of fuel oil. As scenario 2 incorporates the drying of biomass, land is required for the harvest of this willow supply estimated at around 300 hectares which is 0.5% of the total land area of Islay.

With an estimated required capital of £18.1m, the payback period would be 13 years with currently available subsidies but 48 years without. This is an improvement on scenario 1 of a year. So it is still questionable as to whether this can be considered financially viable given that investors would most likely prefer a shorter payback period. However there is no question that it would not be viable in the future with no support from incentive schemes. With further use of electricity on-site, greater benefits would be seen with additional savings from a reduction in imported electricity. With careful planning, perhaps the AD site could be placed near to a suitable source of electrical demand which could make use of the excess generated electricity.

## 4.5 Scenario 3 – Optimisation of Biomass Drying

### Technical Configuration

Scenario 3 looks to optimise the biomass drying aspect from scenario 2. All distilleries will have a biomass boiler as a replacement for their current oil system, with all biogas being combusted at the central site through a biogas boiler to dry biomass. No CHP is utilised. The concept is illustrated schematically in *Figure 27*. The quantity of biomass required to cover 100% of the distilleries thermal requirements and the amount of biogas and land area required to do this are calculated.

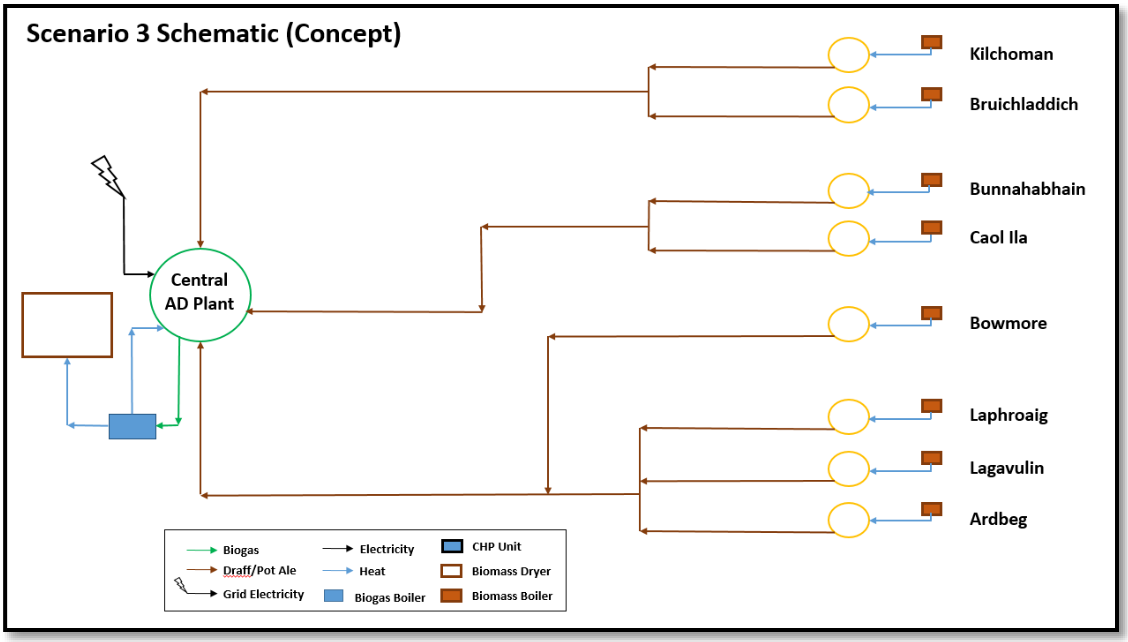


Figure 27 – Scenario 3 Concept Schematic

### Energy Analysis and Results

This scenario uses a backward working method, starting with the thermal requirement in order to identify the mass of woodchip required to meet this demand, along with the quantity of biogas required to dry the woodchip from 50% mc to 25% mc. Results of these calculations are summarised in *Table 34*. The bottom line shows the surplus or deficit of biogas which will exist from best to worst case scenario.

| Optimised Biomass Values | Best Case | Mean | Worst Case |
|---|---|---|---|
| Thermal Requirement (MWh) | 110755 | 130300 | 149845 |
| Input Energy Required (to biomass boilers) (MWh) | 130300 | 153294 | 176288 |
| Dried Woodchip Mass Required (tonnes) | 36194 | 42582 | 48969 |
| Water content of dried woodchip | 9049 | 10645 | 12242 |
| Wet Woodchip Mass (tonnes) | 54292 | 63872 | 73453 |
| Land Area Required (hectares) | 3619 | 4258 | 4897 |
| Biogas Energy Required to dry the woodchip (MWh) | 36194 | 42582 | 48969 |
| % of Land Required | 5.8% | 6.9% | 7.9% |
| Biogas surplus/deficit (MWh) | 8418 | -3858 | -16135 |

Table 34 – Scenario 3 Biomass Optimisation Summary

As displayed in *Figure 28*, there is a fairly close match between the biogas energy available and the amount required to dry the biomass. It is not possible to determine any accurate conclusion without knowing the real energy requirements of the distilleries. Having best and worst case estimates for both the energy requirement and energy available leaves the possibilities open to a wide range of conclusions.

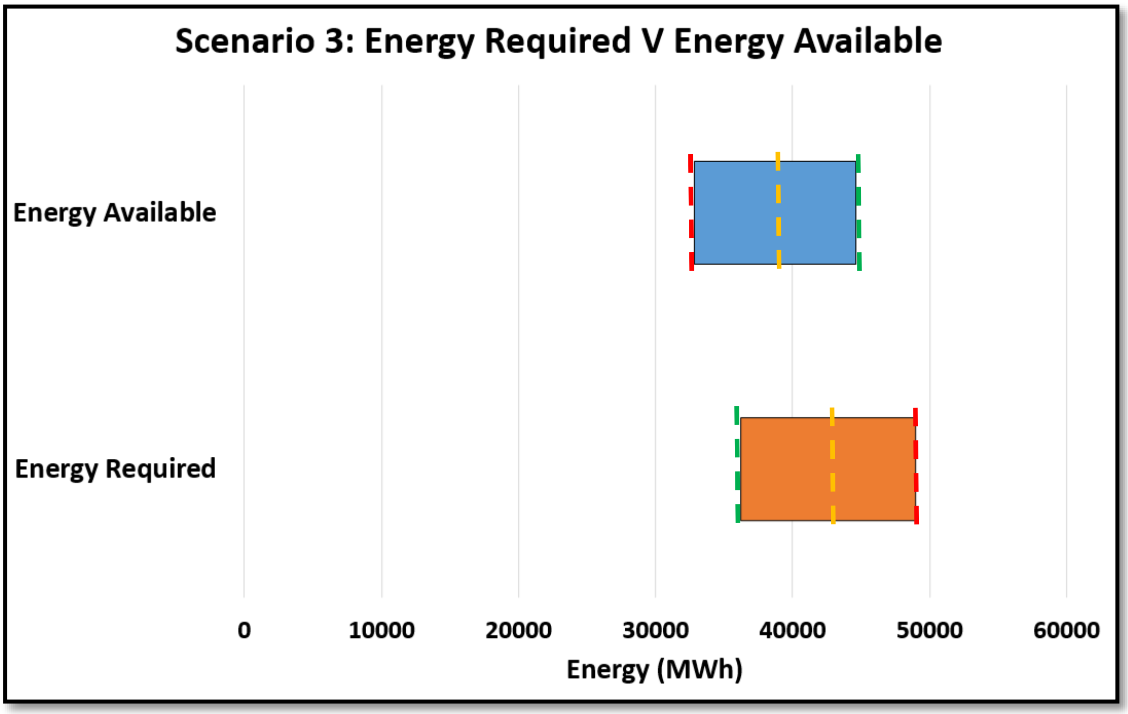


Figure 28 – Scenario 3 Energy Required for Biomass Drying

The worst case scenario (as denoted by the red dashed lines) would mean that there was a deficit of 16,135 MWh per year. The best case scenario (as denoted by the green dashed lines) would give a surplus of 8,418 MWh per year. Although it is unlikely that the reality of the situation would fall at either of these extreme ends of the spectrum, without real data they must still be considered as possibilities. Going on a mean value basis, there would be a deficit of 3,858 MWh per year.

To make up the deficit, sugar beet was selected as a high yielding feedstock for anaerobic digestion. For each case (from best to worst), the quantity of sugar beet which would be required has been calculated, results shown in *Table 35*.

| Sugar Beet Requirements | Best Case | Mean | Worst Case |
|---|---|---|---|
| Area of land required to make up energy deficit (hectares) | 0 | 87 | 363 |
| Total area required for willow and sugar beet (hectares) | 3619 | 4345 | 5260 |
| Percentage of Islay land | 5.8% | 7.0% | 8.5% |

Table 35 – Scenario 3 Sugar Beet Requirements

To provide the energy required for biogas drying, a 7MW biogas boiler was selected, which will also provide heat to run the AD plant.

