Circular Economy

June 2015

Sector Study on Beer, Whisky and Fish

Final Report

Contents

Case studies

Inspiring change for Scotland’s resource economy

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1 Executive Summary

In September 2013, an Evidence Gathering Programme was established to better understand how a more circular economy could operate in Scotland and what the benefits might be. The aim is to use the evidence gathered to inform a road map for the circular economy in Scotland. This Sector Study on Beer, Whisky and Fish is one of several studies by Scottish Government as part of this Evidence Gathering Programme, and recognises that there is strong growth potential in these three sectors and also challenges in meeting future growth targets It is intended that the findings from this sector study will inform next steps (including development projects) and longer term work to understand and maximise the employment, growth and opportunities to be achieved by moving towards a circular approach.

Significant stakeholder engagement was carried out to gather data, to understand current practices for managing by-products, the awareness of such approaches and the barriers to change in each of the three sectors. Our methodology included a combination of desk-based review and stakeholder interviews to understand the data currently available and current practices, and to identify circular opportunities. Forty two stakeholders were interviewed as part of this project, ranging from sector bodies, trade associations and research organisations to individual beer, whisky and fish businesses. These stakeholders provided valuable insights into both the realities and the opportunities relating to the wastes and by-products of the three sectors.

In the absence of any formal data collection system for wastes and by-products from the three sectors, various estimates and assumptions have been gathered from published reports and from the stakeholder interviews. These have been reviewed and cross-checked to provide the estimates given in this report. Similarly, information on the current uses and destination of the by-products produced in the three sectors is not formally provided and has had to be inferred from various sources.

On this basis, the authors have estimated the inputs and outputs produced in each sector. The bio-based wastes and by-products produced by each sector are calculated as:

- Beer: 53,682 tonnes
- Whisky: 4,371,000 tonnes
- Fish and shellfish, including aquaculture fish mortalities: 189,538 tonnes

A high level indication of geographical spread of the sectors and potential hotspots of by-product generation is indicated. These various materials are predominantly not landfilled but instead sent to a wide range of destinations including used for local cattle feed, processed into fish feed, spread to land, used to produce heat and power and discharged to sewer. Use of distillery by-products as an animal feed has been important to Scottish cattle farmers in the past and will continue to remain so. New uses of distillery by-products can be integrated and complement the current commercial arrangements of supplying local cattle farmers.

A range of innovative uses for by-products was identified across all three sectors, which would bring considerably higher value, including:

- Processing whisky and brewing by-products into high value biofuels, chemicals and higher nutrition animal and fish feeds including high purity protein and algae production.
- Extracting highly refined protein compounds from fish wastes, for use in human food supplements
- Replacement of imported soya compounds in fishfeeds with protein from Scottish grown beans, bringing both economic and environmental benefits.
- Various niche and local valorisation options suitable for small scale and dispersed sources of wastes and by-products.

Implications for existing users should be considered in any decision on changing use of by-products.

An assessment of possible future applications of by-products across all three sectors identified:

- Strong benefits to a staged development of biorefinery approaches to produce a range of high value chemicals and products from the wastes and by-products from the three sectors

- The ability to extract value from multiple outputs from a by-product, through integrated successive processes, or cascades.
- The opportunity to develop locally adapted low tech entrepreneurial solutions for small scale and geographically dispersed materials in island and rural regions.
- The opportunity to develop new uses for liquid wastes, which are more commonly disposed of at cost to businesses.
- The need for low-energy drying techniques to enable production of transportable and non-perishable high value products
- The relevance of renewable energy generation as both a competitor to material uses of bio-based materials and potentially a complementary integrated solution.
- The relevance of current arrangements of using solid by-products from distilleries and brewers for local animal feed, the limits to these markets and the opportunities to produce both protein-based animal and fish feeds from these materials as well as high value uses of the remaining residues.

It was not possible to perform a comprehensive assessment of added value to the Scottish Economy from higher value circular economy approaches, owing to a shortage of data. However, figures provided by some of the innovators developing such examples, as shown in the relevant case studies in this report, gives an indication of the scale of the economic prize:

- **Celtic Renewables** technology applied to all malt whisky draff would generate an estimated **£100million** of value from the various biofuel and chemical products including the residue suitable for animal feed.
- **Beans4Feeds** has indicated a total value to Scotland of £65 million (of which an estimated **£9.5 million** would accrue to Scottish farmers) from replacement of imported soya products with Scottish grown bean protein for aquaculture feeds and provision of other animal feeds.
- The **PUREOPE** project team has estimated that the polyphenols content of all the malt and grain distillery by-products in Scotland would have a market value of at least **£50million**.
- **CellsUnited** has estimated that if all Scotland's salmon processing waste could be processed using their technology, the added value would exceed **£300 million** from sales of the protein food supplement alone, plus additional value for the separated salmon oil and the residue used as fertiliser.
- **Horizon Proteins** - The total potential value of protein in pot ale and spent wash in Scotland is estimated at £272 million per year, including the residue suitable for animal feed. In theory, this assumes, that all these by-products could be captured across the sector (although it is more realistic to anticipate around **£80million** of value could be realised). However, it should be highlighted that this would require solutions to be viable at distillery level or at a very local level to minimise any travel costs. This is based on 181,000 tonnes of protein in these by-products: almost twice as much as is needed by Scotland's salmon farms. Further details are given in Section 4.2, under 'Protein available for Scottish aquaculture from Scottish whisky distilleries'.

The above figures add up to a potential economic benefit to Scotland of **£595 million** per year. Some caution needs to be applied, as the above figures do not allow for the value of current uses of the by-products in every case and the Celtic Renewables estimate includes a value of protein in pot ale which is also included in the protein calculation for aquaculture feeds. However, there are further potential high value uses of beer, whisky and fish by-products that could be integrated with the above examples whose economic value it has not been possible to calculate. On this basis it seems reasonable to suggest a total economic prize for Scotland of between **£500million and £803million** per year from full implementation of the high value bio-economy opportunities identified in this report.

Based on the findings of our research, we would make the following recommendations:

1. **Cross-sector awareness raising,** working with the stakeholders in the three sub sectors and the research organisations to raise awareness, share information and provide opportunities for collaboration towards higher value uses of wastes and by-products. This could be provided through different channels including workshop events, webinars and knowledge sharing hubs. Amongst other organisations, Zero Waste Scotland (ZWS), Scottish Enterprise, Highlands and

Islands Enterprise (HIE), The Industrial Biotechnology Innovation Centre (IBioIC) and the Biosciences Knowledge Transfer Network (KTN) could contribute to delivering these activities. There is an opportunity here to develop new bio-based circular economy networks in Scotland that once established other sectors and businesses could take part increasing the overall economic benefit.

Recommended action-oriented project: Build on and complement the work being undertaken by the IBioIC by runnning a bioresources awareness-raising programme that addresses circularity and helps build new networks and collaborations, business models and enterprises.

2. **Co-ordination of support, analysis and innovation,** using the existing organisations in Scotland involved in developing the bio-based circular economy. An overarching approach is needed to help Scotland become an international leader in circular economy approaches for bioresources. This might best be provided through one of the existing agencies acting as a focus for circular economy bio-economy activities and should cover policy research, strategy development, technology innovation, market development, skills and knowledge transfer and funding.

   Recommended action-oriented project: Examine the potential for one or more existing agencies to become a focus for circular economy bio-economy activities, covering policy development, strategy, technology innovation, market development, skills and knowledge and funding.

3. **Support for targeted technical innovations,** in at least marine biorefining technologies to extract high value chemicals from fish and shellfish by-products and integrated technologies suitable for distillery and brewery by-products. In both cases, support is needed to better understand the relative costs, logistics and environmental benefits of different processes, and how they can best be integrated. Support is being delivered by the IBioIC.

   Recommended action-oriented project: Support investment in R&D and innovation that increases circularity and helps to develop and commercialise processes which address technical barriers for valorising bio-wastes[1].

4. **Bioresource mapping,** working with the sectors and Scottish agencies to produce a biological resources map to quantify significant concentrations of by-products available or a new system to provide ongoing data for both by-products and wastes. This will allow a co-ordinated approach to logistics serving dispersed sources of wastes and may provide foundation data for future policy development. Recommended types of bioresource mapping are a top level analysis of all bioresources currently (or potentially) available in Scotland, a focus on the wastes and by-products from specific bio-based sectors (including a more detailed analysis of beer, whisky and fish bioresources) and a stocks and flows assessment of key resources of strategic importance to Scotland, such as: protein, nitrogen and phosphate.

   Recommended action-oriented projects:
   a. Carry out a suite of bioresource mapping analyses for specific wastes and by-products and/or for specific bio-based nutrients and products which complements the feedstock mapping undertaken in *'The Biorefinery Roadmap for Scotland'*[2].

   b. Investigate the potential for formal ongoing data collection systems for specific sectors or bioresources as a circular economy enabler.

5. **Rural bio-economy strategy and support,** to develop bio-economy solutions suitable for small scale and dispersed Highlands, Islands and rural businesses. These are likely to involve low tech processes with relatively low capital requirements and that may result in new by-product derived

[1] It is noted that the Norwegian Food Safety Authority have recently developed a new processing/disposal method for fish mortalities. This process is called the Fish Silage Processing Method and has been approved by the European Commission. There is potential to use this processing method in Scotland but consideration should be given to existing facilities before deciding whether it would need investment to build a new facility and investment at a fish farm level.
[2] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap

products for local or niche markets boosting regional food economies. The approach taken to support such innovation will be of a different nature to that need to support more technical processes that need large economies of scale. An initial step may be an open innovation festival or competition designed to attract a wide range of stakeholders, entrepreneurs and practical experts, aimed at highlighting opportunities and exemplars and fostering new collaborations.

Recommended action-oriented project: Establish a programme to support new ideas and enterprises that contribute to rural economic growth through use of appropriate technologies and processes which valorise local and dispersed bioresources. (An initial step may be an open innovation festival or competition designed to attract a wide range of stakeholders, entrepreneurs and practical experts, aimed at highlighting opportunities and exemplars and fostering new collaborations.)

6. **Assess opportunities of regional bio-based circular economy hubs.** There may be economic and environmental benefits from a regional bio-based circular economy hub approach for island or rural regions. This would involve an integrated approach to the main bio-based wastes and by-products with opportunities to use them in different enterprises within the same region, with varying degrees of processing. The concept would be best developed tailored to a particular island's situation and resources and an assessment of suitability of different islands and regions is suggested as an initial step. Two regions that are suggested as candidates for this approach are Orkney and Islay, both of which have distilleries, breweries, fish and shellfish businesses, agriculture, horticulture and a strong hospitality sector.

   Recommended action-oriented project: Carry out assessments of the best locations for initial urban and rural / island bio-based circular economy hubs. Assessment for an urban hub should build on early work carried out by various agencies on optimal locations for biorefineries. Assessment for a rural or island hub should allow not only for a range of dispersed bioresources but also the interest and potential involvement of key stakeholders in that community.

In summary, if the highlighted opportunities for growth and resource efficiency are to be realised it is recommended that Scottish Government and its agencies/ partners work with stakeholders, not only in the beer, whisky and fish sectors, but also the wider bio-based sectors, to develop a strategy to produce a robust and extensive bio-based circular economy in Scotland. This will involve various elements including better data provision, information sharing and collaboration, and a strategic approach to support innovation of both high tech processes as well as locally-adapted new bio-enterprises. It is hoped that the information and insight provided in the report offers a significant foundation for this strategy. As the solutions are all strongly sector focussed it is recommended that the various opportunities are sector-led in order to provide the required buy-in and ownership of businesses within the sector.

2 Introduction

In September 2013, an Evidence Gathering Programme was established to better understand how a more circular economy could operate in Scotland and identify what the benefits may be. The Steering Group for the Programme comprises members from Scottish Government, Scottish Enterprise, SEPA, Zero Waste Scotland and Highlands and Islands Enterprise. The overall aim is to use any evidence gathered to produce a road map for the circular economy with key milestones over the next 5-10 years and ultimately to 2050.

This Sector Study on Beer, Whisky and Fish is one of several studies as part this Evidence Gathering Programme, and recognises that there is strong growth potential in these three sectors and also challenges in meeting future growth targets. It is intended that the findings from this sector study will inform next steps (including development projects) and longer term work to understand and maximise the employment, growth and opportunities from a circular approach.

The Food and Drink sector is an important part of the Scottish economy, employing >116k[3] individuals (360k across the whole supply chain) and accounting for >£4.3bn GVA to the Scottish economy. Developing a better understanding of circular opportunities and barriers to their implementation in the Food and Drink sector could help deliver further economic benefits. The three key sectors in the Food and Drink sector that are the topic of this study – Whisky, Beer and Fish – together account for around 74% of total Food and Drink GVA (£3.14bn). Whisky is the largest subsector, worth around £2.64bn to the Scottish economy. The Beer and Fish sectors, although smaller, are worth around £331m and £164m respectively.

Scotland has a reputation for being the 'land of food and drink' and there is growing worldwide demand for Scottish produce. As such, there has been significant growth in all three sectors and further growth is anticipated in the coming years. Retail sales of Scottish food and drink brands across Britain increased by £89 million (4.9%) between May 2010 and May 2014, and anticipated further market growth could bring in a further £1bn by 2017. Recognising this opportunity the food and drink industry has set a sector-wide target to increase turnover to £16.5bn by 2017 (£13bn as of 2013) and export to £7.1bn (£5.3bn as of 2012). Specific growth and targets for the Beer, Whisky and Fish sectors are included below. Scottish businesses are expected to increase production to meet this increase in demand for their produce.

- **Beer** – Scottish beer has been seeing double-digit growth in US markets for four straight years and this is expected to continue. Growth area - particularly craft breweries.
- **Whisky** – confidence in the whisky sector remains high with a growth rate estimated at 2.1% over the period to 2018.
- **Fish** – Scottish aquaculture is working towards achieving sustainable growth targets in both marine finfish and shellfish production by 2020 (increase marine finfish to 210,000 tonnes (165,256 tonnes in 2013); and shellfish to 13,000 tonnes (6,935 tonnes in 2013)[4].

Delivering such projected increases cannot be sustainably achieved by simply expanding extraction and/or increasing current resource consumption. For example, imports (such as grains, hops and fishmeal) are subject to price variability and availability problems not to mention the higher costs and carbon emissions associated with transportation. Identifying opportunities to improve circular approaches, for example through substituting imported materials with Scottish/UK-based materials, or keeping by-product materials within Scotland for further processing, reduces the resource risks facing the sectors businesses and provides an opportunity to increase revenues by producing materials of higher value.

The main concepts that underpin the definition of a circular economy are not new, and elements of a circular approach have already been considered in the three sectors to varying degrees. All three

[3] Scottish Enterprise (May 2014)
[4] Scotland's Aquaculture, available at - http://aquaculture.scotland.gov.uk/our_aquaculture/our_aquaculture.aspx

manage biological resources on a day-to-day level and it is useful to consider the materials used in terms of feedstocks, the processes that can be applied to them and the products that result.
Figure 1, taken from the 2014 House of Lords report: *'Waste or resource? Stimulating a bio-economy'* provides a useful representation of this.

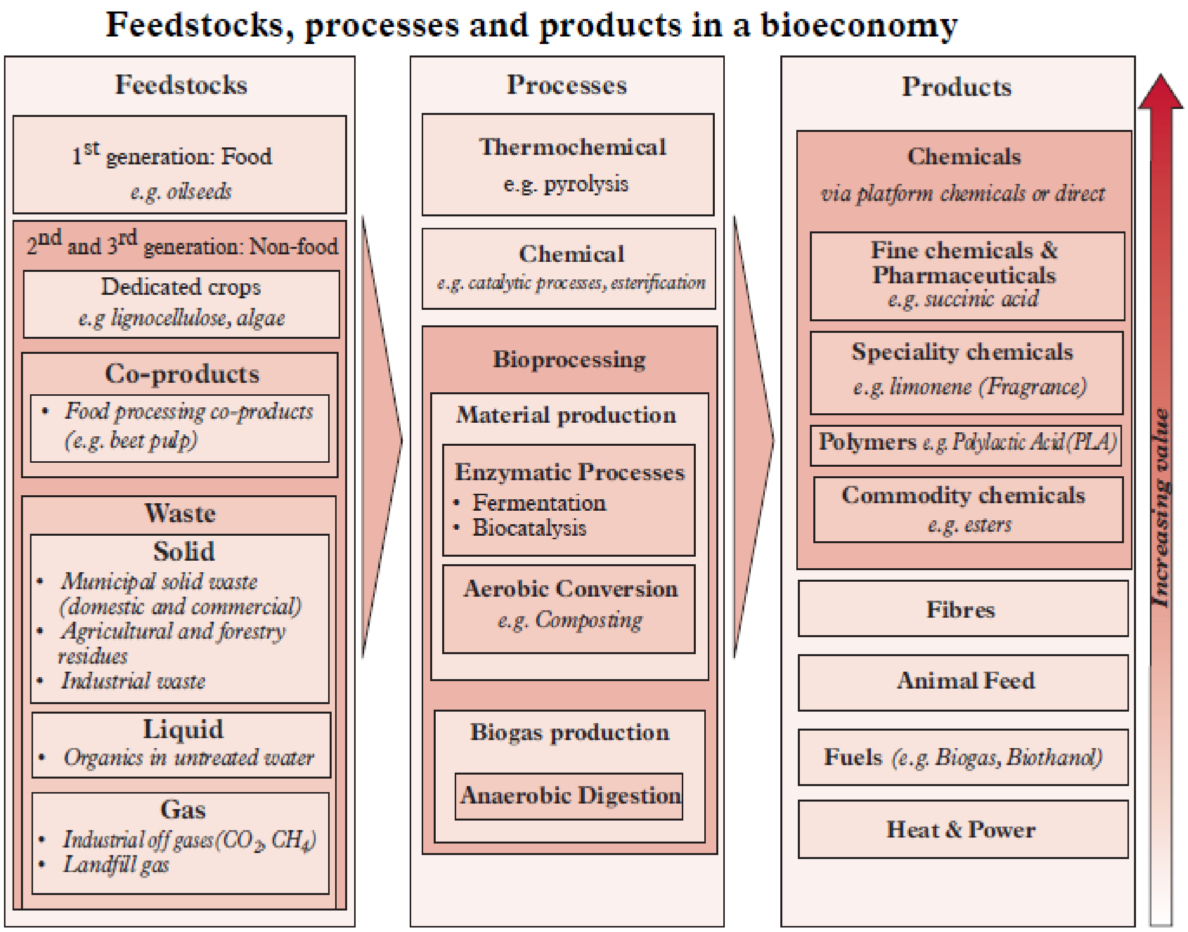

Figure 1 Feedstocks, processes and products in a bio-economy[5]

There is some level of hierarchy implicit in the above, with production of high value chemicals as the highest priority and burning for heat and power as the lowest priority. However, for any given bio-resource, the processing needed to extract or manufacture a targeted high value product will generally leave a residue: this presents an opportunity for further processing to generate further uses and further residues. Hence there is a potential to extract multiple uses from a bio-resource, through a cascade of successive uses. The concept of a bio-resource park is discussed further in Section 7.4.

The production processes used in the whisky, beer, fish and other bio-based sectors can be characterised as extracting the highest value components (i.e. the main products) and leaving various residues. How these residues are dealt with by the business producing them depends on many factors - particularly the overall cost or income to the business, the regulatory requirements and the simplicity or otherwise of implementing a higher value alternative.

How the residues are referred to depends on how they are treated. Generally speaking:

- A co-product contributes profit to the business and the business tries to optimise its production
- A by-product is put to some use on a more or less cash-neutral basis to the business
- A waste costs the business money to dispose of, and is subject to waste regulations.

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[5] From *Waste or resource? Stimulating a bio-economy* (2014) House of Lords

There are many potential products that could feasibly be made from by-products, adding further value to a business. These provide an opportunity for a business to potentially generate new revenue streams. However, there are also factors that are clearly driving the three sectors to consider alternative approaches to current practices, including the rising cost of landfill, landfill restrictions (i.e. for fish mortalities), the landings obligation (an element of the reformed Common Fisheries Policy (CFP)), and saturation of existing disposal routes (i.e. insufficient land or a levelling-off of the animal feed market).This is particularly important given the planned growth in each sector over the next 5 years and beyond.

Ricardo-AEA would like to acknowledge our project partners Biorenewables Development Centre, Heriot Watt University and Scala Consulting who provided valuable insight during the course of this project. Ricardo-AEA would also wish to thank all stakeholders, listed in Appendix A, who gave up their valuable time to speak to us, signpost other useful information and make introductions to key players in each of the sectors.

3 Methodology

Significant stakeholder engagement was identified early on as a key component of the project, as a means to gather sector data to understand current practices, the opportunities for implementing a circular approach, and the awareness of such approaches and the barriers to change. Our methodology reflects this and also incorporates a significant amount of time to review existing data available and data sources that were signposted as part of the stakeholder engagement process. The details of the methodology used are provided in the sections that follow.

3.1 Stakeholder engagement

An initial stakeholder list was drafted and agreed with project partners following the project inception meeting. This included a range of organisations across all levels of the sectors from sector and trade bodies to academic and research institutions and individual businesses. These were split into Tier 1 and Tier 2 for ease of management[6] and were assigned as per the following criteria:

- **Tier 1 -** a membership or sector-wide organisation with strategic overview and influence of each sector (i.e. Scotch Whisky Association, Seafood Scotland, Institute of Brewing and Distilling)
- **Tier 2** – an individual business or organisation involved in innovative activities in each sector.