### Financial and Environmental Analysis Results

| Table 36 – Scenario 3 Financial and Environmental Analysis Results | | |
|---|---|---|
| **Equipment** | CAPEX | OPEX |
| AD plant | -£19,580,752 | -£1,580,466 |
| On-site biogas boiler (woodchip drying and AD plant heating) | -£155,274 | -£7,764 |
| Feedstock rising main pump system | -£1,557,000 | -£77,850 |
| 8 off distillery biomass boilers | -£7,790,000 | -£389,500 |
| **Additional Fuel** | | **Cost** |
| Electricity imported for AD plant and feedstock pumps | | -£35,885 |
| Purchase of wet woodchip | | -£1,916,174 |
| Purchase of sugar beet | | -£200,044 |
| Income from food waste gate fees | | £5,340 |
| **Fuel Saving** | | **Cost** |

| Table 36 – Scenario 3 Financial and Environmental Analysis Results | |
|---|---|
| Fuel oil reduction of 11.5 million litres per year | £5,283,171 |
| **Subsidies Income** | **Cost** |
| RHI from AD plant woodchip dryer | £781,314 |
| RHI from 8 distillery boilers | £2,671,147 |
| **Others** | **Cost** |
| Saving from transportation of pot ale | £282,534 |
| **GHG Emission Reduction** | **Value** |
| Saving from pot ale transportation | 151 $tCO_2e$ |
| Saving from fuel oil reduction | 36,514 tonnes |
| Increase from the importing of electricity | -81 $tCO_2e$ |
| Saving from the AD of food waste | 12 $tCO_2e$ |
| Increase due to harvesting of woodchip | -1,443 $tCO_2e$ |
| Increase due to harvesting of sugar beet | -113 $tCO_2e$ |
| **Land Use Change** | **Value** |
| Short rotation coppice willow | 4258 hectares |
| Sugar beet | 87 hectares |

*Summary of Scenario 3 Results*

| Table 37 – Scenario 3 Results Summary | | |
|---|---|---|
| **Total Capital Investment Required** | | -£29,083,026 |
| **Percentage of Fuel Oil Reduction** | | 100% |
| **Net Energy Reduction (electricity and fuel oil)** | | 95.7% |
| **Yearly GHG Emissions Saving** | | 35,040 $tCO_2e$ |
| **Land Use Change** | | 7% |
| | **With Subsidies** | **Without Subsidies** |
| **Total Yearly Income** | £4,821,163 | £1,368,702 |
| **Payback Period** | 7 years | 22 years |
| **Profit/Loss at end of 20 years** | £67,340,225 | -£1,708,995 |

## Discussion

The percentage of fuel oil reduction is already known to be 100%. This results in a total energy provision of 95.7% including electricity demand. So the question here is how financially and environmentally feasible would it be to achieve this level of renewable energy supply?

The GHG emissions reduction rises dramatically here, to 35,000 $tCO_2e$. This equates to 4.6% of the total emissions from the whisky industry in 2015. However, far greater areas of land would be required to harvest the willow required as well as additional land for energy crop to increase the biogas yield required. A total of 4345 hectares of land would be needed, which equates to 7% of the total area of Islay land. This sounds realistically possible due to the low population density of the island, however further investigation would be required into the exact use of the land currently. The contribution from energy crop in proportion to willow is very low at only 2% of the total. This opens up the opportunity to investigate the feasibility of alternative energy crops which may require larger land areas, but which will most likely be cheaper given that sugar beet was the most expensive of the six investigated[63].

The estimated capital investment required is almost double that of scenarios 1 and 2 at £29m. However, due to the scale of the benefits achieved, the payback period is dramatically reduced, coming down to only 7 years. This figure provides a much higher chance of investment from developers, which could be reduced further with the investigation of cheaper energy crops. Without subsidies, the payback period jumps up to 22 years.

[63] (Gissen, et al., 2014)

## 4.6 Scenario 4 – Optimised Biomass with CHP On-Site

### Technical Configuration

Scenario 4 keeps the same principle as scenario 3, with the view to supplying all distilleries with biomass to cover 100% of their heating requirements. Therefore all distilleries will have a biomass boiler, with the addition of a 500kWe CHP unit on-site which will provide electricity as well as FIT income.

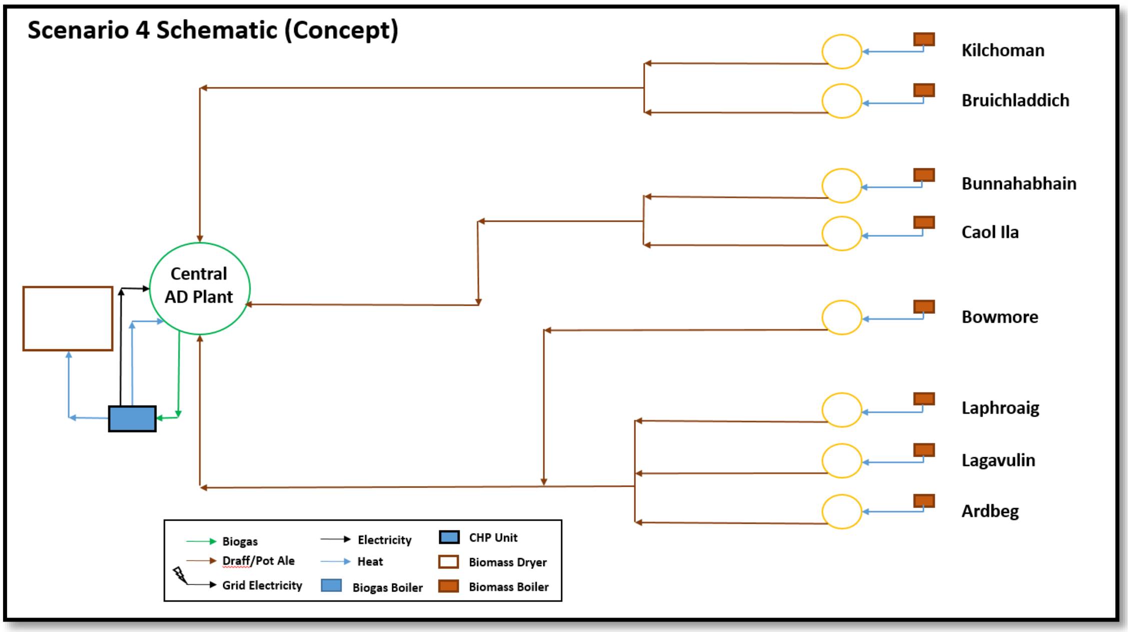


Figure 29 – Scenario 4 Schematic

### Energy Analysis and Results

The requirement for woodchip mass and therefore quantity of biomass remains the same as scenario 3. However the available biomass due to the inclusion of the CHP unit reduces to that of scenario 2. This reduces the potential surplus and increases the potential deficit of biogas.

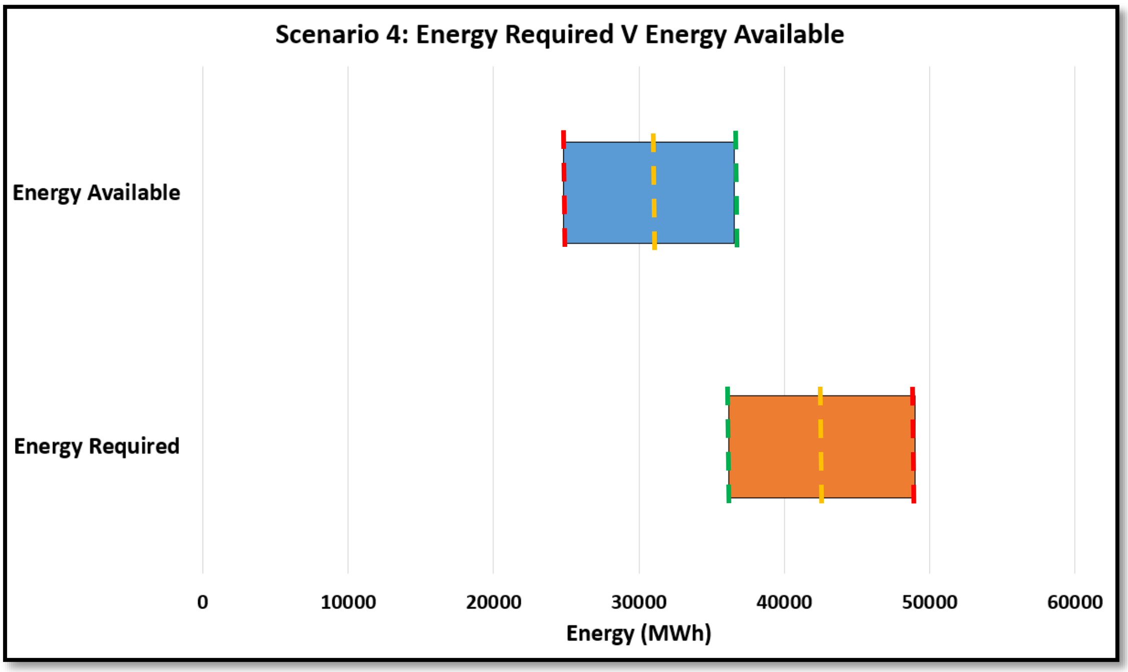


Figure 30 – Scenario 4 Energy Required for Biomass Drying

As can be seen in *Figure 30*, the gap has widened between energy available and energy required. Again using a backward working method, the biogas requirement has been calculated to meet the thermal requirements from best to worst case. *Table 38* shows these results, with the bottom line displaying the surplus/deficit quantities.

| Optimised Biomass Values | Best Case | Mean | Worst Case |
|---|---|---|---|
| Thermal Requirement (MWh) | 110755 | 130300 | 149845 |
| Input Energy Required (MWh) | 130300 | 153294 | 176288 |
| Dried Woodchip Mass (tonnes) | 36194 | 42582 | 48969 |
| Water content of dried woodchip | 9049 | 10645 | 12242 |
| Wet Woodchip Mass (tonnes) | 54292 | 63872 | 73453 |
| Land Area Required (hectares) | 3619 | 4258 | 4897 |
| Biogas Energy Required (MWh) | 36194 | 42582 | 48969 |
| % of Land Required | 5.84% | 6.87% | 7.90% |
| Biogas surplus/deficit (MWh) | 3400 | -8877 | -21154 |

Table 38 – Scenario 4 Biomass Optimisation Summary

Using sugar beet again as the additional anaerobic digestion feedstock to make up this deficit, the land area required would increase as outlined in *Table 39*.

| Sugar Beet Requirements | Best Case | Mean | Worst Case |
|---|---|---|---|
| Area of land required to make up energy deficit (hectares) | 0 | 200 | 476 |
| Total area required for willow and sugar beet (hectares) | 3619 | 4458 | 5373 |
| Percentage of Islay land | 5.8% | 7.2% | 8.7% |

Table 39 – Scenario 4 Sugar Beet Requirement

As the thermal demand being met is the same as in scenario 3, again a 7MW biogas boiler would be required.