Contact details were gathered for the identified stakeholders and initial contact was made by phone and e-mail. All engagement was recorded in the master stakeholder for accuracy of tracking. The 50-word project summary, drafted for Scottish Government, was used as a basic introduction to the project and further details were provided verbally.

Initial contact was made with each Tier 1 stakeholder via telephone to setup the most convenient time to meet or call back to discuss the project in more detail. Each call was followed up with a supplementary e-mail. All activity was recorded in the master stakeholder list to track engagement. During these initial discussions the aims of the engagement were clearly set out. These were to:

a. gain insight from industry leaders to help inform the project;
b. understand where existing information and data existed; and
c. confirm that the stakeholder would be supportive in helping the project team engage with their members/the businesses they represented.

Based on the initial feedback a number of additional stakeholders were identified, particularly for a small number of organisations involved in innovative activities. Comments/notes from these discussions were recorded and signposted articles/reports were catalogued and later reviewed to

[6] 'Tier 1' and 'Tier 2' – internal project definition only. Not used externally.

inform the follow-up work. The vast majority of these stakeholders were keen that their membership/businesses they represent should be engaged directly – through our targeted questionnaires/follow-up in the next stage of the project. In total around 16 Tier 1 stakeholders were interviewed as part of the project and a list of these is provided at Appendix A.

More targeted engagement with Tier 2 stakeholders began after Tier 1 engagement had been completed. To complement the Tier 2 stakeholder list already generated and agreed by the project partners, Tier 1 stakeholders were also asked to nominate a representative sample of members who could participate in the project. These stakeholders were included in the Tier 2 engagement. These were either contacted directly by the Tier 1 stakeholder or by Ricardo-AEA.

To facilitate consistent data capture we developed simple sector specific questionnaires. Feedback provided during our initial engagements suggested that the perceived complexity of information requested was a barrier to participation. As such, questionnaires were used as a reference document to guide interviews rather than a form for participating business to fill in themselves. In total 46 organisations were interviewed to discuss innovative approaches and potential case study material. A list of these organisations is included at Appendix A.

The majority of the Tier 1 stakeholders were keen to help. There appears to be significant appetite to participate in any follow-on workshops that may occur in light of this initial sector study (i.e. to allow Scottish Government and its agencies to gather industry feedback on shortlisted circular approaches and input into next steps). Should Zero Waste Scotland feel this type of summary workshop is appropriate to run, Tier 1 stakeholders will likely be a good source of support to gather attendees from their respective sectors.

3.2 Desk-based research

Desk-based research was conducted to review a range of data sources that were either publically available, or signposted through the Tier 1 stakeholders. In total around 100 documents were reviewed which included: stakeholder reports, academic articles and sector research papers published in the past 10 to 14 years. From reviewing this work, it became clear that there is a significant understanding of higher value use of by-products in each of the three sectors, although we know from our sector engagement that uptake on these appears to be low. Discussions with stakeholders of both tiers suggest this may be due to a combination of reasons which are discussed more fully in Section 4.

It is also clear that individual organisations across the three sectors have a very good understanding of their inputs and outputs, but a limited understanding of the overall sector-wide material inputs and by-product outputs – with the exception of the whisky sector which, through the Scottish Whisky Association, does collect a lot of data. As such, our research has identified that access to quality data is patchy and is often not shared due to issues around commercial sensitivity. This is understandable due to competitive nature of the three sectors.

4 Review of sector inputs and outputs

An indicative mass balance was produced for each of the three sectors, to understand the scale of the opportunities available from adopting circular approaches. Existing data sources were reviewed and stakeholders interviewed to gather insight into how representative these were of current activity levels. Further details are provided in the following sections.

4.1 Beer

Beer is a significant contributor to the value and employment in the food and drink sector. A recent study for the British Beer & Pub Association found that the sector sustains **49,960 direct jobs** in

Scotland and **71,093 in total when indirect and induced jobs are included**. The beer and pub sector also adds nearly £1.5 billion in value to the Scottish economy[7].

According to the Institute of Brewing and Distilling, the brewing sector is dominated by two large producers (Belhaven Brewery (Green King) and Tennant Caledonian (C&C)) and these account for >75% of the total barley, hops and yeast consumed by the sector[8]. However, there has been a significant increase in the number of smaller craft brewers in Scotland with numbers doubling over the past 10 years[9]. There are now around 80 craft breweries operating across Scotland and more are expected in the coming months and years. These breweries are geographically spread across Scotland from Sulwath Brewery in Dumfries and Galloway to Valhalla Brewery on Shetland. An indicative map of the breweries in Scotland is included at Appendix B. A number of these breweries have seen significant growth in recent years (for example Williams Bros. and Brewdog) and now brew in the region of 50k hectolitres (HL) per year.

The brewing process involves fermenting malted barley (or other grains) to produce beer and various by-products and wastes. The main inputs are barley, water and yeast. The process comprises several stages depending on the type of beer being produced. The main stages can be summarised as:

- Malting: the barley is germinated and then heat treated. Malting produces 'malt culms' (the broken off rootlets from the germinated grains) as well as barley screenings and dust as by-products. Malting is commonly carried out by a malting company as a separate stage in the brewing supply chain.
- Mashing: the milled malt is mixed with hot water to convert the starches into simpler sugars. The resulting mixture is then strained to remove the spent grains and leaving the liquid wort.
- Boiling: the wort from the mash process is boiled with hops, after which the solids are removed as trub and spent hops, in some cases separately and in other cases they are mixed together.
- Fermentation: the cooled liquid is fermented with yeast, to produce the beer. This stage also produces excess spent yeast. The beer is then matured.
- Filtration: the beer is filtered, often using a fine texture mineral called kieselguhr. Spent kieselguhr is a by-product produced from this stage.

Further by-products are produced from the upstream supply of resources into the brewery sector: notably barley straw, largely produced in Scotland and hop crop residues, largely produced outside of Scotland.

The Society of Independent Brewers (SIBA) for 2013 estimate that ~312,000 HL of beer was produced in Scotland in 2013 by independent brewers It is felt that there is a degree of underreporting within the SIBA membership and does not included non-SIBA members or production of the large breweries (Tennant Caledonian and Belhaven). As such it is clear that total beer production in Scotland is well in excess of this figure.

Figures published by Scottish Brewing reported Belhaven as producing 75,000 barrels per year[10] - or ~123,000 HL per year[11]. In addition to this, industry sources estimate that Tennant Caledonian (C&C) produce around 2,000,000 HL. Therefore, it seems reasonable to assume that total **Scottish beer production is at least 2,435,000 HL per year**, excluding other non-SIBA members and non-reporting organisations. An indication of the main inputs and outputs for the beer sector is provided in Figure 2 below.

Individual brewers were reluctant to share production data during the stakeholder interviews due to commercial sensitivity. Therefore, it was not possible to add to or verify the data provided by SIBA.

[7] http://www.scottish.parliament.uk/S4_ScotlandBillCommittee/Inquiries/Scottish_Beer_and_Pub_Association(1).pdf
[8] Institute of Brewing and Distilling (2014)
[9] CAMRA (2014)
[10] Scottish Brewing - http://www.scottishbrewing.com/breweries/edinburghandlothians/belhaven.php
[11] 1 barrel = 1.64hl

As such these figures represent the best estimate using the sector data available, cross-checked with the known 'brewer's equation' (the approximate by-product produced per litre of beer brewed[12]).

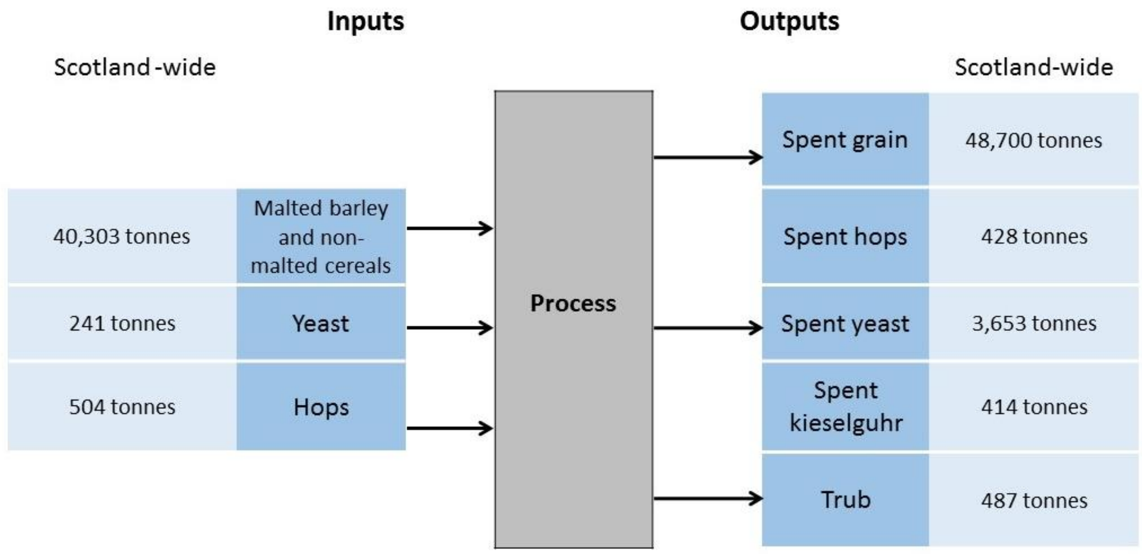

Figure 2 Indicative inputs and outputs for Scottish beer sector – based on annual production of ~2,435,000 HL

Using the 'brewer's equation' it is possible to understand the approximate tonnes of by-product produced per litre of beer produced. Table 1 provides an overview of the approximate tonnes of by-product generated in a small and a large brewery per year. With the exception of the two large breweries - Belhaven (Green King) and Tennant Caledonian (C&C) breweries – and rapidly expanding brewers (such as Brewdog and Innes and Gunn) - the majority of breweries in Scotland are <30k HL per year.

By-product	Approximate weight of by-product by litre of beer produced	Small brewery[13]– approximate tonnes by-product per year	Large brewery[14] – approximate tonnes by-product per year
Spent grain	100-200g	104	2,000
Spent yeast	15g	3.3	78
Spent hops	85% input volume	-	-
Spent kieselguhr	1.7g	0.37	8.8

Table 1 Approximate by-product generated per litre of beer and per year for small and large breweries

4.2 Whisky

Whisky is one of Scotland's major products and remains one of the country's most famous and economically significant exports. The Scotch Whisky Association (SWA) states that there were 115 distilleries licenced to produce Scotch whisky in early 2015[15]. Distilleries are located across the country with a few areas of high density, most notably Islay and Speyside. An indicative map of the distilleries in Scotland is included at Appendix C. Yearly production, in 2012, was in the region of ~407m litres of pure alcohol[16]. Approximately 10,600 people are directly employed in Scotch whisky

[12] For every litre of beer produced: 15g surplus yeast, 2g trub, 1.7g kieselguhr, 85% input hops and 100-200g of spent grains.
[13] Approximately 4,500 litres beer brewed per week
[14] Approximately 7,000 HL beer brewed per week
[15] 'Scotch Whisky Association, available at - http://www.scotch-whisky.org.uk/what-we-do/facts-figures/
[16] Malt distillers ~2547m LPA, Grain distillers ~350m LPA, (Russell and Stewart (2014)

production, 80%[17] of whom are employed in the Strathclyde, Central and Fife and Grampian regions of Scotland.

Malt and grain distilleries use similar processes, based on fermentation and distillation. The early stages are also similar to those used in brewing beer and so produce similar by-products. However there are some notable production differences between malt and grain distilleries:

- Malt distilleries are smaller and more numerous than grain distilleries (~100 malt distilleries as opposed to seven grain distilleries).
- Malt distilleries are sited predominantly in the highlands and islands; grain distilleries in the lowlands.
- Malt distilleries use malted barley as their prime ingredient; grain distilleries use unmalted grains such as wheat and maize.
- Malt distilleries use copper stills, leading to the presence of copper in the pot ale and other by-products; grain distilleries use stainless steel vessels.
- Malt distilleries generally only begin sales at least seven years after starting a new batch; grain distilleries can start product sales from around 3 years. This difference is relevant in the context of the current growth in Scottish whisky production and the volumes of wastes and by-products produced from the start of production.

The wastes and by-products produced by the two types of distilleries are broadly the same, but are given different names.

Malt distillery By-product / waste	Grain distillery By-product / waste	Description
Draff	Spent grain	Wet grains, with a moisture content of ~80%, which are no longer useful in the production of alcohol. This material is rich in protein, carbohydrates and fibre.
Pot Ale	Spent wash	Liquid residue from distillation stage, with ~5% solids content containing protein from the yeast and grain, as well as copper in the case of malt distilleries using copper stills. This liquid is produced in very large quantities: about 8 litres of pot ale and 18 litres of spent wash generated per litre of alcohol in the whisky.
Spent Lees		Liquid residue from the second distillation stage in malt distilleries. Similar in properties to pot ale, but more dilute.

Table 2 Descriptions of by-products and wastes from malt and grain distilleries

For ease of reading, we use the malt whisky terminology for both malt and grain distillery by-products throughout the rest of this report, unless stated otherwise.

Section 5 describes the various uses of the by-products by different distilleries, including direct use as animal feed, discharge to sea, spreading to land and renewable energy feedstock. In some cases, the draff and pot ale are processed on-site to produce more concentrated animal feeds, either separately (pot ale syrup) or combined (dark grains).

This variability across different distilleries combined with a lack of formal data presents difficulties in identifying the weights and destinations of distillery by-products. However, various information sources and calculations have been used in this report to produce the following figures.

Figure 3 gives summary inputs and output weights for the whisky sector, provided by the Scotch Whisky Association (SWA). In 2013, the industry used around 1.59m tonnes of cereals (malted barley and other cereals such as wheat and maize); approximately 88% of the malted barley used was sourced from within Scotland. It should be noted that the output figures presented in Figure 3 were

[17] 'Statistical Report 2013', Scotch Whisky Association (2012)

provided by the SWA as made available for animal feed in 2013 and do not include other uses of outputs.

Based on known assumptions regarding malt whisky spirit yield and grain conversion factors, it has been possible to provide further comment as presented below.

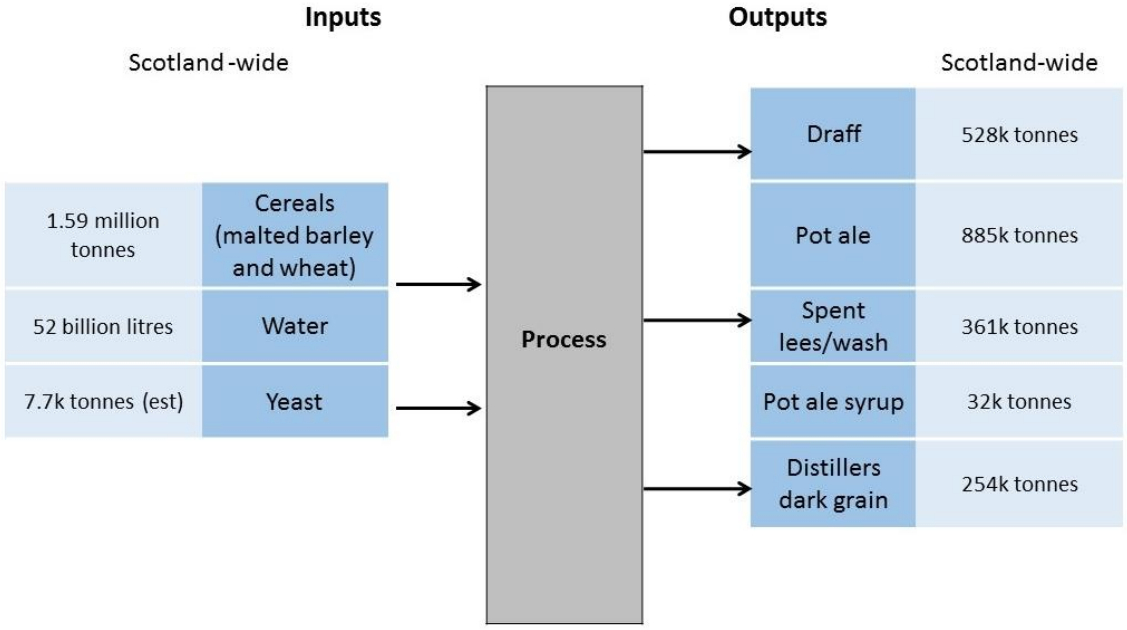

Figure 3 Indicative whisky sector inputs based on litres of pure alcohol (LPA) data (2013) and outputs made available for animal feed (2013)

Based on production data provided by the SWA (Statistical Report 2013), approximately 275M litre of pure alcohol (LPA) was distilled by malt distilleries in 2013 and 350M LPA for grain distilleries (extrapolated from most recent full year reported – 2011).

Based on known average production ratios of 10 litres pot ale produced per LPA of malt whisky and 18 litres of spent wash per LPA of grain whisky, the above whisky production figures give a theoretical maximum of 2.75M tonnes of pot ale and 6.3M tonnes of spent wash produced per year: a total of around 9 million tonnes of pot ale and spent wash produced per year. It should be noted that this is the estimated production at source: a proportion of this is then converted into pot ale syrup and dark grains.

It is possible to calculate (and cross-check) the approximate output amounts of dark grains and the remaining draff and pot ale using the malt whisky spirit yield and grain conversion factors from previous sector reports[18].

Supporting calculations are provided in Appendix G, however the potential by-product tonnages from 2013 LPA data are shown in Table 3. The estimate of 7,700 tonnes of yeast input is based on the assumption that 2 kg yeast yields 32kg of pure alcohol with an alcohol density of 0.79kg/l.

Whisky outputs	Reported as available (tonnes)	Potential by-products (tonnes)[19]	Discrepancy
Draff	528,000	684,000	156,000
Pot ale	885,000	2,336,000	1,451,000
Distiller's Dark Grain	254,000	254,000	0

[18] Bell, J; Morgan, C; Dick, G; and Reid, G. (2012) *'Distillery feed by-products briefing: An AA211 Special Economic study for the Scottish Government'* SAC Consulting
[19] These figures assume that the amount 254,000 tonnes of DDG reported in 2013 is correct.

(DDG)			
TOTAL	n/a	4,371,000	1,607,000

Table 3 Difference between whisky outputs reported and anticipated based on LPA data (2013)

There are a number of reasons that account for the differences in what is reported as available and what is potentially produced, and it is important to understand why these differences exist. The reasons include:

- **Pot ale syrup production** – there is an approximate ratio of 10 litres pot ale to 1 litre pot ale syrup (10:1). This means that the 32k tonnes of pot ale syrup reported by SWA accounts for approximately 324k tonnes of pot ale that would otherwise have been reported.
- **Distillers' Dark Grains** (DDG) – draff and pot ale are both used to make Distillers' Dark Grains in ratios of 2.7:1.0 (draff to DDG) and 9.1:1.0 (pot ale to DDG) respectively.
- The *potential* amount of DDG in 2013 was approximately 510k tonnes (210kt from malt and 300kt from grain). In 2013, some 254k tonnes DDG were reported and this would equate for an additional 685k tonnes of draff and 2.3m tonnes of pot ale that would otherwise have been reported.
- **Discharge of pot ale direct to sea (coastal distilleries)** – a number of coastal distilleries currently discharge pot ale straight to the sea under a relevant SEPA consent. From the data available it is not possible to qualify the amount of pot ale disposed of by this route, but this will account for some of the shortfall in amount available for animal feed.
- **Spreading of pot ale direct to land** – a number of distilleries currently apply pot ale straight to land under a relevant SEPA consent. As described above for pot ale discharged to sea, this will account for some of the shortfall in amount available for animal feed.

It is anticipated that the whisky sector will continue to expand overall production, both through commissioning of new distilleries[20] and expansion of existing sites. Based on previous production figures published by SWA, it is not unreasonable to assume that production could increase by 5% in each of the next two years. If this was the case an additional 65M LPA would be produced. This would result in an approximate increase in by-products in the region of:

- **Draff** – 52.8k tonnes
- **Pot ale** – 88.8k tonnes

Volumes of both DDG and pot ale syrup will depend on plant capacity to produce these products. Draff and pot ale are used to produce both, but could be as much as

- **DDG** – 25.4k tonnes
- **Pot ale syrup** – 3.2k tonnes

Suitable routes will need to be found for these by-products as existing routes (such as animal feed/disposal to land) are near their natural capacity.

Protein available for Scottish aquaculture from Scottish whisky distilleries

The protein requirement of Scottish salmon farms is estimated as 96,000 tonnes per year. This figure is based on 160,000 tonnes of salmon produced per year, an average feed conversion ratio of 1.2 and a 50% protein content of fish feed.

The amount of protein that in theory could be extracted from all of Scotland's whisky sector, using the Horizon Proteins process, could be as much as 181,000 tonnes per year: <u>almost twice what is needed by Scotland's salmon farms.</u>

This is based on the total amount of pot ale and spent wash produced at source - 9 million tonnes per year – and does not allow for the current processing of a proportion of the pot ale into pot ale syrup and dark grains. Pot ale contains approximate 2% protein on a wet weight basis.

[20] Between 30 and 40 are expected by 2020.

The price attainable for high concentration protein in the aquaculture feeds market varies and is increasing as global protein demand increases. Using a conservative figure of £1,500 per tonne gives a total potential value of protein in pot ale and spent wash in Scotland available for use in aquaculture feeds and other markets of £272 million per year.

4.3 Fish

Fishing, including sea fisheries, aquaculture (finfish and shellfish) and processing, is another of Scotland's major industries. Sea fishing alone directly employs 4,992[21] people in Scotland and there are 2,046 active, registered vessels. Over 63% of the total workforce is employed in Aberdeenshire, Western Isles, Orkney and Shetland, and Highland regions[22]. The aquaculture industry generates over 4,800[23] jobs in total across farm production, suppliers, processing and retail, with some 2,800[23] jobs involved in direct production across 800[24] sites. The fish sector employs in excess of 9,792 people across Scotland. Indicative maps showing the locations of fish processors and finfish and shellfish aquaculture sites are included at Appendix D and Appendix E respectively.

An indication of the inputs and outputs for the fish sector is provided in Figure 4 below. These figures are based on a range of data sources and insight gathered from the stakeholders engaged and includes: sea fisheries (shellfish, pelagic[25] and demersal[26] fish), finfish aquaculture and shellfish aquaculture. The landed fish volumes from sea fisheries will fluctuate year to year in line with quotas and species caught[27]. It is anticipated that outputs from both finfish and shellfish aquaculture (salmon, trout and shellfish) will increase year on year as the aquaculture sectors continue to grow. Aquaculture mortalities vary significantly from year to year (depending on a number of factors), and

[21] Scottish Sea Fisheries Statistics 2013, Marine Scotland
[22] Scottish Sea Fisheries Statistics 2013, Marine Scotland
[23] 'An Assessment of the Benefits to Scotland of Aquaculture' (2014), Marine Scotland. Available at - http://www.gov.scot/Resource/0045/00450799.pdf
[24] Scottish Sea Fisheries Statistics 2013, Marine Scotland
[25] Pelagic fish – live in the pelagic zone of the ocean, neither near the bottom nor near the shore
[26] Demersal fish – live and feed on or near the bottom of the ocean
[27] At the time of going to press the Scottish Government has just published the Provisional Scottish Sea Fisheries Statistics (2014), indicating the volume of fish landed by the Sottish fishing fleet was up on 2013 by ~31%.

can range from anything between 4-11%[28] of annual stock harvest levels.

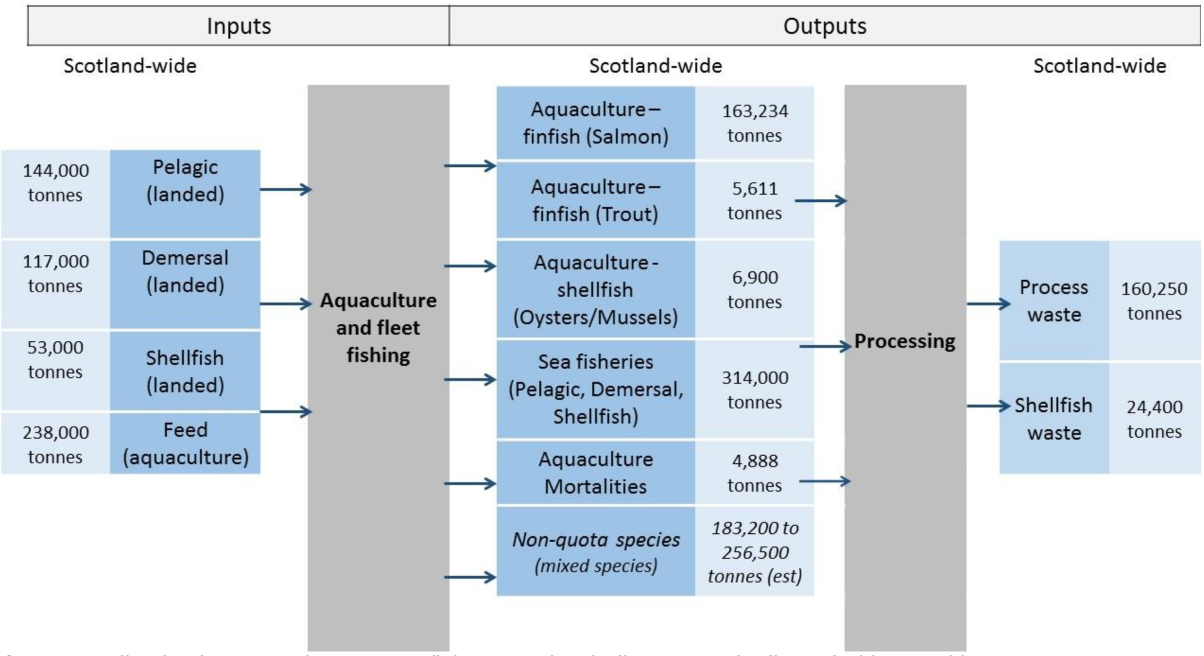

Figure 4 Indicative inputs and outputs to fish sector (excluding currently discarded by-catch)

Total 2013 landings in Scotland by landings of all nationalities of pelagic, demersal and shellfish was 313,500 – a reduction of some 20,000 tonnes on the previous year. Of the total catch landed around 73% was landed at three ports – Peterhead (130,405 tonnes), Shetland (73,289 tonnes) and Fraserburgh (25,988 tonnes)[29]. However, it is anticipated that the landings obligation will result in greater use of more selective fishing methods and should mean by-catch does not continue at these high levels. Processors have suggested there is processing capacity in the sector to manage additional landings should they occur.

Based on current value of finfish process waste (£130 to £160 per tonne), where the material is sold for onward processing into fishmeal and oils, the value to the Scottish economy is between £20.8m to £25.6m[30].

Waste and the Reformed Common Fisheries Policy (CFP) - landings obligation

A key element of the reformed Common Fisheries Policy (CFP), effective from 1 January 2014, is the progressive elimination of discards in EU fisheries through the introduction of the new landings obligation. The landings obligation is effectively a ban on discarding fish overboard. A key objective of the landing obligation is to create incentives for fishermen to avoid the capture of any unwanted catch.

The landings obligation constitutes a new way of managing fisheries, and making it work for all parts of the fleet will require a great deal of effort by industry, agencies and the Scottish Government.

Under the landings obligation, skippers will be obliged to land all commercial (quota) species they catch (i.e. 'land-all'). Quotas will now represent an entitlement to catch a set amount of a particular fish stock, rather than simply land a set amount, while <u>all</u> catches <u>must</u> be landed. This leads to a number of concerns and opportunities, particularly where fish cannot be sold for human

[28] Scottish Salmon Producer's Organisation (2014). Note: publication of mortality data is commercially sensitive and is not legally required by SEPA. However, mortality data is published on a monthly basis by weight via 'Scotland's Aquaculture'.
[29] Scottish Sea Fisheries Statistics 2013, Marine Scotland
[30] From Figure 4 – Fish Process waste = 160,250 tonnes. Value of fish process by-product for further processing into fishmeal, oils etc. ranges from £130-£160/tonne. Value is calculated as @ £130/tonne = <u>£20,832,500</u> ; 160,250 tonnes @160/tonne = <u>£25,640,000</u>

consumption, and ultimately a disposal issue (in circumstances where no buyer of landed fish can be found). Fish discards will immediately become category 3 animal by-products when they are brought to shore. Further detail regarding disposal of animal by-products is provided in Section 5.3. As soon as an operator generates an animal by-product, the material is in scope of the Animal By-Product Regulation (ABPR). In these circumstances the fishing vessel captain will be responsible for the safe disposal of the material in line with the requirements of ABPR. If should be noted that the ABPR does not apply to discards on commercial fishing vessels at sea except for fish showing signs of disease.

- **Undersized fish** – this will occur in instances where fish are undersized (below the Minimum Conservation Reference Size (MCRS)). The landings obligation means that all fish landed, including undersized fish, will be covered by the quota. As the costs of doing this are prohibitive, the incentive will be for fishermen to use more selective gear or change fishing patterns. While this will not always be able to prevent catching smaller fish, the fish caught will be able to go for non-human consumption routes (as described in Section 5).

- **Landing of low value species** – as for undersized fish, low value species caught will need to be landed and will be covered by the set quotas. These species can be sold for human consumption, but no market may currently exist. Work would be required to help develop markets for these species, and where no market can be found, the fish can be utilised through existing non-human consumption routes (as described in Section 5).

- **Disposal of fish** – if no buyer can be found for the landed fish, 'whole carcasses' of fish fall under animal by-products regulations (ABPR). Further regulations also cover the management of fish wastes depending on what disposal route is used i.e. incineration, AD, composting. In these cases the skipper of the landing vessel is responsible for disposing appropriately. In more remote ports (i.e. Kinlochbervie), the managing authority may choose to provide services to treat fish waste for disposal.

4.4 Data quality and availability

During the course of the project, a number of issues were observed in all three sectors around data availability and quality. This reflects the fact that there are a number of key sector bodies and trade associations operating across each sector with a different remit. Sector level data would require all businesses in the sector to report information on a regular basis to a single organisation to collate, analyse and summarise. There are issues around commercial sensitivity of data. Businesses are reluctant to share and this is reflected in our recommendations. Sector bodies and trade associations also have limited responsibility for gathering such information. Commonly observed reasons for no data available or no access to data:

- no sector-level reporting;
- UK-wide datasets (rather than broken down by nation or region);
- difficult to reconcile available data with brewing and distilling equations;
- commercial sensitivity; and
- lack of engagement by stakeholder – contacts were either too busy to engage or did not see the immediate importance of volunteering to take part.

Future work is suggested in Section 9 to address some of these issues and improve data availability and quality.

5 Current practices for managing by-products

5.1 Beer

There are various methods to manage different brewery by-products in Scotland, and Figure 5 shows uses and disposal routes known to be in operation. Table 4 gives more detail for the main by-products and wastes.

By-product / waste	Use or disposal route
Malting by-products	Malt culms, barley dust and screenings (small corns, husks) are generally mixed together and used as cattle feed either directly or sold to animal feed companies. Malt culms are light but can be pelletised to produce a denser product.
Spent grains	Spent grains contain cellulose, hemicelluloses, lignin, sugars and amino acids, making them suitable for use as a feed for cattle and other ruminants. Spent grains are predominantly used for local animal feed, directly or via feed merchants who sell it as a ‘moist feed’. Spent grains are a good source of protein (~25% on a dry matter basis), fibre and energy suitable for cattle and other ruminants. Larger breweries may be able to charge up to £30 per tonne for this whilst smaller breweries are more likely to give the spent grains to local famers for free. In its raw form, spent grains has a high moisture content and can easily spoil so has to be rapidly used. It can be dried or ensiled to allow longer storage time and to deal with seasonal feed requirements; drying also reduces onward transport costs, but is energy intensive.
Spent yeast	The fermentation process produces a surplus of yeast, some of which is reused in the brewing process. The remaining spent yeast is produced in a liquid form and can be disposed of with other liquid wastes to the sewage system, with or without on-site aerobic pre-treatment. The spent yeast can be dewatered and used as a by-product with a high protein content: either added to the spent grains to be used for cattle feed or fed to pigs, although it often has a bitter taste due to hop compounds. As with spent grains, spent yeast has a short storage life.
Spent hops	Spent hops are usable as a mulch or soil conditioner, with or without composting. Smaller breweries often give away their spent hops to local gardeners. Another common option is to add the spent hops to the spent grains and so use as an animal feed; the bitter taste of the hops is masked by the larger quantities of the spent grains.
Trub	Trub comprises the predicated solids from the wort and has a high protein content. As with spent yeast, trub can be disposed of as an effluent discharged to drain, or it can be de-watered to varying degrees and used as an animal feed, mixed with the spent grains. Trub can also be used a soil conditioner and it is likely that some smaller breweries give it away to local gardeners.
Spent kieselguhr	Spent kieselguhr largely comprises the mineral kieselguhr itself, along with the organic filtrate material held within it. Small amounts of kieselguhr can be assumed to be disposed of to drain, but generally this material is either sent to landfill or used as a soil additive.
Waste water and waste beer	Various types of waste water are produced in breweries, including from cleaning processes. These effluents are discharged to sewer, with or without on-site treatment to reduce oxygen demand and solids content. This represents a significant cost to brewers.

Table 4 Descriptions of current uses of beer by-products in Scotland

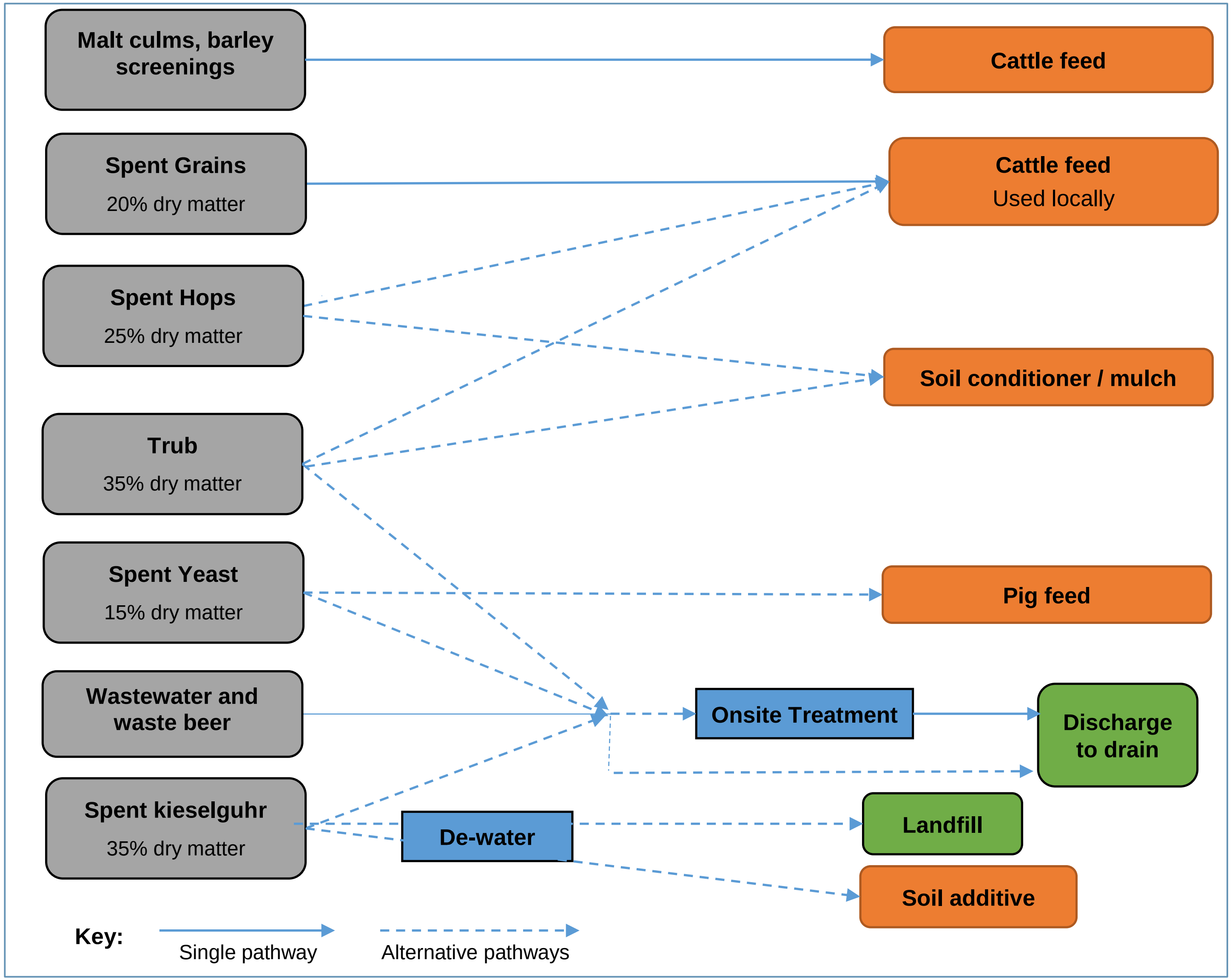

Figure 5 Current uses for beer by-products in Scotland

5.2 Whisky

Distillery by-products are used in a variety of ways in Scotland, and there has been investment in recent years especially in higher value animal feeds and renewable energy generation. These are summarised in Figure 6 and described in the text below.

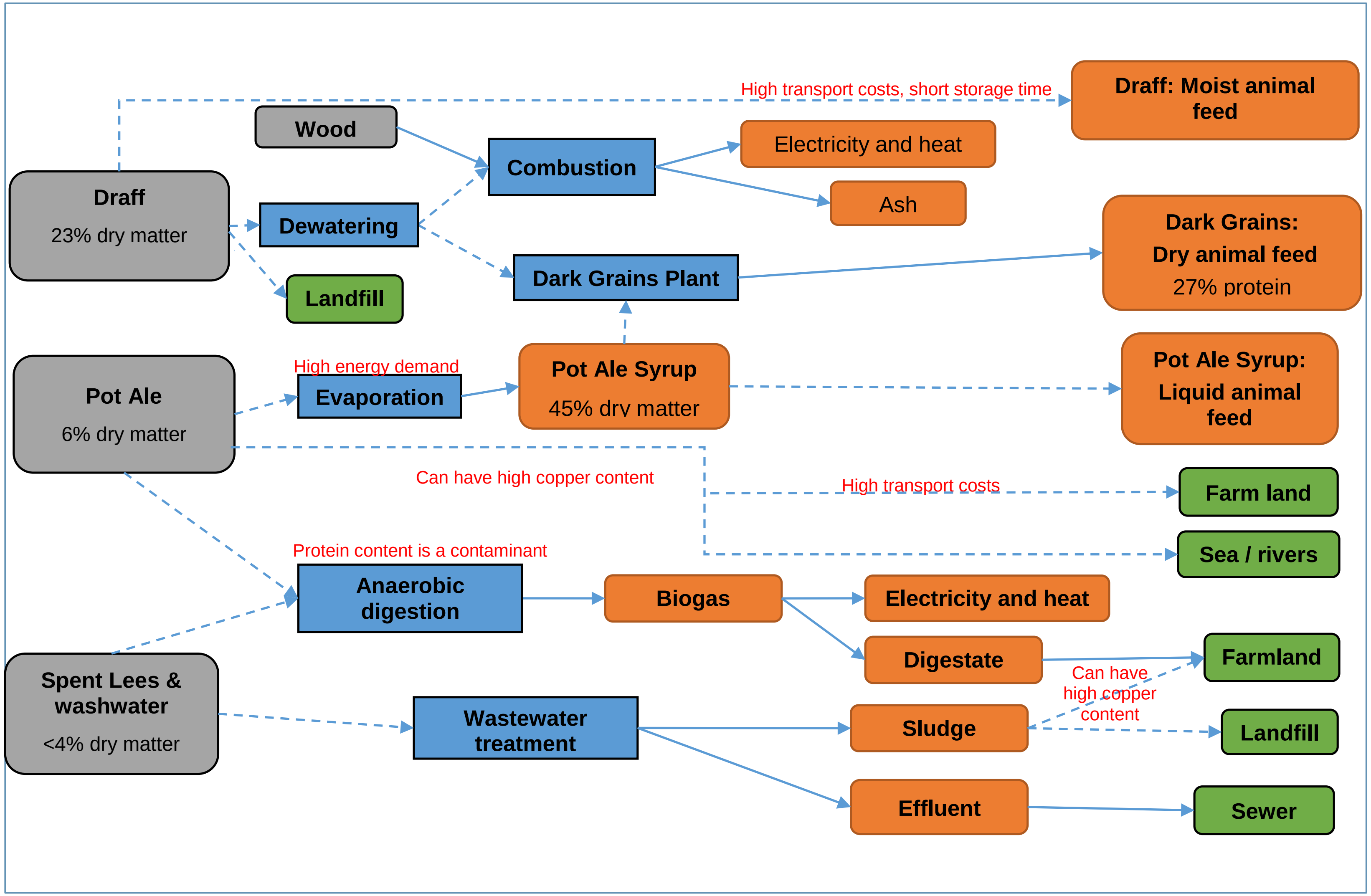

Figure 6 Current uses for whisky by-products in Scotland

5.2.1 *Draff*

Draff is used in three main ways, as follows.

Moist animal feed
Traditionally and commonly for smaller distilleries, draff is sold or given away as a cattle or sheep feed for local farmers. Its nutrient value for ruminant animals is broadly similar to that of grain feeds, although its high moisture content even after basic dewatering limits its storage life and limits the distance it can be economically transported. Livestock feeds have a seasonal demand and have fluctuating value. To at least partly address these challenges, given the continual production of draff from distilleries, draff is sometimes ensiled (placed in a silo or other sealed container to preserve it) – a low energy storage method.

Dark grains animal feed
Larger distilleries or clusters of distilleries have invested in technology to process draff and pot ale into a drier and more concentrated animal feed, dark grains. This is a high energy process especially due to the heat needed to evaporate the pot ale (see below). Dark grains has a higher nutritional value than raw draff, can be economically transported greater distances and attracts prices similar to that of grain. An estimated 40% of dark grains from Scottish distilleries are sold to farmers in northern England, with the rest used throughout Scotland[31].

With both draff and dark grains, there is often a strong and well established commercial relationship between the distilleries and the animal feed companies or the farmers, which has the potential to be a barrier to developing new uses for these materials.

A further stage in nutrient recycling occurs through manure from the cattle fed on draff and dark grains being spread to farmland as a fertiliser and soil-builder. Nitrogen and phosphate in particular are present in the draff in significant concentrations and these valuable nutrients are recycled back to the land via the manure. In the case of manure spread on barley fields, this provides a closed loop nutrient recycling for the whisky industry.