### Financial and Environmental Analysis Results

| Table 40 – Scenario 4 Financial and Environmental Analysis Results | | |
|---|---|---|
| **Equipment** | CAPEX | OPEX |
| AD plant | -£21,086,386 | -£1,697,906 |
| On-site CHP system | -£430,000 | -£21,500 |
| On-site biogas boiler (woodchip drying) | -£155,274 | -£7,764 |
| Feedstock rising main pump system | -£1,557,000 | -£77,850 |
| 8 off distillery biomass boilers | -£7,790,000 | -£389,500 |
| **Additional Fuel** | | **Cost** |
| Electricity imported for feedstock pumps | | -£11,878 |
| Purchase of wet woodchip | | -£1,916,174 |
| Purchase of sugar beet | | -£460,243 |
| Income from food waste gate fees | | £5,340 |
| **Fuel Saving** | | **Cost** |
| Fuel oil reduction of 11.5 million litres per year | | £5,283,171 |
| **Subsidies Income** | | **Cost** |
| RHI from AD plant woodchip dryer | | £736,663 |
| RHI from 8 distillery boilers | | £2,671,147 |
| RHI from CHP system | | £65,464 |
| FIT from CHP system | | £194,755 |
| **Others** | | **Cost** |
| Saving from transportation of pot ale | | £282,534 |

| Table 40 – Scenario 4 Financial and Environmental Analysis Results | |
|---|---|
| **GHG Emission Reduction** | **Value** |
| Saving from pot ale transportation | 151 $tCO_2e$ |
| Saving from fuel oil reduction | 36,514 $tCO_2e$ |
| Net effect of importing/exporting electricity | 1,503 $tCO_2e$ |
| Saving from the AD of food waste | 12 $tCO_2e$ |
| Increase due to harvesting of woodchip | -1,443 $tCO_2e$ |
| Increase due to harvesting of sugar beet | -259 $tCO_2e$ |
| **Land Use Change** | **Value** |
| Short rotation coppice willow | 4258 hectares |
| Sugar beet | 200 hectares |

*Summary of Scenario 4 Results*

| Table 41 – Scenario 4 Results Summary | | |
|---|---|---|
| **Total Capital Investment Required** | | -£31,018,660 |
| **Percentage of Fuel Oil Reduction** | | 100% |
| **Net Energy Reduction (electricity and fuel oil)** | | 98.6% |
| **Yearly GHG Emissions Saving** | | 36,477 $tCO_2e$ |
| **Land Use Change** | | 7.2% |
| | **With Subsidies** | **Without Subsidies** |
| **Total Yearly Income** | £4,661,597 | £993,569 |
| **Payback Period** | 7 years | 32 years |
| **Profit/Loss at end of 20 years** | £62,213,279 | -£10,992,002 |

## Discussion

Again, it is known that the thermal energy supply here is 100% of the demand due to the nature of this scenario analysis approach. However because of the addition of the CHP system, the total energy supply increases to 98.6%. If there was no cap on CHP unit capacity for FIT subsidies, then it is reasonable to assume that 100% of total renewable energy supply could be achieved within a similar financial and environmental range.

Compared with scenario 3, the GHG emission reduction is slightly improved again, seeing a 36,500 $tCO_2e$ reduction which is 4.8% of the whisky industry emissions in 2015. The land area required is only slightly higher than scenario 3 at 7.2% on a mean value basis which again sounds feasible but would require further investigation into current usage.

A £31m capital investment would be required with results again estimating a 7 year payback period. To look in more detail at whether the CHP unit improves the yearly financial situation with the reduction in imported electricity as well as the FIT income, the 'total yearly income' figure 'with subsidies' can be compared from *Table 41* against *Table 37*. This actually shows that, taking everything into account, there is a higher yearly income in scenario 3 with no CHP unit, i.e. the income from FIT and electricity bills savings are not enough to offset the high capital and operational costs associated with CHP systems. Without any subsidies, the payback period jumps up to 32 years, which is 10 years more than scenario 3 due to the CHP unit.

## 4.7 Scenario 5 - Individual AD Plants

### Technical Configuration

For the purpose of comparison, a final scenario is considered where every distillery has an individual anaerobic digestion plant sized to their own by-products, and a CHP system and biogas boiler (if required) sized to the biogas yields of the AD plant. Using the same values as previously calculated for energy yield from biogas for the individual distilleries, electrical and thermal outputs were calculated assuming the same thermal and electrical efficiencies for CHP systems with results shown in *Table 42*. The individual values are totalled in order to allow a gross value comparison with the previous scenarios.

Due to the FIT payment cap at 500kWe capacity CHP systems from 2017, it is assumed that none of the distilleries would have a CHP system of any higher than this capacity. The only distillery with enough energy available from biogas to support a larger CHP system is Caol Ila, so the calculations assume a 500kWe CHP unit along with a biogas boiler to optimise the thermal output.

### Energy Analysis and Results

After parasitic energy demand has been deducted, the useful electrical and thermal energy outputs for each distillery AD plant were calculated and shown in *Table 42*. The bottom section of the table shows values for all distilleries total outputs.

| Individual AD Plants with CHP | | | | | | | |
|---|---|---|---|---|---|---|---|
| Distillery | Equipment | Electrical Energy Out (MWh) | | | Thermal Energy Out (MWh) | | |
| | | Lower | Mean | Upper | Lower | Mean | Upper |
| Ardbeg | CHP | 1105 | 1300 | 1495 | 893 | 1051 | 1208 |
| Laphroaig | CHP | 1961 | 2307 | 2653 | 1585 | 1864 | 2144 |
| Lagavulin | CHP | 2141 | 2519 | 2896 | 1730 | 2036 | 2341 |
| Bruichladdich | CHP | 1195 | 1406 | 1617 | 966 | 1136 | 1307 |
| Bunnahabhain | CHP | 1420 | 1671 | 1921 | 1148 | 1350 | 1553 |
| Bowmore | CHP | 1150 | 1353 | 1556 | 929 | 1093 | 1257 |
| Caol Ila | CHP & Biogas Boiler | | 3745 | | 6395 | 8515 | 10635 |
| Kilchoman | CHP | 136 | 161 | 185 | 110 | 130 | 149 |
| Gross Values | | Electricity | | | Heat | | |
| | | Lower | Mean | Upper | Lower | Mean | Upper |
| Useful Output (MWh) | | 14311 | 16837 | 19362 | 11567 | 13608 | 15649 |
| Percentage of Requirement | | 225% | 305% | 412% | 7.7% | 10.4% | 14.1% |
| | | Electricity and Heat | | | | | |
| | | Lower | | Mean | | Upper | |
| Percentage Total Requirement | | 10.4% | | 14.1% | | 19.1% | |

Table 42 – Individual AD Plant Energy Outputs (CHP)

In every case, the electrical demand of the distilleries are met 100% by the electrical output from the CHP, with surplus for exporting to the grid. The thermal energy is enough to reduce the heating demand by 8-14%.

Totalling the electrical and thermal energy used from the CHP system together shows an overall energy reduction of 10.4 – 19.1%. Note that this does not include the energy exported to the grid, it only counts the actual requirement which has been provided by the CHP output.

Alternatively, biogas boilers alone may be used in order to optimise the thermal energy reduction specifically. This situation results in higher overall percentage reductions, in the range of 20-37% on an overall basis as displayed in *Table 43*.

| Individual AD Plants with Biogas Boilers | | | |
|---|---|---|---|
| | Lower | Mean | Upper |
| Percentage of thermal requirement | 20.5% | 28.3% | 38.3% |
| Percentage of total requirement | 19.7% | 27.2% | 36.8% |

Table 43 – Percentage of Demand Met (Biogas Boilers)

### Financial and Environmental Analysis Results

*Table 44* shows the results of the analysis performed assuming a CHP unit at every distillery, with *Table 46* displaying the results assuming only biogas boilers are used for thermal energy supply.