Renewable heat and power
In recent years, some distillers have invested in renewable energy generation involving co-combustion of dewatered draff with wood chip (e.g. forestry wastes) to generate steam for on-site generation of electricity and process heat. A proportion of the heat is needed to dry the draff. Excess heat can be used to convert the pot ale to pot ale syrup.

[31] Bell, J; Morgan, C; Dick, G; and Reid, G. (2012) *'Distillery feed by-products briefing: An AA211 Special Economic study for the Scottish Government'* SAC Consulting

Case study: The CORDe renewable energy plant

CORDe is an operational biomass energy plant in Rothes, Speyside, Scotland, which uses by-products from nearby malt whisky distilleries to produce renewable energy and liquid animal feed product (Pot Ale Syrup). The plant comprises a 7.2MWe Net Capacity power plant and a 66.5t/h pot ale evaporator plant. The plant is accredited as a combined heat and power plant (CHP) under Renewables Obligation legislation.

The plant accepts the draff and pot ale from a cluster of Speyside distillers. The draff is dewatered and dried before being burnt to produce renewable heat. This heat is used to evaporate the pot ale into pot ale syrup, a much more concentrated animal feed.

In July 2013 the CoRDe plant was taken over by its owner, the CoRDe joint venture between Helius Energy Plc, Rabo Project Equity BV and the Combination of Rothes Distillers Limited ("CoRD"), for commercial operation. The Combination of Rothes Distillers (CORDe) is a consortium of six distillers – Chivas Brothers, Glen Grant, Inver House, Diageo, The Edrington Group and BenRiach. CORDe is investing nearly £30m to build a new Combined Heat and Power (CHP) Plant to replace the existing dark grains facility and produces pot ale syrup as an animal feed.

Interim results for the first six months to 31 March 2014 confirmed that the CoRDe plant generated 32,158Mwh of electricity during the period and received 67,221 tonnes of draff, and 208,385 tonnes of pot ale for processing.

5.2.2 Pot Ale

Pot ale is a liquid containing about 5% solids including a high protein content (~35% protein on a dry weight basis). It is generated in large volumes: about 10 litres of pot ale produced for each litre of alcohol in the malt whisky and 18 litres of spent wash for each litre of grain whisky. Disposal can represent a major challenge for distilleries, and in most cases represents a significant cost to the distillery through the cost of transport or on-site treatment.

Disposal to land and sea
Traditionally, pot ale is discharged to sea or river or is removed by road tanker and spread to on local farmland. Discharge to sea is only possible for those distilleries located near to the sea and which are licensed to do so. A new or expanded distillery may not be issued with a discharge licence. Spreading pot ale to farmland adds some nutrient value to the soil but is (in theory) a seasonal demand. Distilleries often need large storage tanks to allow for this and have to pay for the removal of the pot ale.

Pot Ale Syrup
To reduce these disposal costs, larger distilleries have installed evaporators to convert the pot ale to pot ale syrup. This concentrated liquid can be sold as cattle feed (but not as sheep feed due to high copper content) – often being added to raw draff or straw – or incorporated into dark grains to increase the dark grains protein content. However, the high energy costs of operating the pot ale evaporators means pot ale syrup production can offer only a marginal financial improvement; the use of subsidised renewable heat being an exception.

Anaerobic Digestion
Increasing numbers of distilleries have invested in anaerobic digestion as an alternative for treating their pot ale, along with spent lees, washings and other liquid wastes. The biogas generated by the anaerobic digestion is burnt for heat and power both of which can be used on site. The liquid effluent produced by the digestion process may require further on site treatment before discharge to sewer, and copper in the pot ale, spent lees and washings may present problems. One industry source suggested that discharge to sewer of the digestate from their pot ale anaerobic digestion plant was costing one lowland distillery £2m per year.

5.2.3 *Spent Lees and other liquid wastes*

Distilleries generally treat spent lees, washings and other liquid wastes via an onsite aerobic treatment process: this produces a liquid effluent and a sludge waste. The sludge can contain high a copper content which can limit its uses although it can be of value as a soil enhancer for low copper soils.

Case study: Biogas production from Pot Ale, Cameronbridge

Diageo’s Cameronbridge single grain whisky distillery in Fife, has built what is believed to be the largest investment in renewable energy technology by a non-utility company in the UK.

The facility uses a range of technologies, including anaerobic digestion and biomass combustion to provide 98% of the steam and 80% of the electrical power required to run the distillery using distillery by-products. The plant separates the spent wash (the equivalent of pot ale in a malt distillery) into a solid and a liquid fraction. The solid fraction is burnt to produce renewable heat and the liquid fraction is fed into the anaerobic digestion plant to create into biogas and a liquid effluent.

5.3 Fish

There are a number of different uses for fish by-products and this is related to their classification as a waste/non-waste or animal by-product. A summary of these is shown in Figure 7.

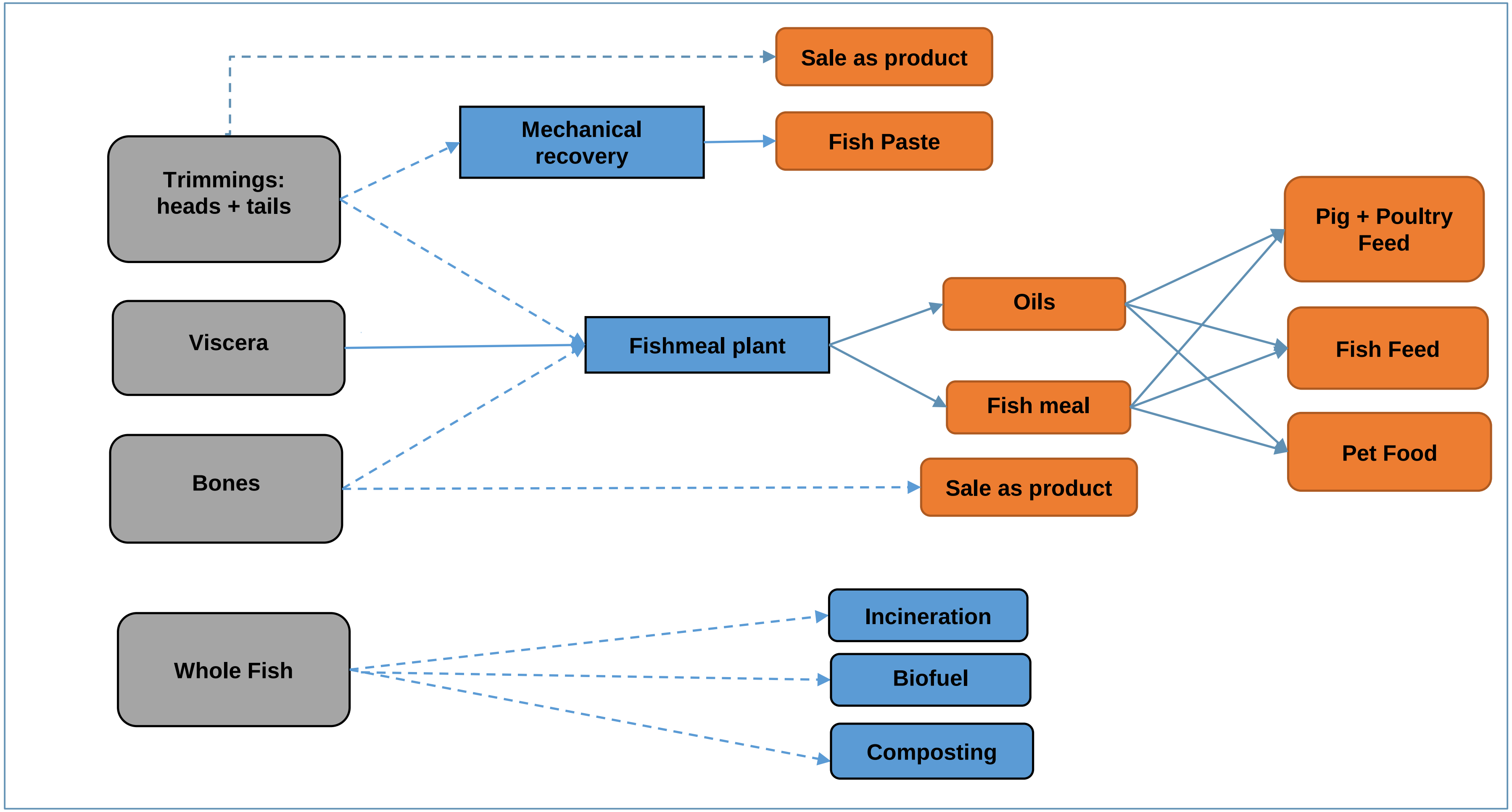

Figure 7 Current uses for fish by-products in Scotland

The disposal of animal by-products is tightly regulated in Scotland and the EU. The regulations cover the collection, transport, storage, handling, processing use and disposal of animal by-products[32]. Material designated as an animal by-product cannot be used for production of human foods and this has implications for how this material can be managed. Material designated as animal by-products are divided into three categories according to their potential risk to human and animal health, each with different rules for disposing of waste in each category.

- Category 1 – very high risk material – for example, wild animals suspected of having infectious disease communicable to humans or animals;
- Category 2 – high risk material – for example, animals and parts of animals which die by means other than slaughtering (e.g. fallen stock, fish mortalities); and
- Category 3 – low risk material – for example, carcases (heads and frames) and parts of slaughtered fish which are fit for human consumption but not intended for consumption, shells from shellfish that contain soft tissue or flesh, or food rejected for commercial reasons or packaging defects.

In accordance with the three categories, aquaculture wastes and processing wastes are dealt with very differently due the way they arise. Few aquatic animals would be classed as 'Category 1' under ABPR but examples could be fish contaminated with fuel from an oil spill or fed contaminated feed. Aquaculture fallen stock or fish suspected of having an infectious disease (such as infectious salmon anaemia) would be classed as 'Category 2' under ABPR. Both Category 1 and Category 1 material must be disposed of by either direct incineration or rendering (followed by incineration or landfill). Fish processing wastes (such as shells, fish trimmings) would be classed as 'Category 3' under ABPR and could be processed into pet food or disposed of by composting or biogas plant.

5.3.1 Sea fisheries

The Scottish fishing fleet is predominantly based in the North East of Scotland at Peterhead and Fraserburgh, although there are also significant ports on Shetland and at Scrabster. Total landings by the fleet are reported annually by Marine Scotland. Of the total catch landed in 2013 around 73% by weight was landed at three ports – Peterhead (130,405 tonnes), Shetland (73,289 tonnes) and Fraserburgh (25,988 tonnes)[33] Similar processes are in place in all locations for managing catch, as follows:

- Many whitefish are gutted on board the trawlers and the viscera disposed of to sea (still permitted under the Landings Obligation). Pelagic fish are landed whole.
- Some landed fish are immediately frozen whole for export and are hence later processed in other countries.
- There are niche international markets for many fish parts (mainly West African countries and the East Asia), including roe, heads, stomachs, livers, tongues and fins.

A large proportion of fish landed in Scotland are processed locally. Primary processing involves removal of some or all of the trimmings: guts, heads, tails, frames and skin. Increasingly, fish processors extract as much value from the fish as possible, including mechanical removal of flesh from heads, tails and frames, to sell as a fish mince for either human food or animal feed / pet food markets. The remaining residues are sent to centralised fish waste processing plants. The main plants are in Aberdeen, Shetland, Grimsby and Donegal, Ireland, where the wastes are processed under ABPR. ABPR requirements prevent any of these wastes being re-introduced to the human food chain.

- Around 75% of these products are sold for blending into aquaculture feeds. Lower value markets for the products include their use as protein enhancers in pig and poultry feeds and pet food.
- Current rate: ~£160 per tonne for pelagic wastes (although there is a range of between £130 and £160 - some processors are able to negotiate better value from their by-products than others).

[32] NetRegs (2015) – available at - http://www.netregs.org.uk/library_of_topics/waste/animal_by-products_food_waste/disposing_of_animal_by-product.aspx
[33] Scottish Sea Fisheries Statistics 2013, Marine Scotland

Case study: United Fish Industries

In Aberdeen, The United Fish Industries plant processes significant volumes of (non-salmon) fish trimmings. Their main products are fishmeal (with a 66% protein content) and fish oil derived from both the muscles and from the liver and viscera. The remaining tonnage is water, mostly lost as condensate discharged to sea under licence.

Should additional fish process wastes be made available in light of the initial stages of the landings obligation, the facility has the capacity to treat these in the short to medium term and could increase throughput by as much as 100%.

United Fish Industries are aware of innovative processes to extract higher value products and regularly review new and alternative uses (i.e. through sister plant at Rossyem, Greenock).

Processors – Trimmings (heads, tails, viscera, frames, skin) produced by the salmon processors in Scotland are kept separate from the trimmings of other fish. Based on our engagement, some fish processors are currently undervaluing their process wastes. The difference between the successes of some firms rely on how proactive they are in agreeing commercially competitive deals for their by-products and the value they perceive of the waste material/by-product.

Selected parts underutilised include:

- Cod livers – can be used to extract oils (use in food supplements), but struggle to get livers in good enough condition (training and time issue?).
- Skins – further processors want them 100% meat free (very difficult to achieve in cost effective way). Can extract the gelatin from the skin for use in pharmaceuticals.
- Fish guts (i.e. cod and other pelagic fish) disposed of at sea. There are established markets for these materials – for example in China - but entrails disposed of at sea a limited space on vessels to store safely.

Due to the effort that has gone into securing better cost/tonne for material going to fishmeal, and the steady income this now provides processors, any change suggested will need to be ‘significantly better’ than the status quo to change from current practices. However, it should be noted that removing further value for the by-products has implications for downstream processors (such as United Fish Industries, Mapco Group etc.) who further process trimmings into further products, extracting higher value from the sector by-products produced.

5.3.2 Finfish aquaculture

Both salmon and trout are cultivated in Scotland and annual production in 2013 was approximately 169,000 tonnes. Salmon accounted for approximately 163,000 tonnes of total production with trout production reaching in the region of 6,000 tonnes per year. Both salmon and trout are processed within Scotland for either domestic consumption or for export. Intra species recycling is banned under ABPR (i.e. salmon wastes are not permitted to be recycled back into salmon feeds). The Rossyew plant in Greenock processes salmon wastes into a protein hydrolase and salmon oil, both of which have markets in animal feed / pet food applications. Some salmon trimmings are sold to Chinese markets for use in human food products.

An estimated 4-11% of farmed salmon is lost as mortalities (depending on seasonal environmental variations, disease prevalence and other events, such as jelly fish blooms). Salmon mortalities cannot be put back into the human or animal feed chains. Based on feedback from the sector, some of this waste is ensiled (treated with formic acid) and transported to Widnes for incineration, and in exceptional circumstances has been transported to Norway. However, this presents a logistical issue for most operators as they are located in remote areas[34].

5.3.3 *Shellfish*

Both mussel and oysters are cultivated in Scotland and annual production in 2013 was approximately 6,700 tonnes – of which 65% was in Shetland. Mussels accounted for >95% of the annual production (~6,300 tonnes) with oysters making up the remaining 5% with annual production (175 tonnes). According to industry representatives, the vast majority of shellfish produced were exported live or vacuum packed. The main markets are currently the rest of UK, France, Spain and rest of EU/world. Processing is avoided wherever possible as this removes value from the shellfish – the most value is kept when mussels and oysters are kept whole (this helps evidence sourcing and traceability). As such, there is limited waste from this part of the sector, although small pockets of waste do exist in rural areas. Due to this, shellfish growers have not implemented higher value routes to deal with these by-products, favouring local disposal options.

Wastes from crustacean (e.g. crabs and Nephrops[35]) and from scallops is more significant and predominantly includes the shells/carapace. There is a derogation that allows shells from crustaceans with soft tissue and flesh attached, which do not show any signs of disease communicable to humans or animals, to be applied to land as organic fertilisers/soil improvers without additional processing or treatment[36]. Seafish[37] has estimated between 3,485 and 6,970 tonnes per year of crab wastes in Scotland and 6,526 to 13,052 tonnes of Nephrops wastes. The large range in the data reflects the difficulties in accessing information on processing practices and on waste generation across such a varied sector.

6 Innovative uses for by-products

6.1 Beer

Beer production is common across the world, and there are a wide range of options identified to make use of the various wastes and by-products beyond using them as a local animal feed. These are shown in Figure 8, and further detail is provided on those uses that may be applicable to Scotland in Table 5.

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[34] At the time of writing there is a waste disposal working group (facilitated by the Animal Health and Welfare division of Scottish government) looking at the possibilities/ best options for collection and disposal of fish mortality across the Scottish aquaculture industry including AD/ incineration/ biofuel as well as the potential for use of a Norwegian method of ensiling and processing which would allow the end product to be used as fertiliser.
[35] known variously as the Norway lobster or Dublin Bay prawn
[36] At the time of writing it is understood that one processing plant in East Lothian benefits from the derogation to reduce their disposal costs.
[37] 'Crustacea processing waste management' (2008), Research & Development SR593, Seafish – available at: http://www.seafish.org/media/Publications/SR593.pdf

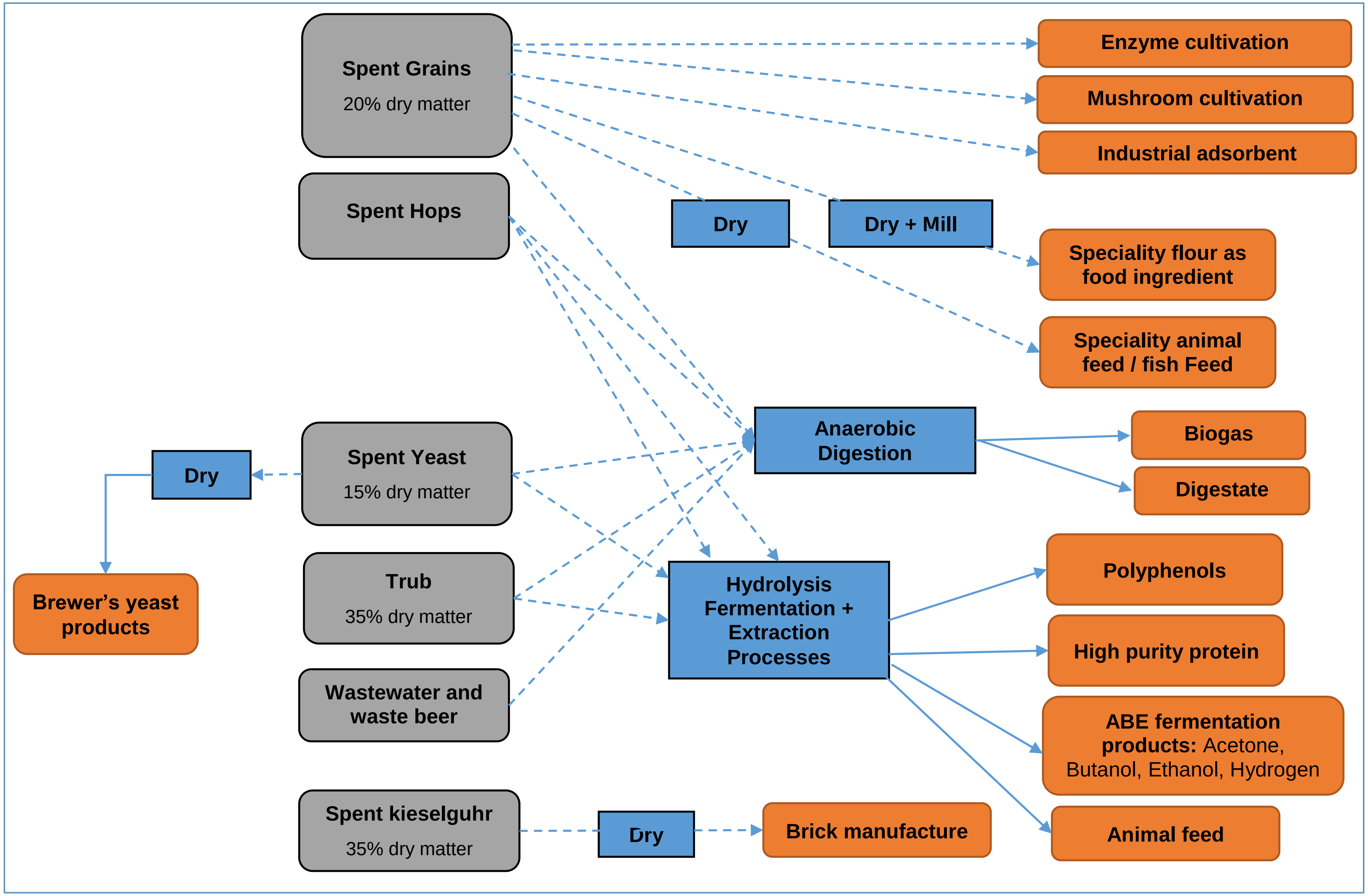


Figure 8 Potential future uses for brewery by-products

Process and products	Feedstock	Technology Readiness	Notes
Human food supplement	Spent yeast	High	Once dried, brewer's yeast is a commodity product commonly sold as a food supplement or ingredient. Energy costs for drying and the potential of contaminating flavours from hops are two barriers to more widespread practice of extracting spent yeast at breweries.
Hydrolysis and fermentation processes	Spent grains	Medium	Of the above bio-refining processes, fermentation of spent grains with a prior hydrolysis step to release sugars from the cellulosic material is perhaps the most commercially developed option. Various types of fermentation process are available including yeast fermentation to produce ethanol and the microbial ABE fermentation process being developed by Celtic Renewables (see case study in Section 6.2) in Scotland, with whisky by-products as the initial feedstocks. Celtic Renewables has indicated that their process is also suitable for brewers spent grains if mixed with wastewater. These fermentation processes allow the protein fraction to be retained in the residues, which can thus be used as an animal feed, with further processing if necessary.
Extraction of anti-oxidants, metabolites, fragrants.	Spent grains, hops	Medium	Techniques such as pressing, solvent extraction and steam distillation can be used to extract and purify high value but low volume chemicals available in spent grains and related materials. These extractions can be carried out prior to fermentation processes. Anti-oxidants are of particular interest with growing demand across numerous sectors including automotive lubricants, home care products and food supplements. A process being is being developed by FDT Consulting in Ireland (see case study in Section 6.2) to extract the polyphenol anti-oxidants from brewers spent grains and hops, although whisky draff and pot ale are also suitable.
Substrate for mushroom cultivation	Spent grains	Low to high	Spent grains have been shown to be a successful substrate for cultivation of specific mushrooms, in laboratory research. There are also numerous references to spent grains used in small scale or specialist commercial mushroom cultivation.
Anaerobic digestion	Various brewery wastes	Low to high	Liquid brewery wastes have been successfully used to produce biogas from anaerobic digestion (AD), including operationally at the Adnams brewery in Suffolk. Spent grains, however, are not an ideal feedstock for AD due to the hard-to-digest cellulose and lignin content. The protein content can also lead to ammonia contamination in the digestion process. Hop crop residues (stalks and leaves) are shredded and anaerobically digested in dedicated anaerobic digestion facilities, in Germany at least. The digestate can be returned to the hop fields as a high phosphate fertiliser.
Composting / soil enhancer	Various brewery wastes	Low to high	As with many biological wastes, there are numerous examples of formal and informal uses in local composting or direct application to land as a soil enhancer or mulch. The nitrogen content of spent grains and spent yeast especially is a benefit.

Human food supplement	Spent grains, yeast	Low	Spent grains can be heat treated, dried and milled to a high protein high fibre flour which has been successfully used as a partial replacement of wheat flour in various bakery products. A similar process has been used to produce ‘germinated barley foodstuff’, for use as a dietary supplement for certain medical conditions – or simply as a cheap source of protein and fibre.
Refining into platform chemicals and nutraceuticals	Spent grains, trub, spent yeast	Low	Various techniques including hydrolysis, fermentation, ultrafiltration and alkali fractionation have been demonstrated to produce different platform chemicals (chemicals commonly used as feedstocks in chemical manufacturing), and nutraceuticals (isolated chemicals used in dietary supplements for human and animal nutrition). Techniques have been researched which can isolate sugars, polysaccharides, acetic acid, lactic acid, phenolic acid, hydroxycinnamic acids and phytosterols, as well as various proteins.
Growth medium for microorganisms and enzymes	Spent grains	Low	The polysaccharide, protein content and high moisture contents of spent grains make them suitable as a substrate for commercial production of micro-organisms and enzymes.
Metal adsorption and immobilization	Spent grains	Low	Spent grains have been shown to be successful at adsorbing dyes and heavy metals including copper, lead and cadmium. Spent grains could be thus used as a low cost adsorbent in industrial wastewater treatment.
Paper manufacture	Spent grains	Low	Spent grains have been used as a raw material for manufacture of paper towels and business cards.
Brick production	Spent kieselguhr, spent grains	Low	Research has been carried out into the potential for using spent kieselguhr sludge in the production of calcium silicate bricks. Spent grains have been also been shown as a potential ingredient in bricks, to increase brick porosity. These applications could offer high volume uses for these by-products.

Table 5: Innovative processes to valorise brewery by-products

Technology Readiness: Low = process proven at laboratory scale; Medium = process tested at pilot scale /commercial demonstrator; high = commercially operational.

6.2 Whisky

Numerous potential future uses of distillery outputs have been identified from academic research papers and other sources. Some of these are being trialled to assess technical and commercial potential. Figure 9 shows the most significant of these.

It should be noted that the spent grains output from distilleries ('draff' from malt distilleries, 'grain moist feeds' from grain distilleries) are broadly similar in their constituents and characteristics to the spent grains from the beer industry and spent grains from commercial bioethanol production (Distillers Dry Grains with Solubles (DDGS)). Discussions with researchers confirm that, in most cases, research carried out on one of these varieties of spent grains can be considered broadly applicable to all of them. Table 6 provides a summary of processes to extract value from distillery wastes that are not currently operational in Scotland. Many of the processes shown in are also applicable for spent grains from breweries (and vice versa).

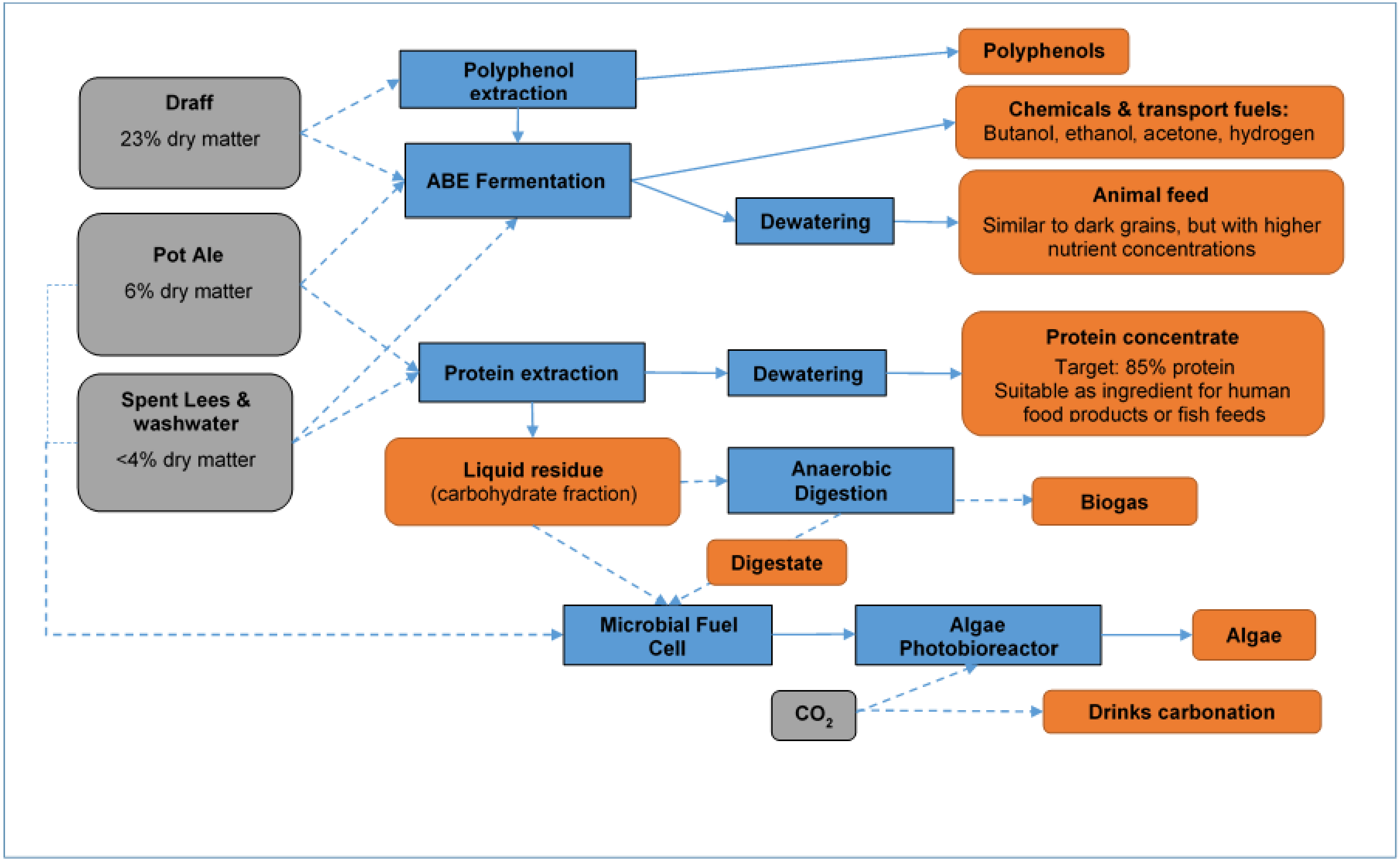


Figure 9 Potential future uses for distillery by-products

Process and products	Feedstock	Technology Readiness	Notes
Hydrolysis and fermentation processes to produce commodity chemicals and animal feed	Draff and pot ale	Medium	The process described for spent grains in Table 5 is also applicable to distillery draff. Celtic Renewables' ABE fermentation process (see case study in Section 6.2) to produce acetone, butanol, ethanol, hydrogen and animal feed is being initially developed for distillery by-products. Another UK company, Green Biologics, produces butanol using ABE fermentation with corn cobs in China and has a USA plant to come on line in 2016. Much research has also been carried out on DDGS (the equivalent of whisky draff) from bioethanol plants in USA and Brazil. Some research includes a focus on retaining the animal feed value of the final residues. The most common initial processes applied to the DDGS are acid or enzymatic hydrolysis and fermentation. Commodity chemicals that can be extracted from DDGS include simple and complex sugars and higher value products that can be produced from these: glutamic acid and furfural are two examples that have been demonstrated at laboratory scale. Alkali treatment of DDGS to produce a bio-adhesive has also been demonstrated. Other research has been carried out on producing thermoplastics from DDGS.
Extraction of anti-oxidants, metabolites, fragrants.	Draff, pot ale	Medium	As with spent grains (see Table 5), various techniques can be used to extract and purify high value but low volume chemicals available in draff. A process being is being developed by FDT Consulting in Ireland to extract the polyphenol anti-oxidants from brewers spent grains and hops, although whisky draff and pot ale are also suitable (see case study in Section 6.2).
Protein extraction	Pot ale	Medium	A process being developed by Horizon Proteins in Scotland (see case study in Section 6.2) involves extracting the protein from pot ale and refining this to a purity suitable for using as a high value human food supplement or component for fish feeds.
Microbial Fuel Cells	Pot ale	Medium	A process is being developed by M Power in Scotland (see case study in Section 6.2), and is applied to the digestate effluent from anaerobic digestion of pot ale. The process generates energy and treats the effluent, reducing the COD and potentially removing copper.
Algae production	Pot ale	Medium	A process is being developed by M Power in Scotland (see case study in Section 6.2), and is applied to the effluent from the microbial fuel cells as above. The algae can be processed into a variety of oils and chemicals, or used more directly as a pig feed. Scottish Bioenergy is also trialling on-site algae production at Glenturret distillery.
Fertiliser extracted from pot ale	Pot Ale	Medium	Practical trials were carried out using reverse osmosis to extract a solid fertiliser product from pot ale, avoiding the high energy cost of evaporators. The fertiliser was certified as organic and had a high nitrogen and phosphate content in particular. It was tested on cereals and potatoes over three years, with successful results.
Copper extraction	Pot Ale	Low	Various techniques have been tested to remove copper from pot ale, primarily as a treatment method to allow disposal of the pot ale, although there is also an objective of recovering the copper as a metal to be recycled.

Table 6: Innovative processes to valorise distillery by-products

Technology Readiness: Low = process proven at laboratory scale; Medium = process tested at pilot scale /commercial demonstrator. High = commercially operational.

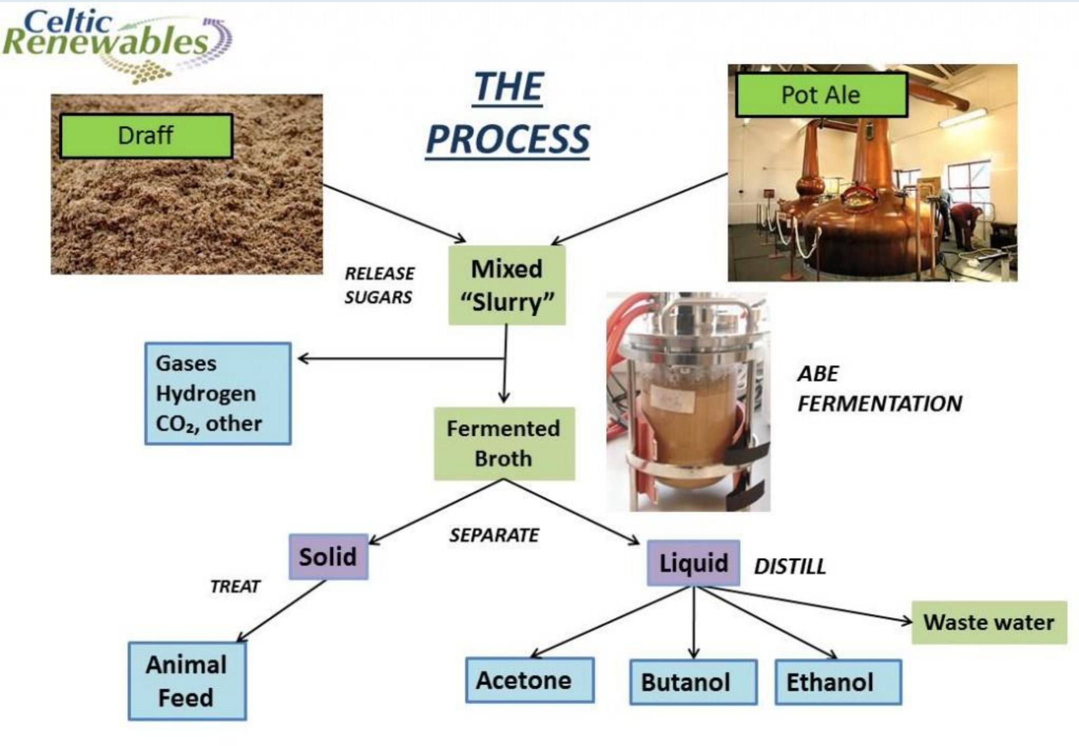
CASE STUDY: Commodity chemicals from draff and pot ale: Celtic Renewables

Celtic Renewables is a spin-out company from Edinburgh Napier University, established to commercialise a process to produce bio-based fuels and chemicals from industry wastes and by-products.

The heart of the Celtic Renewables technology is a microbial fermentation process that was a standard industrial technique producing solvents commercially until the 1960's. Celtic Renewables is developing a modern version to apply initially to whisky by-products, although it could also be used for brewers spent grains and other food industry wastes. The main products are acetone, butanol and ethanol, which gives the process the name of 'ABE fermentation'.

The ABE fermentation process also produces industrial gases and an animal feed product. The animal feed is essentially the residual solids produced following the fermentation, with the protein components still intact, but lower concentrations of cellulose and sugars which have been largely used up in the fermentation. The animal feed thus has a higher protein content than the original draff and can be dried and pelletised to produce a higher value animal feed which can be stored and readily transported and which potentially has a higher nutritional value than dark grains.

The biobutanol is the key product from the Celtic Renewables process. There is considerable interest in the biobutanol both as a sustainable biofuel and as a commodity chemical. As a biofuel, butanol has benefits over ethanol, currently the standard type of biofuel: it has a 30% higher energy content than ethanol and can be incorporated into petrol at a higher proportion (up to 16%) than ethanol, for unmodified engines. Biobutanol can thus attract a higher price than bioethanol. All of the chemicals and fuels produced by the Celtic Renewables process can supply the growing bio-based markets as alternatives to their petrochemical derived equivalents and are attracting strong market interest on this basis.



The Celtic Renewables process requires a liquid source and has been shown to work best with equal volumes of pot ale and draff as feedstocks. In principle, the process could treat all of Scotland's draff and a significant proportion of the pot ale. The remaining pot ale could also be used as a feedstock by Horizon Proteins, if mixed with other suitable bio-wastes such as low grade potato or paper industry wastes.

Celtic Renewables has demonstrated its technology at pilot scale in Belgium and is now planning to build a commercial-scale demonstration plant in Grangemouth, suitable for treating the by-products from a cluster of six distilleries in that area. The Celtic Renewables technology is predicted to offer a commercially competitive option for distilleries compared to current uses of their by-products, if operated at a multi-distillery scale. In particular, the technology offers a reliable solution for pot ale throughout the year.

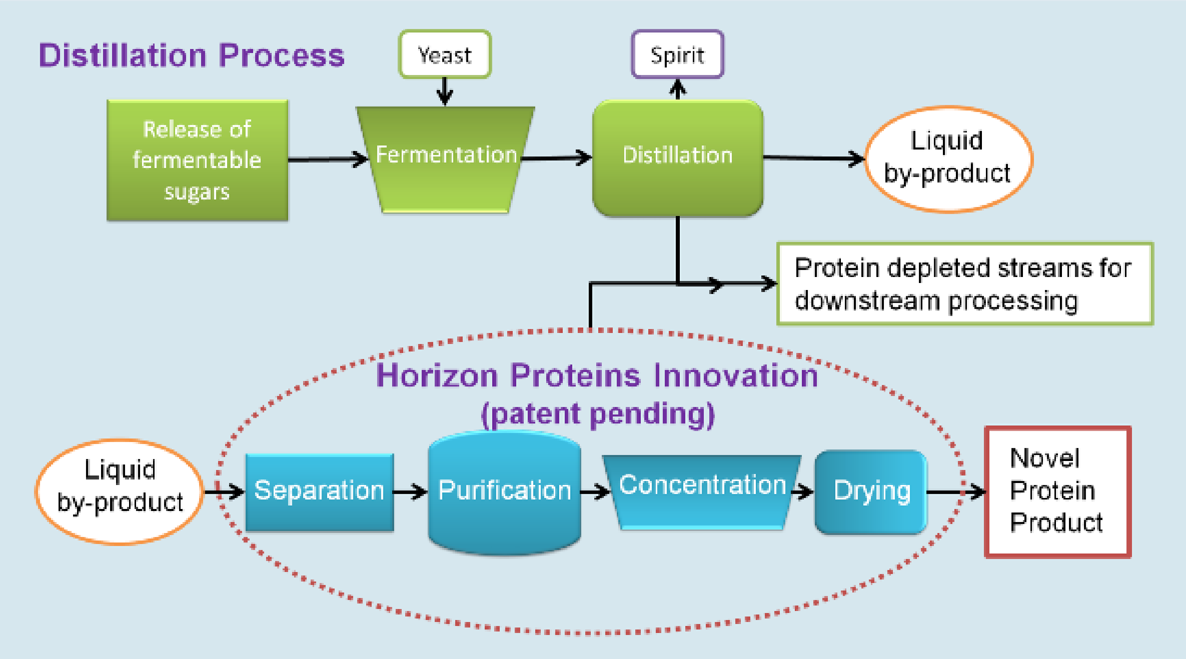
CASE STUDY: High purity protein from pot ale: Horizon Proteins

Horizon Proteins has developed a process for transforming underutilised resources from food and drink industries into higher value, high quality protein products. Initially the focus is on the synergies between Scottish malt whisky and aquaculture; specifically converting the proteins in distillery by-products into a local, sustainable and nutritional protein feed ingredient for salmon.

The process has low energy requirements, uses mild processing conditions and is being developed as a low cost solution. The process extracts proteins directly from pot ale, leaving the remaining carbohydrates and other components in a liquid residue which can be used for energy recovery (for example through anaerobic digestion) or to process into biofuels or related chemicals. The protein fraction can be dried to varying degrees, suitable for the blending processes used by aquaculture feed companies. The technology is notable for being able to produce proteins at sufficiently high concentration levels (>80%) to be of value in aquaculture feed formulations.

The process is being developed in different configurations to be suitable for different scales, including suitability for building the technology on-site at single distilleries.

The technology can be extended to proteins from other by-products and developed for specific proteins with attractive functional and nutritive applications. The process is applicable worldwide, offering new protein sources tailored to specific markets. Horizon Proteins' vision is to be a market leader in production and supply of quality, sustainable and valuable proteins to global feed and food manufacturers.