#### *CHP Systems*

| Table 44 – Scenario 5a Financial and Environmental Analysis Results | | |
|---|---|---|
| **Equipment** | CAPEX | OPEX |
| 8 off AD plants | -£13,785,957 | -£1,456,306 |
| 8 off CHP systems | -£2,021,000 | -£101,050 |
| 1 off biogas boiler | -£81,932 | -£4,097 |
| **Fuel Saving** | | **Cost** |
| Fuel oil reduction of 1.5 million litres per year | | £696,384 |
| Electricity import reduction | | £601,878 |
| **Subsidies Income** | | **Cost** |

| Table 44 – Scenario 5a Financial and Environmental Analysis Results | |
|---|---|
| RHI from CHP and biogas systems | £297,128 |
| FIT from CHP systems | £633,062 |
| **Others** | **Cost** |
| Saving from transportation of pot ale | £282,534 |
| **GHG Emission Reduction** | **Value** |
| Saving from pot ale transportation | 151 $tCO_2e$ |
| Saving from fuel oil reduction | 4,813 $tCO_2e$ |
| Net effect of importing/exporting electricity | 6,938 $tCO_2e$ |

*Summary of Results*

| Table 45 – Scenario 5a Results Summary | | |
|---|---|---|
| **Total Capital Investment Required** | | -£15,888,889 |
| **Percentage of Fuel Oil Reduction** | | 10.4% |
| **Net Energy Reduction (electricity and fuel oil)** | | 14.1% |
| **Yearly GHG Emissions Saving** | | 11,901 $tCO_2e$ |
| **Land Use Change** | | 0% |
| | **With Subsidies** | **Without Subsidies** |
| **Total Yearly Income** | £949,534 | £19,343 |
| **Payback Period** | 17 years | 822 years |
| **Profit/Loss at end of 20 years** | £3,101,787 | -£15,502,026 |

*Biogas Boilers*

| Table 46 – Scenario 5b Financial and Environmental Analysis Results | | |
|---|---|---|
| **Equipment** | CAPEX | OPEX |
| 8 off AD plants | -£13,785,957 | -£1,456,306 |
| 8 off biogas boilers | -£604,464 | -£30,223 |
| **Fuel Saving** | | **Cost** |
| Fuel oil reduction of 3.3 million litres per year | | £1,497,250 |
| **Subsidies Income** | | **Cost** |
| RHI from biogas systems | | £653,079 |

| Table 46 – Scenario 5b Financial and Environmental Analysis Results | |
|---|---|
| **Others** | **Cost** |
| Saving from transportation of pot ale | £282,534 |
| **GHG Emission Reduction** | **Value** |
| Saving from pot ale transportation | 151 $tCO_2e$ |
| Saving from fuel oil reduction | 10,348 $tCO_2e$ |

*Summary of Results*

| Table 47 – Scenario 5b Results Summary | | |
|---|---|---|
| **Total Capital Investment Required** | | -£14,390,421 |
| **Percentage of Fuel Oil Reduction** | | 28.3% |
| **Net Energy Reduction (electricity and fuel oil)** | | 27.2% |
| **Yearly GHG Emissions Saving** | | 10,499 $tCO_2e$ |
| **Land Use Change** | | 0% |
| | **With Subsidies** | **Without Subsidies** |
| **Total Yearly Income** | £946,333 | £293,254 |
| **Payback Period** | 16 years | 50 years |
| **Profit/Loss at end of 20 years** | £4,536,246 | -£8,525,336 |

## Discussion

Including CHP units at every distillery limits the potential for thermal energy supply, with a result of only 10.4% being calculated. As electricity is generated, the percentage of total demand provided increases to 14.1%, which is still a very low result compared with previous scenarios. If only using biogas boilers, then these numbers increase to 28.3% fuel oil reduction and 27.2% total renewable energy supply. These results are expected due to the relative high demand for thermal energy. CHP units at each distillery provide a large excess of electricity, shown to be in the range 225-412% in *Table 42*. For the calculation of total demand met, only the actual energy used by the distillery has been considered since this is the ultimate aim of the study; to investigate the possible renewable energy supply. It was not deemed appropriate to also include exported electricity, as this would be offsetting thermal demand which would provide inaccurate results. Therefore the maximum possible benefit which could result from electricity generation is 4% on a total demand basis. Over-delivering on electricity then restricts the potential for thermal demand reduction which shows that CHP is a less desirable use for the produced biogas. This problem could be overcome by sizing the CHP units to meet the electrical demand with no surplus, coupled with storage to optimise the generated electricity, allowing supply and demand matching. The remaining biogas could then be used in biogas boilers to increase the thermal energy supply. This would of course have financial implications, with greater capital being required, the extent of which would require further investigation.

The situation is reversed when considering the GHG emissions reduction, with scenario 5b outperforming 5a. This is because the benefit from exporting electricity is included in this calculation. The emissions reduction with CHP systems is around 12,000 $tCO_2e$ per year, and with only biogas boilers it is 10,500 $tCO_2e$. These values are comparable with scenarios 1 and 2. As the AD plants would be on the distillery land, there would be restricted space which is why additional feedstocks were not considered and therefore no land on Islay would be required to change use.

The investment required for both options is similar at £15.9m for CHP units and £14.4m for biogas boilers. The payback periods with subsidies are also similar at 17 and 16 years for CHP units and biogas boilers respectively. Without subsidies however, the results are very different at 822 years with CHP units and 50 years with biogas boilers. Even with the subsidies, the payback periods are fairly high which reduces the chance of interest from investors.

## 4.8 Comparison of Scenario Results

The following section summarises the main results of each scenario and presents them side by side for direct comparison. *Table 48* contains descriptions of each scenario for ease of reference. Each of the graphs display the mean value from the results.

| KEY | Description |
|---|---|
| Scenario 1 | Central AD plant, provided biogas to distilleries for use in biogas boilers. |
| Scenario 2 | Central AD plant plus CHP system, provides remaining biogas to distilleries for use in biogas boilers. Biomass drying with on-site CHP thermal energy. |
| Scenario 3 | Central AD plant which dries the required quantity of biomass to supply 100% of distilleries thermal demands. Energy crop added to feedstock. |
| Scenario 4 | Central AD plant plus CHP system which dries the required quantity of biomass to supply 100% of distilleries thermal demands. Energy crop added to feedstock. |
| Scenario 5 | Individual AD plants at distilleries with either CHP systems (5a) or biogas boilers (5b) |

Table 48 – Scenario Key

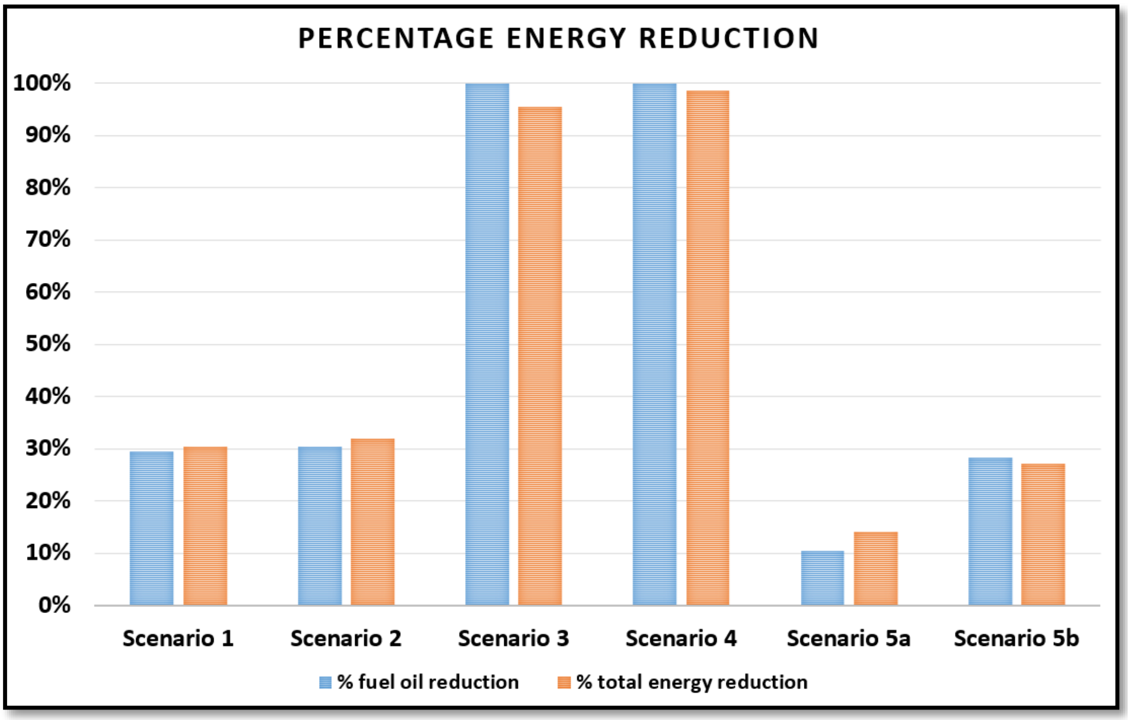


Figure 31 – Comparison of Energy Reductions

The main aim of this study was to investigate possibile solutions for providing a renewable energy supply to meet the demands of the distilleries on Islay, so the first comparison relates directly to this. *Figure 31* shows both the percentage fuel oil reduction (i.e. supply of thermal energy) and total energy reduction (i.e. supply of both thermal and electrical energy). Scenarios 1, 2 and 5b all have similar results at around 30%. Scenario 5a has the lowest result, with only a 10% fuel oil reduction due to the use of CHP rather than biogas boilers. Scenarios 3 and 4 have the highest results as they used backward working methodology in order to assess the feasibility of meeting 100% of the thermal demands. Due to the relatively small proportion of total demand the electrical demand makes up (around 4%), meeting 100% of the thermal demand automatically results in a high total demand reduction.

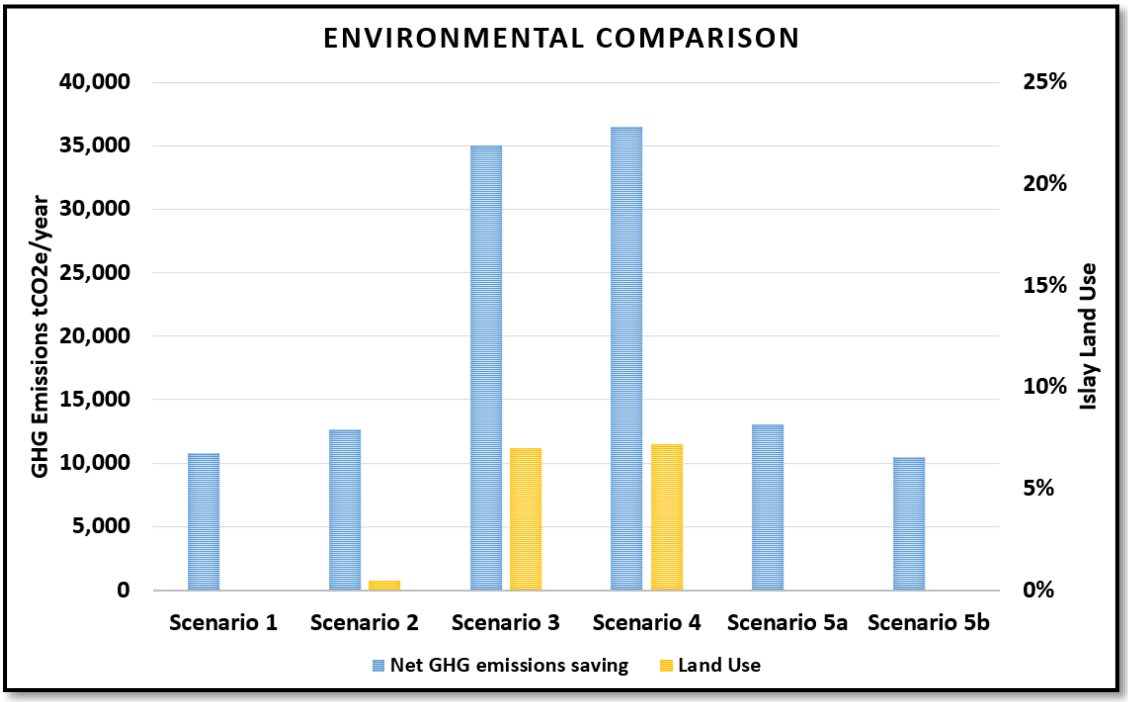


Figure 32 – Comparison of GHG Emissions and Land Required

*Figure 32* goes on to compare environmental factors, in this case GHG emissions reductions and land use change. It is clear that the effect on emissions is greatly influenced by the reduction in fuel oil, with scenarios 3 and 4 again showing the highest results. However the payoff for this benefit is the highest resulting land use change, with around 7% of the area of Islay being required to grow willow and sugar beet to meet the high thermal demand of the distilleries. Because Islay has such a low population density, it could be the case that there would not be adverse effects of this level of land use change, however further studies into specific current land use would be required to determine whether this was feasible.

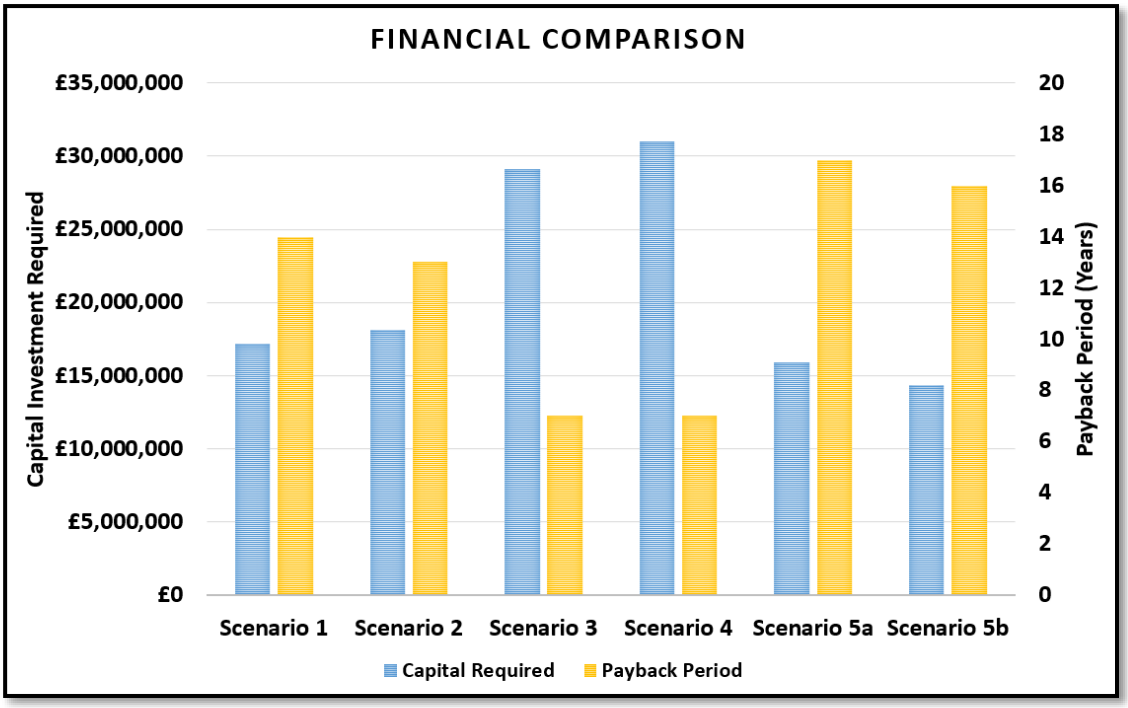


Figure 33 – Comparison of Capital and Payback Period

*Figure 33* compares the main financial aspects, in particular the initial capital investment required along with the payback period. Interestingly the scenarios with the highest capital required (3 and 4) also have the lowest payback periods. This is due to the high savings from eliminating the reliance on fuel oil. It is difficult to identify any cut-off marks which would define which options are financially feasible or not as this depends on investors' ideas about ideal payback periods. However if this type of project was to be jointly funded by those receiving the benefits themselves, perhaps they would favour longer than usual payback periods due to the longer term continued benefits. Diageo is one of the owners of distilleries on Islay and they are known to have invested heavily in other renewable energy projects which suggests they may be interested in further projects.

# 5.0 Discussions

## 5.1. Technical

The technology itself is well established, therefore it is known that these concepts are technically feasible. It is more a question of configuration, with some scenarios proving to be more successful than others.

The pumping of feedstocks requires deeper research which should include actual testing to identify specific material properties. It is still considered to be technically feasible, however the energy required must be confirmed.

Unless there is a constant thermal demand at the location of biogas use, a solution to biogas storage is required. In this case, the drying of biomass provides a solution. Biogas is not easily stored due to the high composition of $CO_2$ which would require large volumes to store at lower pressure. An alternative solution could be to convert to biomethane, the potential energy savings and financial viability of which would have to be analysed.

The study could be used as a model which can be applied to other locations that have a regular supply of organic waste or by-products. For example, a fishing port which may have processing plants in close proximity could utilise the high biogas yielding fish waste in a central plant rather than transporting it to a disposal site.

The greatest results in terms of percentage of energy supply comes from focussing on the production of thermal energy, rather than electrical. This is because the total energy demand of distilleries is composed of 96% thermal and only 4% electrical; therefore the maximum benefit which can be achieved from electricity production is 4% of the total energy requirements.

## 5.2. Environmental

The results suggest that it could be possible to entirely eliminate the distilleries reliance on fossil fuel for heating which would require the use of all available feedstocks. Scenario 4 shows a GHG emission reduction of 36,500 $tCO_2e$/year.

By drying biomass as a way to 'store' the energy from biogas, an additional benefit is found in that the energy available is effectively tripled (compared with the energy available in the biogas which is used to dry the biomass). This of course comes at a cost; in this case, a lot of land would be required for harvesting of willow. But there is a low population density on Islay, and only around 7% of the land would be required for this purpose.

## 5.3. Financial

Currently, most biogas plants in the UK use CHP systems as higher income has been made from the feed-in tariff. However with the degression of tariffs, the results here show that FIT is now so low that it may not compensate for the high capital and on-going costs associated with CHP systems. Therefore the use of biogas boilers is more profitable, provided there is a use for the heat on site since thermal energy cannot be transported easily.

Sugar beet is an expensive energy crop, but was selected because of the high energy yield per hectare in order to reduce the land area required. With the results showing reasonable land usage, it may be possible to select a cheaper alternative energy crop, which uses more land area.

The lowest payback period is 7 years, for both scenarios 3 and 4, which also require the highest capital investment. At over £30 million for scenario 4, this is considered reasonable based on reports of other similar projects capital requirements such as Cameronbridge distillery which required £65 million.

## 5.4. Social

It is important to consider the social implications of a project of this scale, especially in such a remote area as it could be more sensitive to change. There could be a negative effect with regards to jobs; for example Gleaner Oil on the island supplies the fuel oil which a large proportion of goes to the distilleries. Without this income revenue, the business would suffer and jobs could be lost. Likewise with the end to the transportation of pot ale to the discharge point; it was disclosed that this is carried out by local people which they would no longer be required to do. In both cases due to the remoteness of the location, the solution would not be as simple as finding work elsewhere. Having said that, keeping people in a job should not be a barrier to projects with such environmental benefits.

The employment situation would not all be negative however, there would also be opportunities for job creation. A centralised AD plant would require staff for operation. There is also the need for more diverse farming activities with the requirement for willow and energy crops. Although a recent study[64] has shown that a high proportion of farmers would not choose to switch from livestock to energy crop farming, Islay's dairy farming industry has been on the decline for a number of years. Therefore it could be possible that farmers here would be happier to make the switch to energy crops if it is the only viable option.

General logistics mustn't be overseen. Having spoken with a member of the IET, it became clear that Islay has over the years, settled into a balanced routine. Making sudden changes can have knock on effects to many other aspects. For example it was stated that the grain which is imported onto the island by truck via the ferry also collects the spent grain which is exported on the return journey and used for animal feed. Removing the return load would increase the cost of grain. It is not known to what degree this would affect the price, however it must be considered.