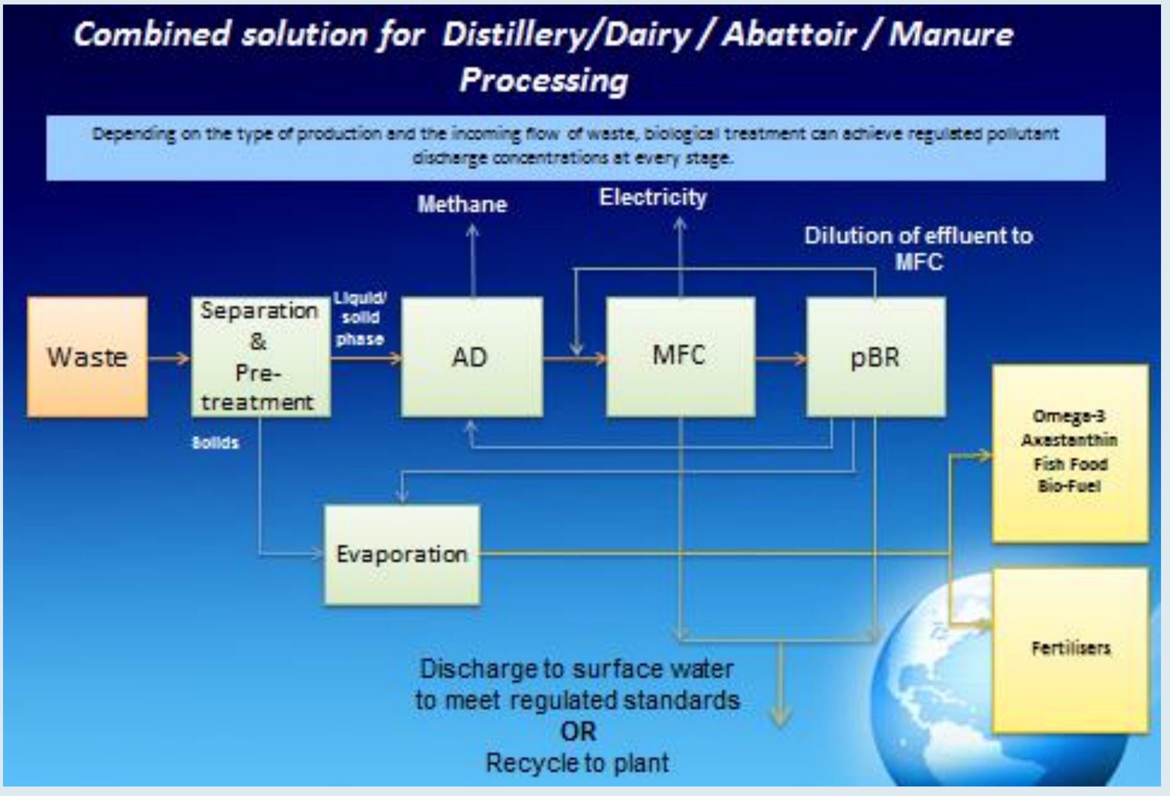
The team is based in the School of Engineering and Physical Sciences and the School of Life Sciences at Heriot-Watt University. The technology and intellectual property was developed over the last three years by the founders with funding from the Scottish Funding Council.

In Nov 2014 Horizon Proteins was awarded funding of up to £0.6m from Scottish Enterprise under its new the High Growth Spin-Out Programme (HGSP). At the end of the HGSP, Horizon Proteins will have the design and investment in place for a production prototype to commence operation at a Scottish distillery with the overall aim of the company developing to a £5m turnover within five years. The initial goal is to replace traditional proteins used in salmon feed such as fish meal and soya bean meal with locally sourced, readily available, sustainable protein which is competitively priced and a very attractive option for Scottish salmon farmers.

CASE STUDY: Biogas and Algae from Pot Ale: M Power

Edinburgh-based M Power is developing a synergistic treatment system that includes anaerobic digestion (AD), microbial fuel cell (MFC) and photobioreactor (pBR) in order to remediate the organic content of pot ale and spent wash from distilleries to meet legislative and local environmental standards. The system is designed to produce electricity (from the MFC as well as the AD) that can be supplied back to the distillery, algae (from the pBR) that can be used to produce fish feed, fertiliser, nutraceuticals and biofuel. The pBR's clean water output can either be discharged to river without cost or recycled for use in the distillery. The copper and phosphate content of the pot ale and spent wash can be extracted from the MFC.

The team have already developed versions of these technologies with similar wastes in Russia and Japan and have also successfully applied the MFC process to pot ale directly.
Our MFC technology processes the remaining high content organic liquor from the AD unit. A microbial fuel cell (MFC) can directly release that energy as electricity and at the same time reducing the organic content. However the organic content is still too high for discharge to river.
M Power have recently completed trials using these processes at the North British Distillery, to allow the distillery to save the high costs of discharging the AD output to sewer. M Power's business model suggests an investment payback of around three years.



CASE STUDY: Polyphenols from brewery and distillery by-products: FDT Consulting

FDT Consulting is the lead partner in the European project PUREOPE: Process for Upgrade and Recovery of Polyphenol Extracts.

The project is developing a technique to extract high value polyphenols, primarily from brewery by products including spent grains and spent hops, but pot ale from distilleries is also considered a suitable feedstock. A commercial demonstrator to extract polyphenols is planned to be built in Ireland in 2015.

Polyphenols are a type of antioxidant that can be extracted from liquid wastes or materials such as brewers spent grains following a hydrolysation step, using membrane technology and processing in to a liquid or powder form. There is a growing demand for polyphenols, which are used in food and drink products, pharmaceutical applications and increasingly as a preservative in bio-based products.

Global polyphenol demand was 14,071 tons in 2013 and is expected to reach approximately 25,000 tonnes by 2020.

FDT Consulting has estimated that there are 2,700 tonnes polyphenols available annually in all the malt and grain distillery by-products in Scotland would have a market value of at least £50million per year.

6.3 Fish

Various processes were identified that could offer higher value options for Scotland's fish sector wastes and by-products. A number of these potential future uses are shown in Figure 10. These include a mixture of processes identified in academic research papers, those trialled at small scale in Scotland and techniques used commercially outside of Scotland. Table 7 summarises these processes for aquaculture and caught fish; and Table 8 for shellfish wastes.

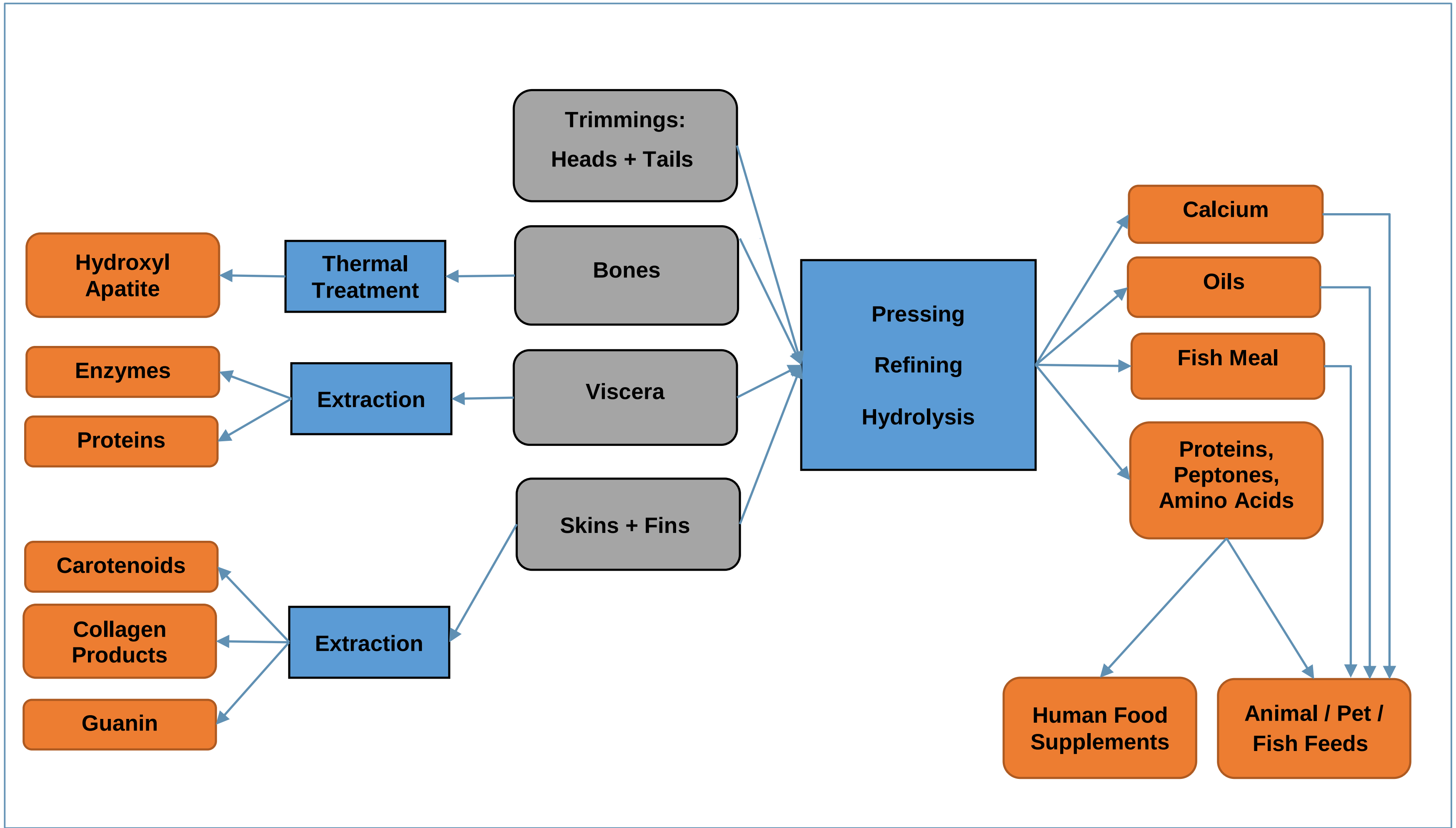


Figure 10 Potential future uses for fish by-products

Process and products	Technology Readiness	Feedstock	Notes
Composting and land spreading	High	Fish wastes	Fish wastes have various agricultural benefits, notably a high nitrogen content. Under ABPR legislation, these wastes require pre-treatment such as through in-vessel composting, anaerobic digestion (see below) or heat treatment, and evidence of agricultural benefit, before they can be applied to land. Fish wastes can be co-composted with a suitable high carbon content material such as shredded garden or wood wastes. This approach is relatively low-tech and is less reliant on large economics of scale than other processes. However, it still brings a disposal cost rather than an income for the waste producer.
Anaerobic digestion (AD)	High	Fish wastes	Anaerobic digestion of fish wastes is described in numerous research papers and is also carried out commercially, notably for fish mortalities that cannot be entered into the human or animal food chains. Protein is difficult to process in AD, with the nitrogen component producing ammonia contamination. The digestate produced from AD can be used as an agricultural fertiliser or soil enhancer.
Organic fertiliser	High	Fish wastes	Processing of fish wastes into a slow release fertiliser is a traditional activity. The addition of sulphuric acid or urea makes the plant nutrients (notable nitrogen and phosphate) more bio-available and reduces odours. A different approach is offered by at least one company (Biotel) which provides the technology to process fish and similar wastes into pathogen-free organic fertiliser using aerobic thermophilic micro-organisms.
Protein hydrolysation	High	Fish wastes	A wide range of protein-based products of varying degrees of purity and value can be manufactured from fish wastes, based on different hydrolysation techniques (acid, alkali, enzymatic and thermal), along with other refining processes. These techniques are more prevalent in Norway and contrast with the basic presscake fishmeal most commonly produced in Scottish fish waste processing facilities. The resultant products include: o Fish protein powder o Fish protein isolate o Fish protein hydrolysate o Marine Protein Concentrate o Amino acids and peptides With suitable adherence to relevant risk and quality standards, these products have a range of markets including in human food supplements and in specialist animal feeds based on easily digestible protein.
Extraction of collagen and related products	High	Fish frames, skins, fins, swim bladders	Research has shown opportunity to extract collagen from different fish parts; fish collagen is different to mammalian collagen, and can be used in a variety of nutraceutical, cosmetic and food applications as a concentrated protein, as well as biomedical applications based on its structural properties. A specialist form of collagen is isinglass, derived from fish swim bladders, and used commercially in clarifying beer. Fish collagen can also be further processed into gelatin, although this has limited markets compared to mammalian gelatin. Typical Scottish fish species reportedly have low collagen content, presenting a potential commercial barrier to this opportunity.

Fish glue	High	Fish skin, fish frames	Fish skins and frames have been traditionally used to manufacture fish glue, which still has a specialist market, although it has larger been replaced by modern adhesives.
Guanin extraction	High	Fish skin	Fish skins have been traditionally used as a source of guanine, or pearl essence: a substance used to give iridescence in synthetic jewellery, nail varnish and similar applications. It has largely been replaced by cheaper synthetic sources.
Refining into biodiesel	Medium	Fish mortalities	For fish mortalities not suitable for entering food chain, a case study could be relevant of biodiesel production from fish processing wastes in Alund islands (Baltic) for local use. Enerfish feasibility study for Shetland concluded 100,000 litres of biodiesel could be produced from currently landfilled salmon mortalities.
Extraction of protein nutritional supplement	Low	Fish viscera	See CellsUnited case study in Section 6.3.
Process into peptones	Low	Fish wastes	Research carried out with Norwegian fish waste processor Biomega demonstrated the ability to produce a peptone powder suitable for commercial use as a substrate for micro-organism cultivation, and a peptone liquid suitable as a speciality ingredient in petfoods.
Extraction of enzymes	Low	Fish viscera	Similar processes used to extract chemicals from general fish wastes can be used to extract specific enzymes present in the guts of different fish species, along with proteins and related components.
Extraction of carotenoids	Low	Fish skin	Astaxanthine is a type of carotenoid present in fish skin and is a commodity food sector chemical sold for its strong antioxidant properties. Different techniques can be used to extract astaxanthine from fish skins, in combination with the extraction of other chemicals. Astaxanthine is used as an ingredient in salmon feeds: it provides the source of the pink colour of salmon flesh. However, it is against industry practice and regulations to feed salmon-source ingredients back to salmon. Astaxanthine used in salmon feeds is generally produced from petrochemicals although it can also be extracted from brown algae.
Hydroxyapatite	Low	Fish bones	Hydroxyapatite is an inorganic chemical that can be isolated from fish bones through thermal decomposition. Hydroxyapatite is conventionally manufactured from mineral sources. It has various uses including as a food supplement, and in prosthetic implants, and has potential new applications in materials engineering due to its high strength.

Table 7: Innovative processes to valorise fish by-products/wastes

Technology Readiness: Low = process proven at laboratory scale; Medium = process tested at pilot scale /commercial demonstrator. High = commercially operational.

Process and products	Technology Readiness	Feedstock	Notes
Composting	High	Shellfish wastes	Shellfish wastes have various agricultural benefits, notably a high nitrogen content. There is also evidence of pesticidal properties of chitin in shellfish shell applied to land (see below). Under ABPR legislation, these wastes require pre-treatment such as through in-vessel composting, anaerobic digestion (see below) or heat treatment, and evidence of agricultural benefit, before they can be applied to land. The softer parts of shellfish wastes can be co-composted with a suitable high carbon content material such as shredded garden or wood wastes. This approach is relatively low-tech and is less reliant on large economics of scale than other processes. However, it still brings a disposal cost rather than an income for the waste producer.
Anaerobic digestion (AD)	High	Shellfish wastes	Anaerobic digestion has been used to extract energy from shellfish wastes. AD is applicable more to the soft parts of shellfish wastes such as viscera, or the liquid residues after extraction of chitin for example. However, a pilot project in Orkney has successfully digested crab shells, at least in a batch process. Protein is difficult to process in AD, with the nitrogen component producing ammonia contamination. The digestate produced from AD can be used as an agricultural fertiliser or soil enhancer.
Process mollusc shells into agricultural lime	High	Scallop shells	Current trials are being run by Mountwest4 to investigate the development of an agricultural lime substitute derived from waste scallop shells, in the Isle of Mull, displacing conventional lime fertilisers. Mountwest 4 is based in Aberdeenshire and they take in shells from Aberdeenshire-based processors.
Mollusc shells as aggregates	High	Mollusc shells	Free-of-flesh shells from scallops and other molluscs are often used informally and locally as a generic aggregate for building applications or as a track surfacing. Although this avoids landfill costs, it does entail a processing cost to remove the flesh in order to satisfy ABPR requirements.
Mollusc shells as calcium source in animal feeds	High	Mollusc shells	Although no specific Scottish example has been identified, cleaned milled mollusc shells are used commercially in other countries as a calcium source for laying hens, for example.
Chitin and related products	High	Crustacean shells	Chitin is the one of the most abundant natural bio-polymers and is found in high concentrations in crustacean shells. Chitin is produced commercially at large scale from the shells of shrimps, crabs and lobsters, especially in China, in a multi-billion dollar global industry. Various biological and chemical extraction methods can be used, some of which can also allow the protein fraction of crustacean wastes to be isolated as an animal feed. Chitin and its derivatives (notably chitosan and glucosamine) have a wide range of uses in agriculture, pharmaceutical applications, cosmetics, industrial waste processing (as an absorbent), medical applications, food preservative uses and dietary supplements. Research has also shown their potential for the production of biodegradable plastics. A UK-Norway project is investigating the potential for a biorefinery process for the coproduction of organic acid and chitin by co-fermenting crab shells with plant sugars.
Extraction of carotenoids	High		Extraction of carotenoids is reportedly carried out commercially on crustacean wastes, integrated with the chitin extraction process.
Seafood bisque and flavourings	High	Crustacean shells	Cooking crab or Nephrops waste after removal of the main edible portion yields flavouring or a stock that is then used in soup production.

Process and products	Technology Readiness	Feedstock	Notes
Crustacea meal	High	Crustacean shells	This process typically involves cooking/heat treatment of the waste to facilitate the extraction of oils & water, to a level where it is stabilised. This product is usually incorporated into fish feed to provide a balanced feed. Includes natural pigments etc. of benefit to salmonids.
Ingredient in petfood	High	Crustacean shells	Crushed crab and Nephrops shells can be used directly or with further processing as an ingredient in pet food manufacturing.
Fertiliser, pesticide	High	Crustacean shells	Heat treated, crushed crab shell is sold as a garden organic fertiliser in some countries. There is reference to this product also being produced in Orkney in the past. As well as providing minerals and improved soil structure benefits, the shell is claimed to reduce incidence of nematodes and other pests due to its chitin content. More commonly, crustacean shells have been spread to local land in Scotland, as a soil additive and/or fertiliser and there is reference to using this material specifically as a treatment for potato nematode.
Enzyme extraction	Low	Shellfish viscera	Research has shown the presence and techniques to extract various types of enzymes from scallop and other viscera.

Table 8: Innovative processes to valorise shellfish by-products/wastes

Technology Readiness: Low = process proven at laboratory scale; Medium = process tested at pilot scale /commercial demonstrator. High = commercially operational.

CASE STUDY: High purity protein food supplements from fish wastes: CellsUnited

CellsUnited is a UK-based company with both commercial and humanitarian objectives. The company's product, Cellper™, has its origin in international long-duration space programme research and has the potential to revolutionize nutrition for the world's most seriously undernourished people, also those with metabolic conditions that inhibit the digestion of protein. The company is seeking grant support to design and build a pilot production facility to run at half commercial scale in Dingwall in 2015, in collaboration with the Loch Duart salmon company (supplier of raw materials). Using CellsUnited's proprietary technology, salmon by-products (heads, frames, viscera) will be processed into Cellper™, a purified amino acid food supplement to be supplied in liquid or granular form according to the intended use The primary applications are to combat malnutrition and aid recovery in hospitals and as a dietary supplement for use in food aid programmes in developing countries.

The industrial–scale technology will be modular and transportable so that it can be deployed quickly and reliably to remote production sites around the world - close to sources of raw materials and local needs. An industrial-scale production plant which will process up to 5,000 tonnes of by-product per year and produce approximately 500 tonnes of Cellper™ is planned as the next development stage in Scotland. This output has the potential to be as valuable per kilogram after primary processing as the salmon fillet itself and, if all Scotland's 60,000+ tonnes of salmon waste could be processed using this technology, the added value would exceed £300 million in Cellper™ alone, plus additional value for the separated salmon oil and the residue used as fertiliser.

CASE STUDY: Bio-marine ingredients from fish: Killybegs Ireland

As part of a €35m project, Killybegs Fishermen's Organisation and a Norwegian technology company, set up a joint venture company (Bio-marine Ingredients Ireland Ltd), to develop a new bio-marine ingredients facility. With the capacity to process 50,000t of raw material every year, the facility will be the largest of its kind in the world.

The purpose of the facility is to extract high-end proteins, as well as oils and calcium from the raw fish materials which will then be used as food ingredients.

There are considerable economic advantages to using fish wastes in this way given the increasing prices for food ingredients and the demand for high quality protein. The potential value can be demonstrated by the company's strategic plan for 2013-17 which stated the intention to deliver 1,200 new jobs and €1bn in seafood sales.

CASE STUDY: Whelk bait from binded shellfish wastes: Burgons of Eyemouth

Burgons of Eyemouth is a crab processing firm which, in conjunction with Glasgow University, is working to develop a solution to handle associated shell wastes. Previously, crushed shell wastes were sent to landfill for disposal, however as a result of increasing costs, the business sought an alternative approach – to use the material to develop whelk bait.

To catch whelks, baits are used inside a whelk pot. Tests were carried out on the material from Burgons, to assess suitability as a whelk pot bait. It was found that the most appropriate solution was to crush and mix the crab shell wastes with other shellfish wastes (such as mussel or scallop), before binding and moulding into the product. This mix prevents the material from dissolving too quickly.

As well as providing an outlet for crab shell wastes, this solution presents opportunities for a variety of other shellfish industries.

6.3.1 Innovative aquaculture feeds

Almost all feeds used in Scottish aquaculture comprise blends of different ingredients formulated for different fish species and fish growth stages. These pelletised feeds are designed to provide the requisite nutrition for the fish as well as having physical properties to ensure minimal losses from sinking through marine fish cages. The key ingredients in aquaculture feeds are proteins chosen to be easily digestible by the target fish species and oils which, for salmon feeds particularly, must include a source of Omega-3 fatty acids.

Traditionally, the dominant source of these proteins and fats has been from wild fish caught from fisheries around the world. According to the Salmon Farming Industry Handbook (2014), since 1990, the fish feed industry has increasingly substituted both fish meal and fish oil with other commodities (such as soy, wheat, corn and vegetable oils) due to fish meal and fish oil availability and cost constraints. In 1990 fish meal comprised on average 59% of fish feed, whereas Norwegian feeds (as of 2013) contains only 14% with a new fraction of vegetable meal which comprises some 48% of the fish feed. The report also highlights large differences in the costs of production between Scotland and other salmon farming nations such as Norway, particularly with fish feed costs (as much as 40% more expensive in Scotland).