There is an opportunity for community benefits in the longer term. The IET are involved in many renewable energy projects on the island which not only improves the environment, but also provides income for the community. After the payback period, there is a lot of cost savings available for the distilleries, a percentage of this could be fed back to the community to benefit the wider island. Working together with a community in such a way is more likely to gain the support of locals rather than encourage resistance.

[64] (Warren, Burton, Buchanan, & Birnie, 2016)

## 5.5. Critical Evaluation

The methodology and approach taken when carrying out this study has been logical, allowing reasonable estimates to be calculated for each scenario. However a number of shortfalls have prevented greater accuracy of results:

- Lack of real data from distilleries – exact energy demands and by-product quantities;
- Lack of accurate costs of equipment – due to commercial sensitivity, companies were not willing to provide cost information;
- Lack of time, specific expertise and accurate details of by-product properties prevented an in-depth analysis of pumping energy requirements.

With exact distillery data and accurate costs, single results could have been obtained for each scenario rather than a range, of which the mean value was taken as the estimated answer. Although it is unlikely for any of the results to fall at either the extreme best or worst case estimate, it is equally unlikely that it would fall exactly in the middle.

The investigation into pumping energy exposed the complexity of the situation, with physical testing of the by-products being a requirement for exact inputs to the analysis. Accurate results would identify exact electricity requirements, which could change the financial and environmental results to some degree.

# 6.0 Conclusions

It was shown that the distillery feedstocks alone could only provide around 30% of their energy requirements, with central plant scenarios opening up further options to increase the potential supply by adding additional feedstocks compared with individual plants at each distillery due to space required for larger digesters.

Where thermal demands greatly outweigh electrical, the advice based on this study would be to optimise the potential thermal output by drying biomass which can be easily stored and used when required. This maximises the reduction of fossil fuel reliance and therefore achieves maximum GHG emission reductions.

Based on the results and discussions of this study, in the specific case of the whisky distilleries on Islay, scenario 4 would be the chosen option. It provides the greatest total energy (98.6%) and GHG emissions reduction (36,500 $tCO_2e$), which requires a realistically achievable area of land on the island (7.2%). The financial income is slightly lower than that of scenario 3, however has the same payback period of 7 years and is deemed acceptable due to the other benefits.

It is accepted that case by case analyses would be required for other geographical locations as land availability/suitable feedstocks/energy demands etc. will all differ.

This of course assumes the continued support from various subsidy schemes. Subsidies are paramount to the viability of these projects; as degressions continue in future years, long payback periods would be required and as such, would not be financially viable.

# 7.0 Further Work

The results of the analysis and conclusion open opportunities for further work:

- Real data on energy usage from distilleries and equipment costs would help to refine the results.
- Dynamic energy data would allow an analysis of supply and demand matching, which could identify how much biogas would be wasted, or how much storage would be required to cover periods of low demand.
- A comparison of the feasibility of biogas conversion to biomethane against drying of biomass could be conducted.
- A study into the feasibility of using fuel cells instead of CHP would be interesting. They have very high up-front costs, but little to no maintenance required so could be cheaper in the long run. With higher efficiencies, they could provide an innovative solution where both electrical and thermal demands are a requirement.

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# Appendices

## Appendix A: Energy Values

*Table 49* shows a selection of the data obtained from a study conducted in 2015[65]. The total energy, whisky production and electricity were all supplied by the distilleries. The yellow column at the end was calculated for the Islay study, to isolate the thermal energy from electricity as it is of more interest here. Total thermal energy per year against volume of whisky produced was plotted in a graph to investigate the relationship.

| Distillery | Total Energy (kWh/year) | Whisky Production (l/year) | Electricity (kWh/year) | Heat (kWh/year) |
|---|---|---|---|---|
| A | 13960000 | 1500000 | 400000 | 13560000 |
| B | 270300 | 20000 | 9000 | 261300 |
| C | 11898820 | 1400000 | 411120 | 11487700 |
| D | 8505500 | 920600 | 427800 | 8077700 |
| E | 45208000 | 6200000 | 1888000 | 43320000 |
| F | N/A | 140000 | N/A | N/A |
| G | 21551700 | 2400000 | 1011500 | 20540200 |
| H | 26220000 | 2700000 | N/A | N/A |
| I | 87600000 | 10000000 | 3600000 | 84000000 |

Table 49 – Energy Figures from Past Study

Graphical representation of yearly energy demands against total whisky produced:

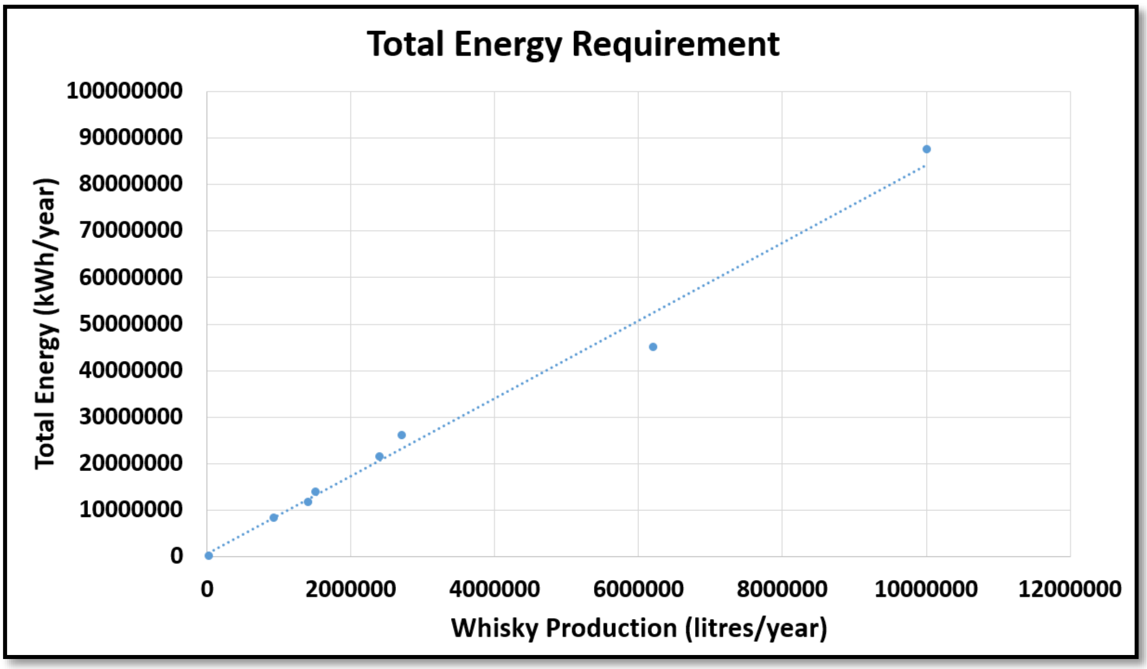


Figure 34 – Total Energy Demand V Annual Whisky Production

65 (Meadows, 2015)