Typical modern salmon feeds contain 30 to 50% proteins and 25% to 35% oils[38]. Discussions with industry sources suggest that fish feeds currently used in Scotland contain around 15% recycled material in total. By law and industry practices, this recycled material cannot comprise salmon by-products as an ingredient in salmon feeds, but instead come predominantly from wild caught fish.

The demand for new sustainable sources of oils and proteins is driven by price and content. In particular:

- Wild fish oils need to be replaced with another oil containing Omega-3 and related components
- Wild fishmeal needs to be replaced with a component with a high (>75%) content of digestible protein: a much higher protein concentration than is needed in other animal feeds.
- New sources of feed components must have low concentrations of anti-nutritional factors such as phosphate.

In essence, aquaculture feeds have much higher specification requirements than feeds for cattle, pigs or poultry. Many food sector wastes –such as draff and spent grains – which are suitable for use as cattle feeds, are not suitable as aquaculture feed ingredients without further processing. The Horizon Proteins technology (see case study) is an example of an opportunity to extract a high purity protein from a high tonnage food waste (pot ale) that would be suitable as a new protein source in aquaculture feeds.

Table 9 below describes innovative new sources of aquaculture feed ingredients that would contribute to a circular economy.

[38] Industry source

Source	Comments
Fish processing by-products	The proportion of fishmeal and fish oil extracted from fish processing by-products (avoiding intra-species recycling) could increase if the supply of the by-products increases, for example as a response to the Landings Obligation. However, there is also increasing demand for higher value products derived from these by-products (see CellsUnited case study) that will limit the availability for aquaculture feeds.
Distillery, brewery and other food processing by-products	Although few food processing by-products have sufficiently high protein or oil levels to be suitable as an aquaculture feed component, there is potential to process some by-products to extract the required components and hence produce a higher value ingredient that can be sold to aquaculture feed manufacturers. A key challenge is to minimise anti-nutritional or other contaminant materials. See Horizon Proteins case study.
Scottish-grown crops	Some legumes and oil crops grown in Scotland can be assumed to already contribute to aquaculture feeds, but these are in competition with protein derivatives extracted from imported soya beans. The Beans4Feeds case study shows the potential for replacing soya-based ingredients with protein derived from Scottish-grown Faba beans.
Algae	Algae are used in some specialist aquaculture feeds, but currently represent an expensive ingredient with no significant commercial supply in Scotland. There is considerable interest in marine algae as an aquaculture feed ingredient, as these contain the essential fatty acids needed in fish diets, which are absent in freshwater algae. The energy needed for drying algae prior to inclusion in aquaculture feeds is a barrier.
Insects	There is considerable interest in the use of insect protein in animal and fish feeds. An extensive European funded research programme, PROteINSECT, is currently investigating the potential, including trials feeding black soldier fly larvae to Tilapia in Ghana. Black soldier fly are also the species used by the South African company AgriProtein to produce a competitively priced animal feed ingredient (see case study). A key benefit of growing insects is that they effectively convert a low grade wet waste into a high protein, high fat content and relatively dry material with low energy demand and minimal further processing needed to use as an animal or fish feed ingredient.

Table 9 Innovative new sources of aquaculture feed ingredients

CASE STUDY: Scottish supply of vegetable protein for fishfeeds: Beans4Feeds

Beans4feeds is a £2.6m collaborative research programme in Scotland, started in 2012 and running for four years, led by the James Hutton Institute.

The research focusses on extracting a high protein fraction from faba beans, to use as a component in aquaculture and animal feeds, as a substitute for soya-based proteins. Faba beans (field beans) can be easily grow in Scotland and bring significant agronomic benefits, including providing a net nitrogen gain to the soil, wider soil building benefits and the ability to grow the beans as an inter-crop or in rotation with other crops.

Faba beans are already used as a component in aquaculture feeds, simply as a milled bean. The Beans4Feeds research involves producing a higher value protein component that is intended to be a replacement for soya bean protein, and that is derived from the hulled faba beans using a cyclonic air fractionation process. The other main product is a starch-rich fraction that can be used to replace wheat and soya components in pig and poultry feeds, or could be used in higher value human food applications including in brewing.

Other research has shown the potential to use faba bean crop residues (the leaves and stalks) as a feedstock in a biogas plant, and for extraction of polyphenols and other chemicals from the resultant digestate.

Calculations provided by the Beans4Feeds team show that around 8% of Scottish arable farmland would be needed to grow enough faba beans (160,000 tonnes per year) to supply the vegetable protein requirements of the Scottish aquaculture sector. This would also produce 36,500 tonnes per year CO_2 savings through reduced nitrogen fertiliser use. The monetary value of this scale of production of fractionated faba is estimated as:

- £19 million for the protein fraction
- Up to £44 million for the starch fraction
- £2.4 million for the bean hulls as an animal feed.

This gives a total estimated value to Scotland of £65 million. Of this, an estimated £9.5 million would accrue to the farmers from sales of the unprocessed beans.

See Appendix H for more details and the basis of the calculations.

CASE STUDY: Insect protein from wastes: Agriprotein

Agriprotein is a South African company which has developed a commercial scale technology to produce animal feed ingredients from insects grown on biowastes.

Agriprotein grows fly larvae on various low grade and problematic biological wastes. The larvae are harvested and processed into a protein-rich fraction and an oil fraction which are sold as ingredients for feeds for fish, poultry and pigs. The process also produces two agricultural fertiliser products.

The first factory to be operational, in 2015, will produce 7 tonnes of protein meal and 3 tonnes of oil per day. At an indicative price of $1,350 per tonne, the protein meal will be competitive with conventional sources of fishmeal.

7 Assessment of possible future applications of by-products

7.1 Beer

7.1.1 Biorefinery approaches

Many of the potential uses mentioned in Section 6.1 constitute biorefinery processes to produce biofuels, platform chemicals and speciality chemicals, which could use by-products from both distilleries and breweries as feedstocks.

Due to the technology and the markets involved, such biorefineries would only work commercially at large scale. There is a potential commercial case for a suitably located spent grains biorefinery fed by the outputs from a cluster of brewers and distillers. Celtic Renewables (see case study) is considering this approach, to use the by-products from around two to five distilleries as feedstocks for its fermentation-based biorefinery and this technology is also suitable for breweries. Work carried out by the Biorenewables Development Centre suggests that spent grains and draff could be transported by road up to 60 miles to a biorefinery under a reasonable commercial scenario. In Scotland, this could serve a significant sized cluster of distilleries and breweries in the central belt or in Speyside for example.

A general approach to biorefining of brewery and distillery by-products would centre on a hydrolysis and fermentation-based process to produce a range of commodity chemicals including sugars and alcohols and leaving a high protein residue suitable for animal feed. This process could be a stand-alone commercial operation and is essentially what Celtic Renewables is developing with the whisky sector. Further processing that could be integrated with this includes extracting high value, low volume chemicals such as polyphenols before the fermentation stage and further refining of the protein fraction. These and further options are shown in Figures 5 and 6 in Section 5 and Figures 8 and 9 in

Section 6. Other local bio-based materials could also be used in these bio-refining processes for brewery and distillery by-products – and further refining technologies could be added, on the same site or nearby. Hence, this presents an opportunity for an industrial bioprocessing park creating a range of high value products from local wastes and by-products or a large-scale biorefinery as identified in *'The Biorefinery Roadmap for Scotland'*[39].

A point made by some of the stakeholders involved in developing these technologies is that a pragmatic guide to commercialising biorefinery processes for particular feedstocks should start with building the simplest biorefining process that can be commercially operated, integrated with an existing distillery or brewery set up. Further processes that may produce higher value products can be integrated in later development phases.

The potential economic prize to Scotland if this biorefinery approach can be fully developed, is clearly substantial, a fact already recognised in *'The Biorefinery Roadmap for Scotland'*[40] and reflected by the activities of the IBioIC. A full economic analysis is beyond the scope of this study, but the market outlook for the products that can be produced from brewery and distillery by-products gives some indication.

To give some context, the European Commission estimates that bio-based products and biofuels represent approximately EUR 57 billion in annual revenue and involve 300,000 jobs. They forecast that the bio-based share of all chemical sales will rise to 22% by 2020, with a compounded annual growth rate of close to 20%.[41] There is a considerable demand for bio-based products as an alternative to fossil-fuel based products – particularly for 'second generation' biofuels and 'renewable chemicals' that are produced from wastes and by-products rather than directly from crops.

The biorefinery approach for brewery and distillery by-products clearly offers a valuable opportunity for Scotland. However, further development is needed before it is likely to be a commonplace commercial reality.

7.1.2 Biobutanol and bioethanol

Much research has been carried out into ethanol production using yeast fermentation on the spent grains from grain-fed bioethanol plants in the USA. This can be seen as a secondary process to produce additional ethanol from the residues produced from the primary fermentation, and is a biorefining technology that can be applied to brewers spent grains as well as distillery spent grains and draff. By contrast, the Celtic Renewables technology involves a microbial fermentation that produces butanol, which has a significantly higher value than ethanol, both as a biofuel, and especially as a commodity chemical.

As a biofuel, butanol has a higher energy value and higher financial value than ethanol and can be blended into conventional fuels at a higher proportion than ethanol. It has an even higher value as commodity chemical: butanol has an established history as a chemical and solvent, particularly for use in paints, coatings, printing inks, adhesives, sealants, textiles and plastics. The annual global market for butanol currently exceeds 1.2 billion gallons and is valued at over $6 billion.[42]

NB The ethanol, butanol and other chemicals produced by any process from brewery and distillery by-products is often given the prefix 'bio' to differentiate from the petrochemical derived versions that they are intended to substitute.

7.1.3 Polyphenols

Polyphenols are a common type of antioxidant that can be extracted from brewery and distillery by-products, as a single process or as part of a wider biorefinery approach. The global market for antioxidants, used especially in food and beauty products, is estimated at $34billion and is growing[43].

[39] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap
[40] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap
[41] http://ec.europa.eu/growth/sectors/biotechnology/bio-based-products/index_en.htm
[42] http://www.informaecon.com/MCSBiobutanol2013.pdf
[43] http://www.kangcare.com/newsab.php?id=117

There is a fast growing demand especially for antioxidants as a preservative in new bio-based chemicals and products.

7.1.4 *Options for microbreweries*

Alternative approaches suitable for microbreweries – especially those that would be outwith the catchment area of a centralised biorefinery – are possible. These include:

- Local human food: use as ingredient in e.g. biscuits, bread or sausages: allow for novel flavour characteristics as well as giving a local focus
- Basic value adding, for example through drying and preserving, of spent grains and yeast to produce a higher value speciality animal or aquaculture feed.
- Substrate for speciality mushroom cultivation
- Feedstock for speciality paper manufacture
- Use as a substrate for enzyme or micro-organism cultivation

These options are suitable for small scale application due to producing products for local markets, using standard low tech processes. Alternatively, they could potentially produce a speciality product based on the unique characteristic of the by-products from a particular brewer and thus avoid competition with the products from larger brewers or distilleries with greater economies of scale. However, these options need to offer a higher value for the breweries than the current practice by microbreweries of giving away their mixed by-products for free for local animal feed or gardening uses.

7.2 Whisky

7.2.1 *Biorefinery approaches*

The opportunities from a biorefinery approach for both distillery and brewery by-products is explored in Section 6.2. This approach is especially relevant for Scotland's distilleries due to the larger scales involved compared to breweries.

The whisky sector has already gone further than the beer sector in developing and commercialising technologies to extract value from their by-products. Distilleries already produce semi-refined animal feeds and generate renewable energy from their by-products as described in Section 6.2.

Four new innovative approaches to higher value uses of distillery by-products in Scotland are being developed that are particularly noteworthy:

- Celtic Renewables (commodity chemicals from draff and pot ale)
- Horizon Proteins (protein extraction from pot ale)
- M Power (microbial fuel cells and algae cultivation from pot ale and spent lees)
- FDT Consulting (polyphenol from pot ale and draff)

These technologies are being developed by different organisations, in collaboration with different distilleries and with support from Scottish agencies, including the IBioIC.

Discussions with each of the organisations developing the above new technologies reveal that there is a good possibility of integrating some or all of the processes with one or more distilleries. Essentially, each of the technologies is targeted at a different component in the distillery by-products and a suitably designed integrated system could therefore produce from the draff, pot ale and spent lees:

- Polyphenols
- Butanol, acetone and ethanol, hydrogen, and a residual animal feed, from the draff
- High purity protein from the pot ale
- Algae from the de-proteinated pot ale
- Energy for on-site use from anaerobic digestion and microbial fuel cells

Figure 9 (see Section 6.2) shows how these technologies could be used for different distillery outputs and how, at least in theory, they could all be integrated at a single distillery or cluster of distilleries. They also present an opportunity for a more extensive industrial bioprocessing park, as described in the previous section, or large-scale biorefinery as identified in *'The Biorefinery Roadmap for Scotland'*[44].

7.2.2 *Fertiliser uses*

Pot ale is commonly spread to land, although this can be seen largely as a quick or low cost method to dispose of the pot ale rather than adding value to the agricultural land.

The successful trials using a concentrated pot ale as a fertiliser (see Table 6 in Section 6.2) showed that this material had an agronomic benefit for cereal and potato cultivation. However, concentrated pot ale has been shown to have a higher financial value as an animal feed ingredient than as a fertiliser, and it can be argued that there is more sense in using protein content as a high value nutrition in feeds rather than as a source of nitrogen for crops.

It may also be possible to extract the phosphate component from pot ale to use as a fertiliser, instead of it remaining as a component of pot ale cattle feed in which it can be seen as a wasted resource, or even a potential pollutant once released to water courses via manure The technologies being applied to extract phosphate from sewage sludge might be adapted and applied to pot ale, with or without other processes extracting components from pot ale.

7.2.3 *Renewable energy*

There is a growing trend for distilleries to invest in technologies to convert their by-products into renewable energy. This move is driven by the renewable energy subsidies (Renewable Obligation Certificates scheme, Feed in Tariffs and the Renewable Heat Incentive) and also from the Scottish Whisky Association's target: by 2020, 20% of the industry's energy use should come from non-fossil fuel sources, rising to 80% by 2050.

Various renewable energy configurations are possible, as shown in the case studies, and include:

- Co-combustion of the dewatered draff with wood chips (e.g. forestry wastes) to generate steam for on-site generation of electricity and process heat. This subsidised renewable heat can then be used in the pot ale evaporators as a cost effective way of producing pot ale syrup
- Anaerobic digestion of the pot ale, spent lees and washings to produce biogas (used for on-site generation of electricity and process heat) and an effluent with reduced need for further treatment

These renewable technologies have a strong commercial benefit, particularly due to the subsidies available from the Renewables Obligation, Feed In Tariff and Renewable Heat Incentive schemes. They also help meet renewable energy and decarbonisation targets.

However they can also be seen as an option low down in a hierarchy for valorising biological wastes, particularly in the case of direct combustion: burning a material effectively destroys valuable long chain molecules that could potentially have a multitude of high value material uses, providing a one-off energy release and ash. Indeed, use of the long chain molecules in by-products by converting them to high value chemicals and feeds may bring higher carbon savings and higher profits. Energy generation (such as AD) should be used as an end process after higher value has been extracted from the by-products.

In particular, the protein fraction in draff and pot ale is the most valuable component for animal feed and can be considered a contaminant in renewable energy generation: the nitrogen in the proteins leads to NOx pollution from combustion and contaminates the anaerobic digestion biochemistry due to ammonia formation. In the case of the CORDe plant (see case study), the nutritional value of the draff is lost by burning it (following dewatering and drying), but the resultant heat is used effectively to

[44] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap

evaporate the pot ale into pot ale syrup, a relatively high nutritional and transportable animal feed that provides an income.

7.2.4 *Animal feed markets*

Use of distillery by-products as an animal feed has been important to Scottish cattle farmers in the past and will continue to remain so. New uses of distillery by-products can be integrated and compliment the current commercial arrangements of supplying local cattle farmers with a readily available source of low-cost feed. Several factors important in this area include:

- For many distilleries the amount of draff produced exceeds the capacity of the local cattle population to use it, especially in summer when there is less need for supplementary cattle feed. Production of dark grains from raw draff provides a drier more concentrated feed that can be stored for longer and allows economic transport across Scotland and northern England. However, it requires a high energy input whose cost largely offsets the additional income that can be attained from sales of dark grains.
- Similarly, the large quantities of pot ale produced by distilleries exceeds local cattle feed demand; converting to pot ale syrup allows more widespread use and higher income, but again the high energy costs offset the additional income. It is notable that the majority of pot ale is reportedly spread to land, discharged to sea or treated as a wastewater rather than used as animal feed.
- Distillery by-products as animal feeds are essentially only suitable for cattle. The type of protein available and the high fibre content makes them unsuitable for pigs and poultry. The high copper content in the by-products from distilleries using copper stills prevent use as sheep feed. Aquaculture feeds require a higher protein content of at least 50%; dark grains contains around 25% protein.

The overall feedback given by many stakeholders in the whisky sector is that, especially allowing for the growth in whisky production, there is a strong need for new uses for draff, and especially for pot ale, beyond the current uses for cattle feed. The introduction of any bioethanol production in Scotland or northern England could make more by-product available, not less, to the cattle feed market and quite quickly there could be an oversupply of whisky by-product in Scotland. This was quoted as being of ‘strategic importance’ to the whisky sector in Scotland and an area for more research.

The extraction of high purity protein from the distillery by-products, either as a stand-alone process or combined with wider bio-refining, could offer a game-changing opportunity. Such protein could be suitable for the growing aquaculture feed market which has a large protein demand in Scotland. The Horizon Proteins technology (see case study) is a key development, as it offers the possibility of low energy extraction of concentrated protein from pot ale. A bonus as pot ale is in less competition with the cattle feed markets than draff. It may also offer a potential solution for smaller or isolated distilleries: Horizon Proteins is developing a form of their technology designed to operate at smaller scales.

There are clearly several new uses of distillery by-products that appear to offer economic and resource use benefits – strong contributors to a circular economy in Scotland – beyond the current uses. Ultimately, if they can be shown to offer a higher income or lower cost option for the distilleries, especially if they can be offered as a turn-key solution for the distilleries, then there will be of real interest to the distillery sector.

7.3 Fish

The wide range of potential innovative uses of different fish and shellfish wastes, summarised in Table 8, compared to the current dominant uses of these materials in Scotland, implies a considerable economic and environmental opportunity for Scotland’s growing fish sector. In particular, the academic research shows a plethora of chemicals of varying degrees of refinement and value that could be extracted from fish and shellfish wastes and by-products.

It is beyond the scope of this report to make a detailed assessment of the commercial or technical viability of these technologies. Discussions held with industry and academic stakeholders and a review of the published literature identified some key benefits and barriers to the marine biorefinery opportunity for Scotland. These are summarised in Table 10 below.

Benefits	Barriers
Treatment of different components (skins, frames, shells etc.) separately allows optimised recovery of specific chemicals.	High level of capital investment required
Extraction techniques generally produce the high value output (which can be further processed to increase value) and one or more residues. In many cases, further value can be successively extracted from these in a 'cascade' approach, including renewable energy generation from the final low grade residues.	A large economy of scale is assumed to be required. This is the case for the current technologies used in Scotland, to process fish waste into fishmeal and oil. The CellsUnited process, by contrast, is being developed to operate at much smaller scale.
Extraction of speciality chemicals (e.g. astaxanthines, collagens) can be integrated with extraction of bulk or refined proteins and oils for animal feed or human food chain markets	Potentially a complex business model, reliant on supplying changing markets for a variety of products
As an overall approach, the biorefinery can maximise the total value extractable from any given by-product.	To access higher value markets, strict adherence to quality standards and transparency is needed for products entering the human food chain especially; parallel sets of controls and regulatory requirements are needed for any wastes generated. New quality and regulatory protocols may need to be developed with SEPA and others.
Many of the techniques involved are in commercial operation in other countries with a large fish sector, or have been trialled at pilot scale.	Manufacture of high value products in Scotland needs to be competitive with other global sources of the same product.

Table 10 Marine biorefinery opportunity for Scottish fish sector: technical and commercial factors

It seems likely that Scotland could support at least one marine biorefinery to produce the higher value products identified in the academic research, making use of currently underused shellfish wastes, making higher value uses of by-products already processed at a basic level in Scotland, or using fish wastes and by-products currently exported for processing outside Scotland. This acknowledges that there are potential issues affecting how this material can be managed where it is designated as an animal by-product as described in Section 5.3.