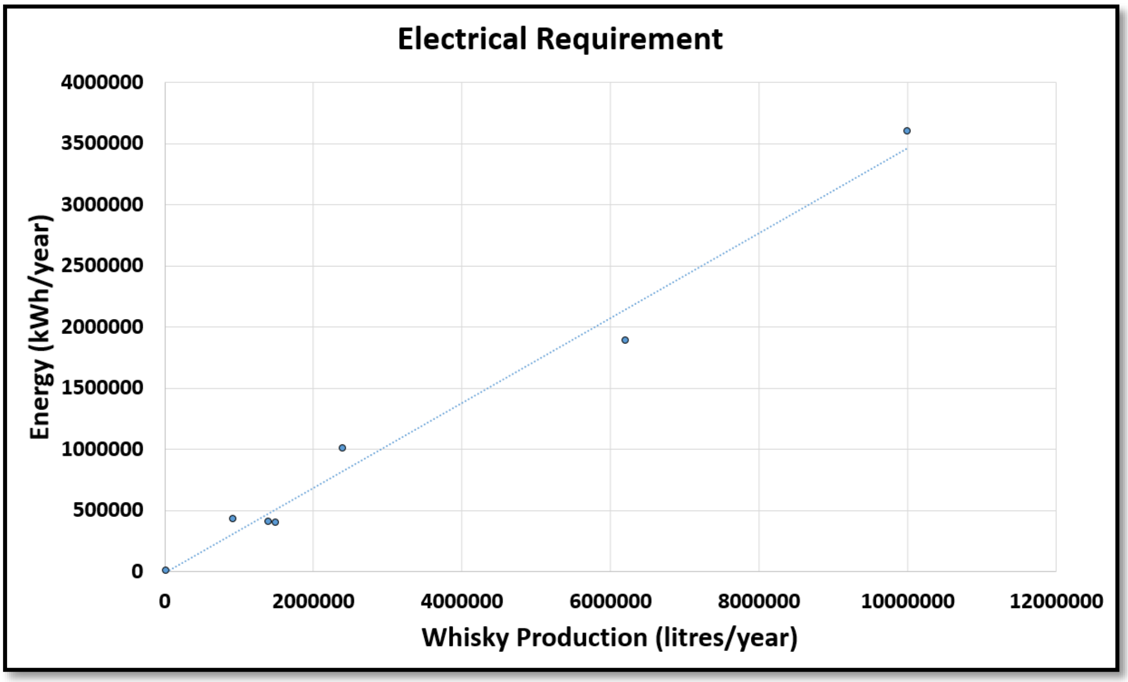


Figure 35 – Electrical Demand V Annual Whisky Production

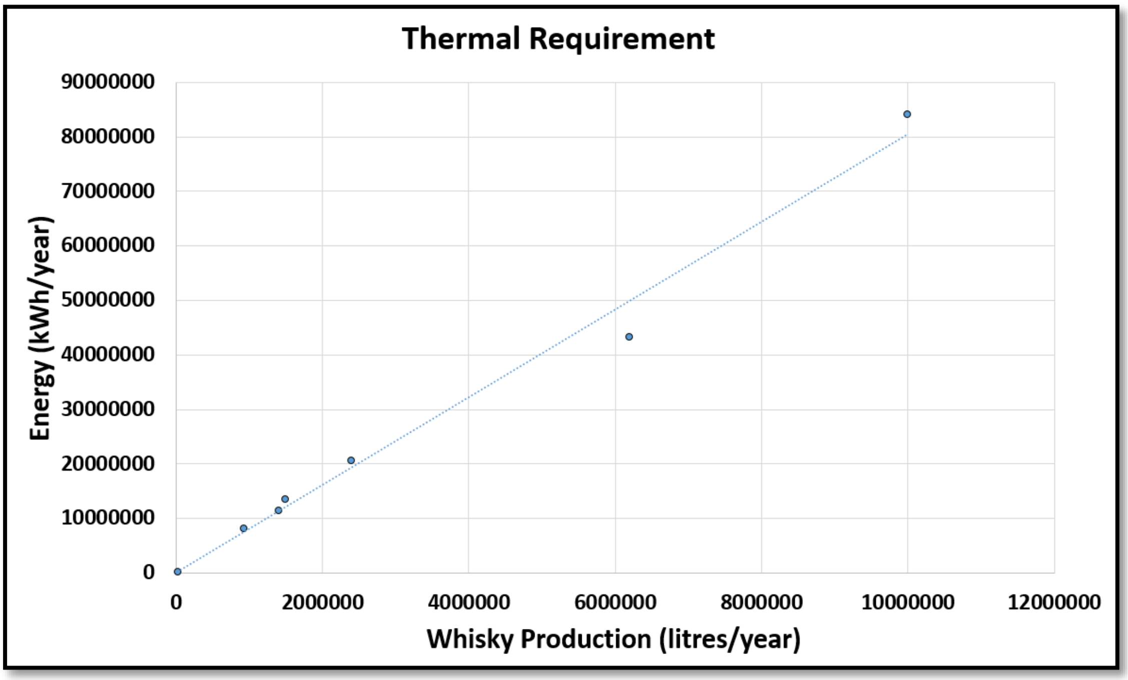


Figure 36 – Thermal Demand V Annual Whisky Production

There is a clear linear relationship between energy demand figures and the total annual whisky produced as can be seen in the figures above. Therefore, these relationships were used to estimate energy values for Islay distilleries using upper and lower error bands, forming a range between best and worst case scenarios.

# Appendix B: By-Product Quantities

## *Draff*

*Table 50* shows draff quantities obtained from a study conducted in 2015[66].

| Distillery | Whisky Production (litres/year) | Draff Weight (tonnes/year) |
|---|---|---|
| A | 1500000 | 3750 |
| B | 20000 | 5.4 |
| C | 1400000 | 3164 |
| D | 920600 | 2234 |
| E | 6200000 | 14500 |
| F | 140000 | 360 |
| G | 2400000 | 6166 |
| H | 2700000 | 8280 |
| I | 10000000 | 25000 |

Table 50 – Draff figures from past study

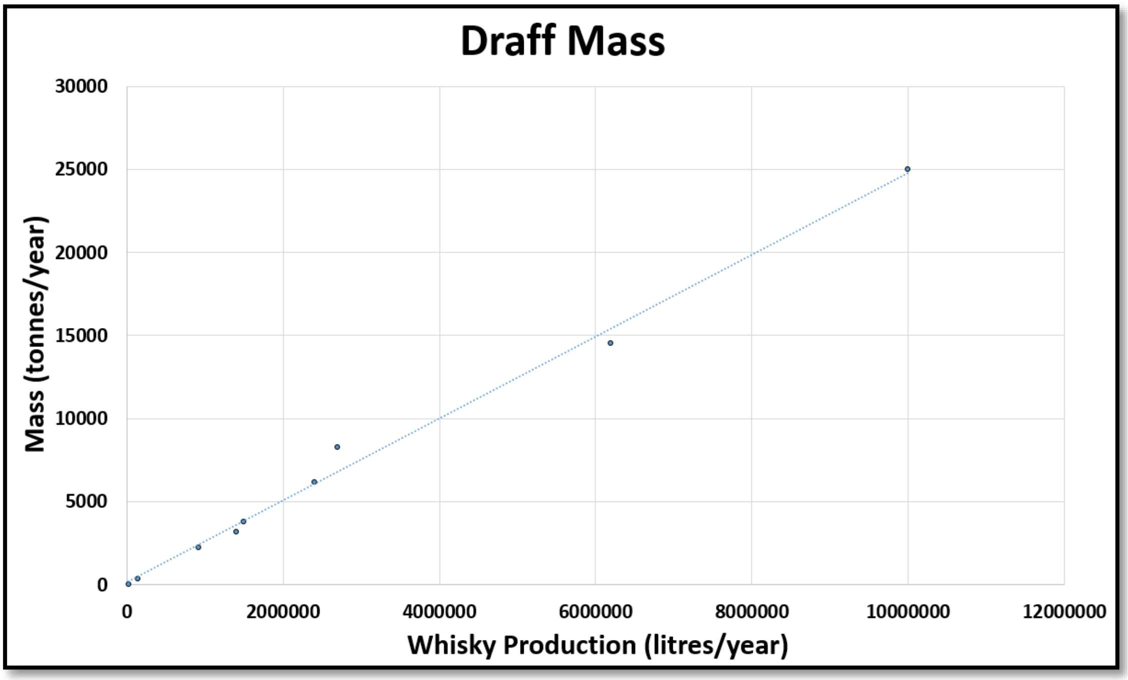


Figure 37 – Draff Mass V Whisky Production

[66] (Meadows, 2015)

*Pot Ale*

*Table 51* shows pot ale quantities obtained from a study conducted in 2015[67].

| Distillery | Whisky Production (litres/year) | Pot Ale Volume (litres/year) |
|---|---|---|
| C | 1400000 | 5300000 |
| E | 6200000 | 50688000 |
| F | 140000 | 1100000 |
| G | 2400000 | 19125000 |
| I | 10000000 | 75413000 |

Table 51 – Pot ale figures from past study

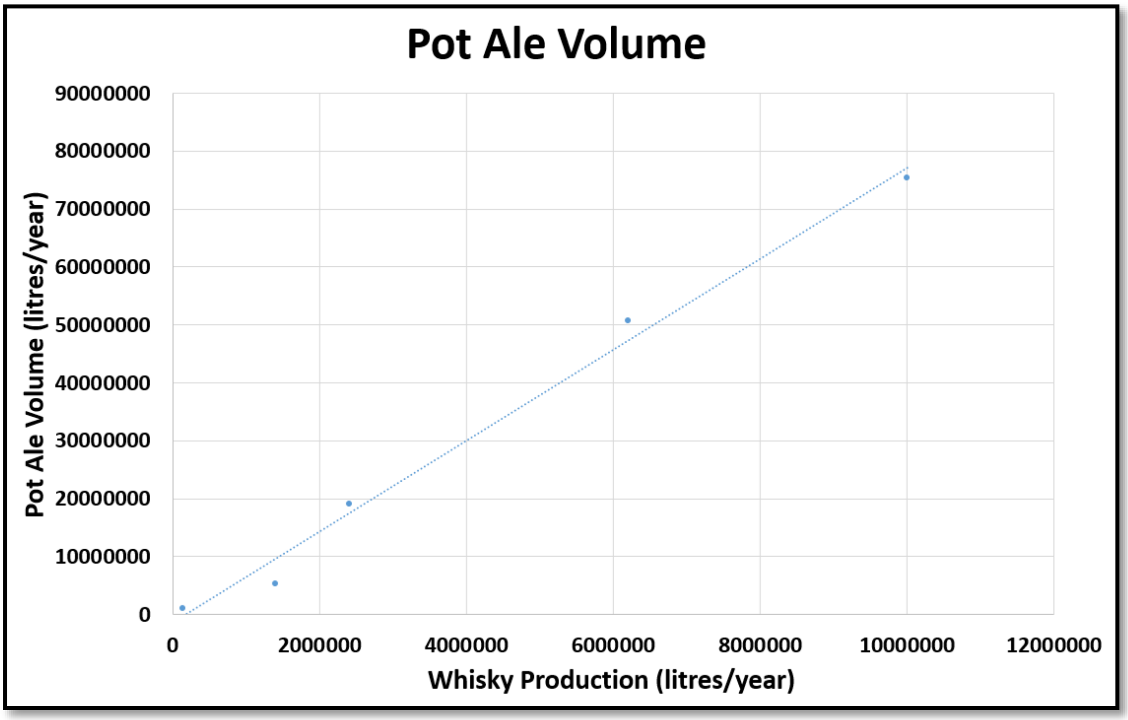


Figure 38 – Pot Ale Volume V Whisky Production

[67] (Meadows, 2015)

# Appendix C: Energy Analysis Calculations

**Feedstock Mass Estimations:**

(Figures extracted from Excel graphs)

| | Pot Ale Mass (per year): | Draff Mass (per year): |
|---|---|---|
| Lower: | $PA_l \equiv 100552\ \textbf{tonne}$ | $Draff_l \equiv 35008\ \textbf{tonne}$ |
| Mean: | $PA_m \equiv 118296\ \textbf{tonne}$ | $Draff_m \equiv 41186\ \textbf{tonne}$ |
| Upper: | $PA_u \equiv 136041\ \textbf{tonne}$ | $Draff_u \equiv 47363\ \textbf{tonne}$ |

Food waste mass (per year): $FW \equiv 267\ \textbf{tonne}$

**Distillery Thermal Requirement Estimations (from Excel graphs):**

Lower: $Thermal_l \equiv 110755\ \boldsymbol{W} \cdot \boldsymbol{hr} \cdot 10^6$

Mean: $Thermal_m \equiv 130300\ \boldsymbol{W} \cdot \boldsymbol{hr} \cdot 10^6$

Upper: $Thermal_u \equiv 149845\ \boldsymbol{W} \cdot \boldsymbol{hr} \cdot 10^6$

**Biogas Yield:**

Yield from pot ale

Pot ale gas yield from total solids (TS) after 31 days $Biogas_{potale31} \equiv 700\ \frac{\boldsymbol{m}^3}{\textbf{tonne}}$

Pot ale gas yield from total solids (TS) after 7 days (85% of potential yield) $Biogas_{potale7} \equiv Biogas_{potale31} \cdot 0.85 = 595\ \frac{\boldsymbol{m}^3}{\textbf{tonne}}$

Pot ale dry matter $DM_{potale} \equiv 4.38\%$ "(TS)"

$$YieldPA_l \equiv PA_l \cdot Biogas_{potale7} \cdot DM_{potale} = 2620485.672\ \boldsymbol{m}^3$$

$$YieldPA_m \equiv PA_m \cdot Biogas_{potale7} \cdot DM_{potale} = 3082912.056\ \boldsymbol{m}^3$$

$$YieldPA_u \equiv PA_u \cdot Biogas_{potale7} \cdot DM_{potale} = 3545364.501\ \boldsymbol{m}^3$$

Yield from draff

Draff gas yield from total solids (TS) after 31 days $Biogas_{draff31} \equiv 628\ \frac{\boldsymbol{m}^3}{\textbf{tonne}}$

Draff gas yield from total solids (TS) after 11 days (85% of potential yield) $Biogas_{draff11} \equiv Biogas_{draff31} \cdot 0.85 = 533.8\ \frac{\boldsymbol{m}^3}{\textbf{tonne}}$

Yield from draff

Draff gas yield from total solids (TS) after 31 days $Biogas_{draff31} \equiv 628 \ \frac{m^3}{tonne}$

Draff gas yield from total solids (TS) after 11 days (85% of potential yield) $Biogas_{draff11} \equiv Biogas_{draff31} \cdot 0.85 = 533.8 \ \frac{m^3}{tonne}$

Draff dry matter $DM_{draff} \equiv 21.7\%$ “(TS)”

$$YieldDraff_l \equiv Draff_l \cdot Biogas_{draff11} \cdot DM_{draff} = 4055137.677 \ m^3$$

$$YieldDraff_m \equiv Draff_m \cdot Biogas_{draff11} \cdot DM_{draff} = 4770763.836 \ m^3$$

$$YieldDraff_u \equiv Draff_u \cdot Biogas_{draff11} \cdot DM_{draff} = 5486274.16 \ m^3$$

Yield from Food Waste

Biogas yield per tonne of fresh food waste $Biogas_{FW} \equiv 110 \ \frac{m^3}{tonne}$

Total biogas yield per year $YieldFW \equiv FW \cdot Biogas_{FW} = 29370 \ m^3$

Total biogas yield per annum

Excluding food waste:

$$TotalYield_l \equiv YieldPA_l + YieldDraff_l = 6675623.349 \ m^3$$

$$TotalYield_m \equiv YieldPA_m + YieldDraff_m = 7853675.892 \ m^3$$

$$TotalYield_u \equiv YieldPA_u + YieldDraff_u = 9031638.661 \ m^3$$

Including food waste:

$$TotYieldFW_l \equiv YieldPA_l + YieldDraff_l + YieldFW = 6704993.349 \ m^3$$

$$TotYieldFW_m \equiv YieldPA_m + YieldDraff_m + YieldFW = 7883045.892 \ m^3$$

$$TotYieldFW_u \equiv YieldPA_u + YieldDraff_u + YieldFW = 9061008.661 \ m^3$$

**Combustion Energy Output Potential:**

Biogas is made up of 55-60% methane and 40-45% carbon dioxide. Take lower value of 55% methane for calculations.

$Methane \equiv 55\%$

Energy available per m^3 methane $I_W \equiv 36 \frac{J \cdot 10^6}{m^3}$

Pot ale only:

$MethanePA_l \equiv YieldPA_l \cdot Methane = 1441267.12\ m^3$

$MethanePA_m \equiv YieldPA_m \cdot Methane = 1695601.631\ m^3$

$MethanePA_u \equiv YieldPA_u \cdot Methane = 1949950.476\ m^3$

Draff only:

$MethaneDraff_l \equiv YieldDraff_l \cdot Methane = 2230325.722\ m^3$

$MethaneDraff_m \equiv YieldDraff_m \cdot Methane = 2623920.11\ m^3$

$MethaneDraff_u \equiv YieldDraff_u \cdot Methane = 3017450.788\ m^3$

Food waste only:

$MethaneFW \equiv YieldFW \cdot Methane = 16153.5\ m^3$

Pot ale and draff total:

$MethaneTotal_l \equiv TotalYield_l \cdot Methane = 3671592.842\ m^3$

$MethaneTotal_m \equiv TotalYield_m \cdot Methane = 4319521.74\ m^3$

$MethaneTotal_u \equiv TotalYield_u \cdot Methane = 4967401.263\ m^3$

Pot ale and draff total (including food waste):

$MethaneTotFW_l \equiv TotYieldFW_l \cdot Methane = 3687746.342\ \boldsymbol{m^3}$

$MethaneTotFW_m \equiv TotYieldFW_m \cdot Methane = 4335675.24\ \boldsymbol{m^3}$

$MethaneTotFW_u \equiv TotYieldFW_u \cdot Methane = 4983554.763\ \boldsymbol{m^3}$

Energy available:

Pot ale only:

$EnergyPA_l \equiv MethanePA_l \cdot I_W = 14412.671\ \boldsymbol{MW \cdot hr}$

$EnergyPA_m \equiv MethanePA_m \cdot I_W = 16956.016\ \boldsymbol{MW \cdot hr}$

$EnergyPA_u \equiv MethanePA_u \cdot I_W = 19499.505\ \boldsymbol{MW \cdot hr}$

Draff only:

$EnergyDraff_l \equiv MethaneDraff_l \cdot I_W = 22303.257\ \boldsymbol{MW \cdot hr}$

$EnergyDraff_m \equiv MethaneDraff_m \cdot I_W = 26239.201\ \boldsymbol{MW \cdot hr}$

$EnergyDraff_u \equiv MethaneDraff_u \cdot I_W = 30174.508\ \boldsymbol{MW \cdot hr}$

Foodwaste only:

$EnergyFW \equiv MethaneFW \cdot I_W = 161.535\ \boldsymbol{MW \cdot hr}$

Pot ale and draff total:

$Energy_l \equiv MethaneTotal_l \cdot I_W = 36715.928\ \boldsymbol{MW \cdot hr}$

$Energy_m \equiv MethaneTotal_m \cdot I_W = 43195.217\ \boldsymbol{MW \cdot hr}$

$Energy_u \equiv MethaneTotal_u \cdot I_W = 49674.013\ \boldsymbol{MW \cdot hr}$

Pot ale, draff and food waste total:

$EnergyTotFW_l \equiv MethaneTotFW_l \cdot I_W = 36877.463\ \boldsymbol{MW \cdot hr}$

$EnergyTotFW_m \equiv MethaneTotFW_m \cdot I_W = 43356.752\ \boldsymbol{MW \cdot hr}$

$EnergyTotFW_u \equiv MethaneTotFW_u \cdot I_W = 49835.548\ \boldsymbol{MW \cdot hr}$

Power Capacity:

Pot ale only:

$$PowerPA_l \equiv \frac{EnergyPA_l}{365\ \mathbf{day}} = 1.645\ \mathbf{MW}$$

$$PowerPA_m \equiv \frac{EnergyPA_m}{365\ \mathbf{day}} = 1.936\ \mathbf{MW}$$

$$PowerPA_u \equiv \frac{EnergyPA_u}{365\ \mathbf{day}} = 2.226\ \mathbf{MW}$$

Draff only:

$$PowerDraff_l \equiv \frac{EnergyDraff_l}{365\ \mathbf{day}} = 2.546\ \mathbf{MW}$$

$$PowerDraff_m \equiv \frac{EnergyDraff_m}{365\ \mathbf{day}} = 2.995\ \mathbf{MW}$$

$$PowerDraff_u \equiv \frac{EnergyDraff_u}{365\ \mathbf{day}} = 3.445\ \mathbf{MW}$$

Pot ale and draff total:

$$Power_l \equiv \frac{Energy_l}{365\ \mathbf{day}} = 4.191\ \mathbf{MW}$$

$$Power_m \equiv \frac{Energy_m}{365\ \mathbf{day}} = 4.931\ \mathbf{MW}$$

$$Power_u \equiv \frac{Energy_u}{365\ \mathbf{day}} = 5.671\ \mathbf{MW}$$

Pot ale, draff and food waste total:

$$PowerFW_l \equiv \frac{EnergyTotFW_l}{365\ \mathbf{day}} = 4.21\ \mathbf{MW}$$

$$PowerFW_m \equiv \frac{EnergyTotFW_m}{365\ \mathbf{day}} = 4.949\ \mathbf{MW}$$

$$PowerFW_u \equiv \frac{EnergyTotFW_u}{365\ \mathbf{day}} = 5.689\ \mathbf{MW}$$