A specific version of a marine biorefinery designed to extract chitin and related products (e.g. chitosan and glucosamine) from crustacean shells may offer a commercially viable solution at a scale suitable for the Scottish shellfish sector. The growing global market for chitin derivatives is estimated to reach $63 billion in 2015.The target feedstock in Scotland would be crab and Nephrops shells, although there is also reference to extracting chitin from scallop shells. The business case for a chitin extraction facility in Scotland may rely on finding a high value regional use of the chitin as an alternative to competing with international supplies of chitin and related products. The market value for chitin is quoted (in 2011) as ranging from $22,000 per tonne to $4.4million per tonne depending on quality.[45]

To proceed with the development of a marine biorefinery, a number of issues will need further consideration, as follows:

- The need for a more co-ordinated approach to developing the relevant technologies in Scotland: which are the most promising techniques / integrations of techniques?
- Scotland has a smaller and more dispersed fish sector than Norway, and there is some expectation for Norway to continue to lead the development of marine biorefinery processes, however there is an interest amongst stakeholders to develop innovations in Scotland suited

[45] http://www.cmag-gams.org/documents/GAMS_snow_crab_value_added_2010.pdf

for Scottish marine wastes and by-products. Further investment in appropriate research and testing facilities is likely to be needed.
- There is a need for a co-ordinated approach to logistics, especially for a large scale biorefinery serving dispersed sources of fish sector wastes.
- There seems to be sporadic interest amongst the existing Scottish fish processing / fishmeal businesses in developing higher value extractions techniques. Most of these businesses are generally focussed on running their core business activity and are often not motivated to invest time and money on innovation projects. The examples of CellsUnited and the Killybegs processing facility in Ireland show two contrasting approaches to innovation for this sector.

There are a number of suitable smaller scale solutions possible for local and dispersed sources of fish and shellfish wastes. CellsUnited is developing a small scale and modular solution for fish process by-products that contrasts with the large economies of scale that have been commented as necessary for conventional fish waste processing and demonstrated by companies such as United Fish Industries.

There appear to be numerous options for crustacean wastes ranging from a soup stock to simple processing into a sellable fertiliser (see Table 8), which are sufficiently low tech to be applicable at small scale for Scotland's producers of Nephrops and crab wastes. Similarly conversion of scallop shells, with basic processing allowing for Animal By-Product Projection Regulations, should be sufficient to allow a local agricultural use replacing standard agricultural lime. This is currently being trialled by Mountwest4[46] in Aberdeenshire.

7.4 Regional bio-based circular economy hubs

The previous sections have described various processes suitable for extracting higher value products from the key wastes and by-products produced by the three sectors. A more ambitious vision might involve creating a single site, local or regional bio-based industrial symbiosis arrangement in which bio-resources flow between different industries and enterprises. This may be presented as the waste from one business being the feedstock in another, but in a wider sense it would involve a web of different resource flows, akin to the material and energy flows in an ecosystem.

Three examples are given here to illustrate this concept.

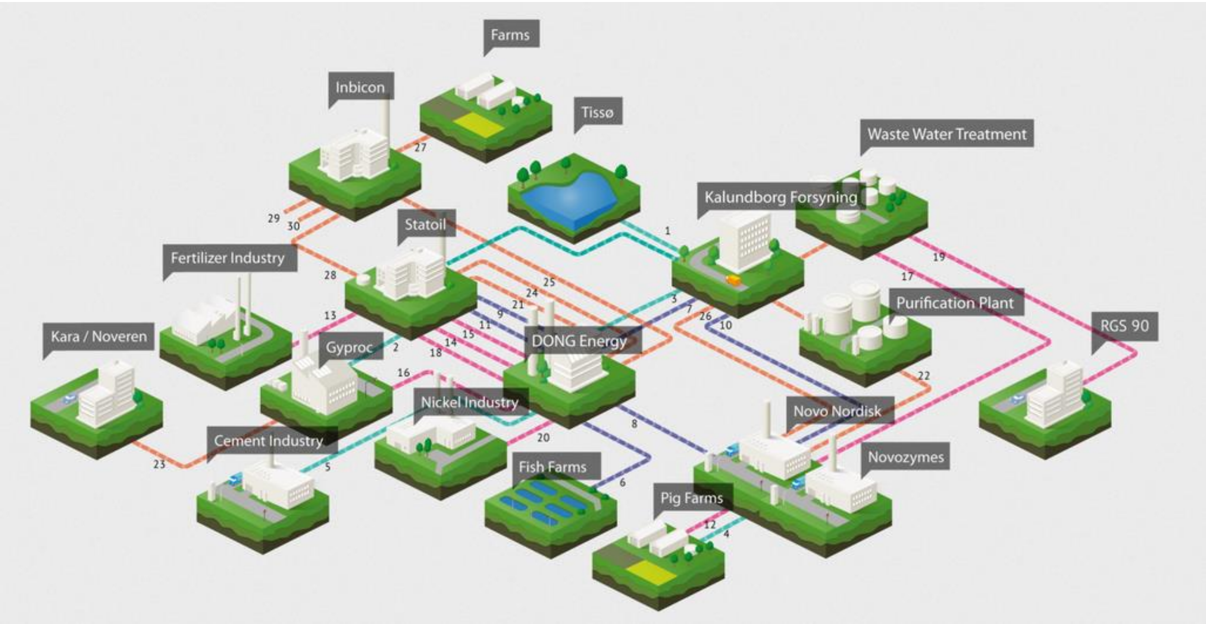
[46] At time of writing are being supported by Zero Waste Scotland separately.

Kalundborg Symbiosis, Denmark

The Kalundborg Symbiosis is an industrial ecosystem, where the residual product of one enterprise is used as a resource by another enterprise, in a closed cycle. An industrial symbiosis is a local collaboration where public and private enterprises buy and sell residual products, resulting in mutual economic and environmental benefits.

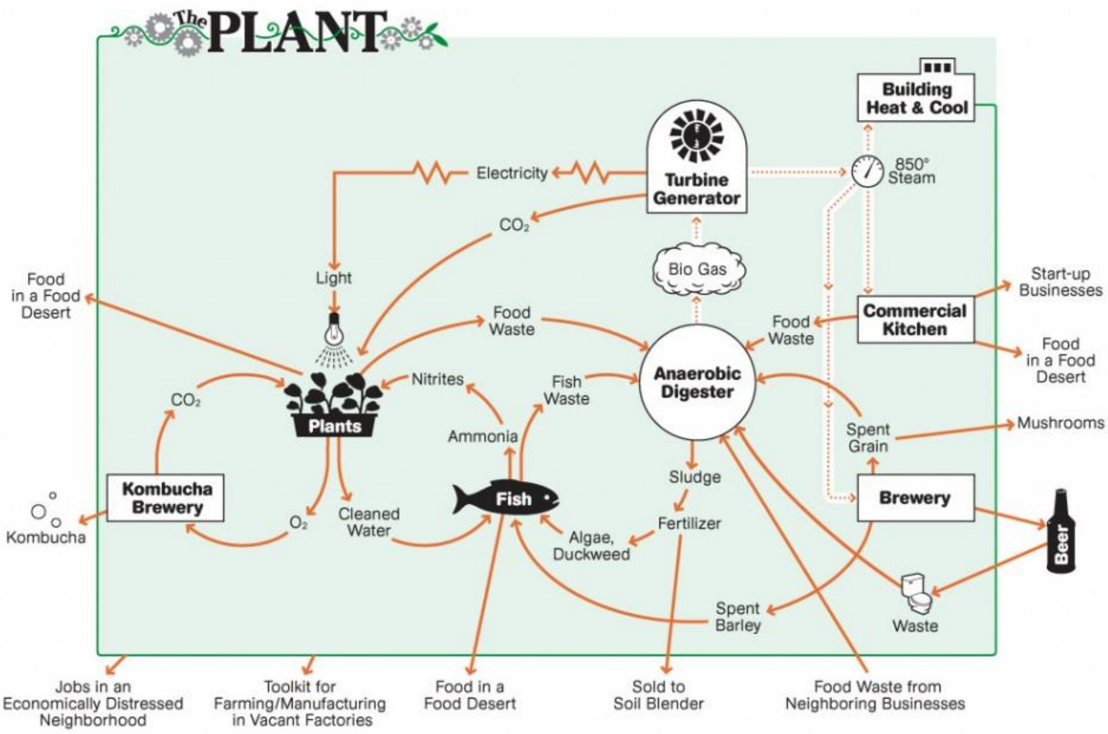
Systems make it possible, people make it happen.
In the development of the Kalundborg Symbiosis, the most important element has been healthy communication and good cooperation between the participants. The symbiosis has been founded on human relationships, and fruitful collaboration between the employees that have made the development of the symbiosis-system possible.

The Kalundborg Symbiosis in Denmark is 'the world's first working industrial symbiosis' and has been developed since 1961. Multiple flows of resources have been established between chemical industries, agriculture and fish farms.



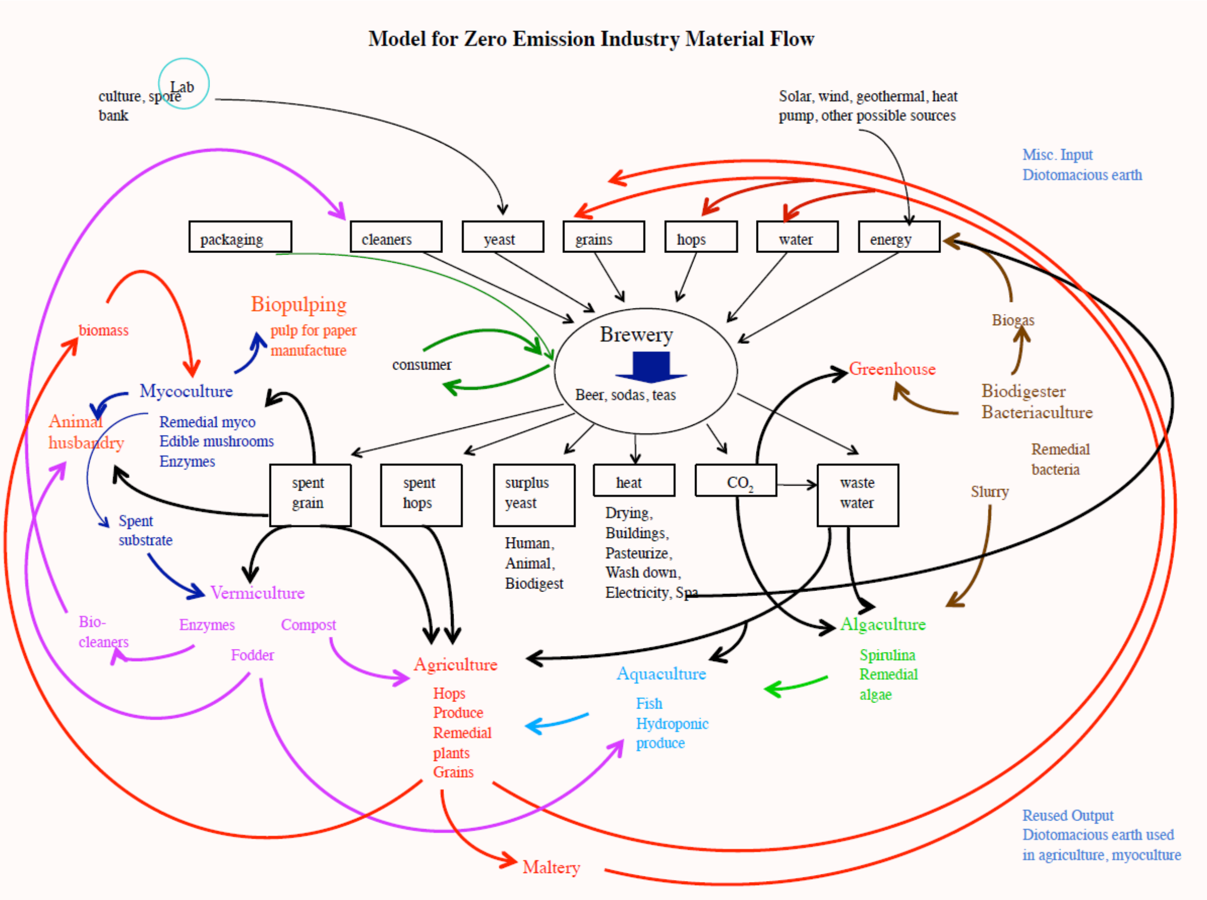
The Plant, Chicago

The Plant in Chicago is an example of small scale integrated bio-enterprises at an urban single site. The Plant is founded on the concept of closing waste, resource and energy loops. All of the systems of production at The Plant function and are interconnected based on this model. We focus on orienting those systems of production so that the waste of one system is recycled as an input into the same or another system of production.



The Five Kingdoms

The Five Kingdoms ‘Zero Emission Industry Material Flow brewing process’ is a conceptual design centred on a brewery, but with resource flows used to create numerous integrated bio-enterprises including cultivation of mushrooms, algae, worms and fish. The concept was produced by 5 Kingdoms Development, LLC from Kokomo, Indiana, USA.



A strong emphasis in both the Plant and the Five Kingdoms examples is on local food production or other forms of bio-based production that benefit from the nutrient flows from the other enterprises.

It is suggested that these integrated biological loop approaches could be developed in Scotland as regional bio-based circular economy hubs that could potentially provide an economic boost from smart resource uses. Such hubs might be of greatest benefit in rural and island communities, where they could provide a foundation for new sustainable local food economies.

8 Analysis

It is clear that the three sub-sectors of the Scottish food and drink sector already show a significant level of biological circularity both as traditional business practice and through new developments. A number of examples can be highlighted:

- The majority of whisky draff and brewers' spent grains are used as cattle feed as a substitute for crop-based feeds. The nutrients in these by-products, notably nitrogen and phosphate, are further recycled when the cattle manures are spread on local farmland.
- Some whisky by-products are used to generate renewable energy for on-site use and a proportion of this energy is used to dry and concentrate draff and pot ale into higher value animal feeds.
- The majority of fish processing wastes are processed into ingredients for aquaculture feeds, pet food and other animal feeds.

It is equally clear that there is enormous scope for more developed and higher value circularity in the three sub-sectors and in the wider food and bio-based industries in Scotland. Some of the key factors that provide these opportunities are:

- The technological capabilities to generate higher value products, such as commodity chemicals, concentrated protein products and food supplements, from by-products, and the growing markets for these. The demand for bio-based products as an alternative to petrochemical products and the demand for sustainable sources of aquaculture feeds are especially notable.
- The growth in the three sub-sectors, resulting in increased volumes of wastes and by-products. In some cases exceeding the capacity of existing markets for the by-products – for example the increased generation of draff and pot ale in many regions whose livestock and farmland capacity to accept these materials is already saturated.
- The increasing costs of disposing of effluents to sewer and of treating them on site through high-energy processes.
- Resource risk creating a need to protect Scottish businesses from rising material costs
- Increasing transport costs making imported materials more expensive and more liable to price fluctuations

This study has revealed numerous examples of higher value circularity in the three sectors that may come to dominate in the future. New enterprises and innovative technologies are being developed – largely in an ad hoc manner – by existing businesses in the sectors, by research organisations and by entrepreneurs. However, it should be emphasised that each potential new use will have specific parameters which will dictate what is economically viable and which is not. For example, it may be possible to use draff or pot ale as an input into a new technology but the transportation or drying costs may dictate that this can only be done at a local level.

The following sections describe some common themes relating to the current and potential new bio-based circularity identified in this study, centred on the three sub-sectors but in many cases relevant to the wider bio-based sector in general.

8.1 Current approaches to bio-based wastes and by-products

Bio-based businesses usually produce a number of biological materials as well as their main products – variously referred to as co-products, by-products and wastes, depending on the business's attitudes towards their use and value. The distinction made between wastes and by-products by the waste regulator is often a separate matter – this is discussed later in the report. Liquid effluents and gas emissions are often not referred to as wastes at all, although they are still outputs from bio-based businesses, with potential value.

Variation in business culture and circumstances means that some businesses will extract a material and sell it as a co-product (e.g. selling fish heads into niche food supply chains) while others will treat it as a by-product or waste. A common practice in the food processing sector is to dispose of non-animal based food wastes as animal feed, usually at zero cost to the business. The alternatives, of sending to landfill, incineration, composting or anaerobic digestion, all involve a cost to the business, although anaerobic digestion has the potential to be a cheaper option due to the value of the renewable energy generated.

Liquid wastes are generally discharged to sewer, at significant cost to the business. Businesses can (or are required to) treat their liquid wastes on site, to reduce effluent disposal costs. On-site treatment may bring overall savings for the business, but still involves significant running costs, notably for the energy needed to run the aerobic treatment process. The use of anaerobic digestion (AD) as an on-site treatment option for liquid wastes is becoming more common. In contrast to aerobic treatment, AD is often a net energy producer through its generation of biogas which can be used to generate heat and power. Renewable energy subsidies also incentivise AD as a value-adding treatment process for liquid wastes.

Businesses have some degree of control over whether to treat their wastes a liquid or solid, and thus the options for processing, using or disposing of them. Many food sector wastes are produced as slurries and sludges. These can be dewatered and treated as a solid waste –for example to allow free disposal as an animal feed – leaving a liquid residue with lower treatment requirements. Conversely, a business can mix a solid waste with liquid wastes to allow it to be processed in an on-site AD plant. The digestate produced from an AD plant can vary in form from a liquid to a sludge: liquids are generally discharged to sewer or spread to land; the more solid digestate, where possible, is spread to farmland as a bio-fertiliser.

8.2 Potential new biological loop approaches and opportunities

It is apparent that many, perhaps most, bio-based wastes and by-products have chemical or biological properties that could allow them to be processed to provide components for new products or materials to substitute conventional sources, many of which are described in this report. These biological upcycling processes can be categorised as:

- Extraction of, or processing into, high value chemicals or biofuels.
- Extracting food ingredients such as proteins, oils, carbohydrates and antioxidants, to varying degrees of refinement.
- Extracting fibres for use in textiles, paper or similar uses.
- Substrate or nutrient feed for new biological production e.g. mushroom cultivation (on solid substrates) algae production (on liquid wastes), insect production (for e.g. animal feed).
- Use as a constructional material.
- Use as a source of renewable heat and power.

Applying these approaches for a wide range of bio-resources across different industries and enterprises would allow a bio-based circular economy, centred on renewable manufacturing, to be developed as shown in Figure 11 below.

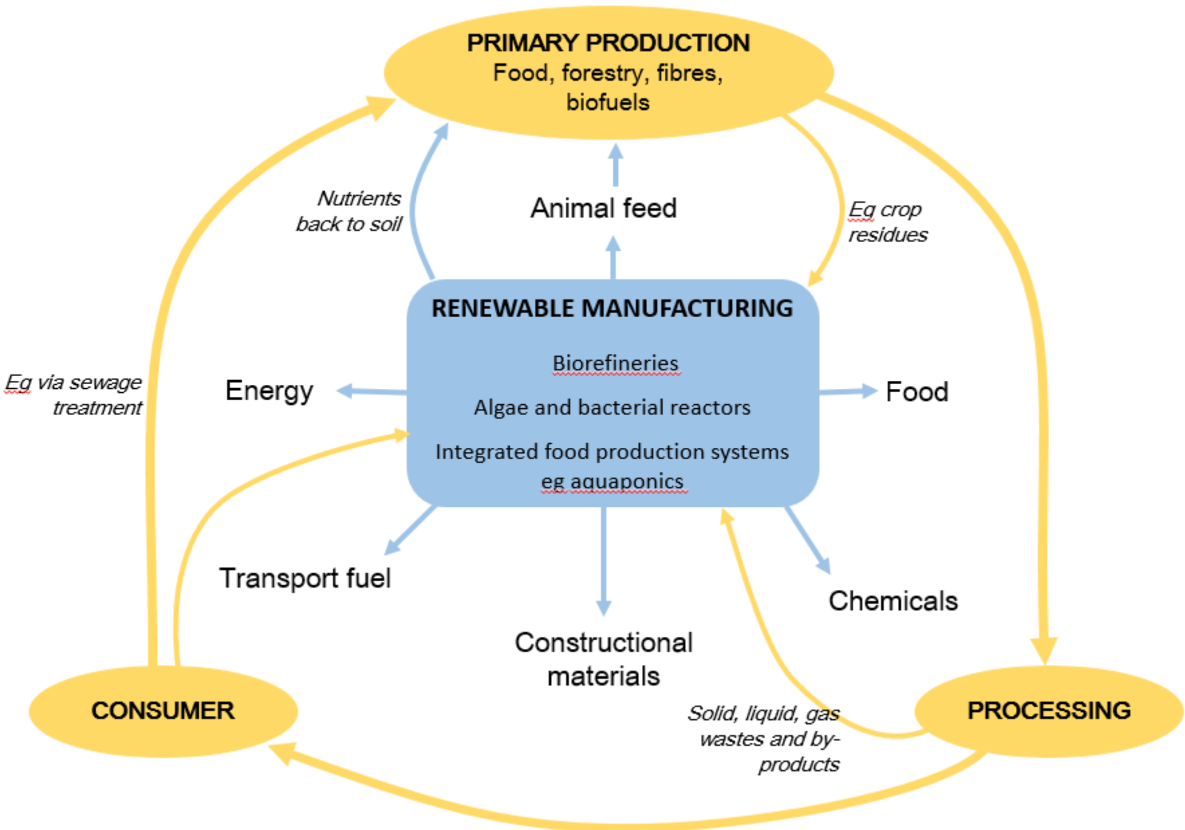


Figure 11 Bio-based processes and products in a circular economy

Some specific themes have been revealed in this study that underpin many of the opportunities:

- Higher value uses of by-products are achievable and demonstrated by emerging technologies and enterprises… but this is very much done on an ad hoc basis.
- Solids vs liquids. Liquids less often valorised but there is still cost to business, even if discharged to sea, plus there are environmental implications from doing so.
- Using on site /locally for existing application e.g. on-site energy generation; local animal feed: can be in a less processed form than above; scaling to the local demand is crucial (e.g. there is too much draff for Speyside cattle demand).
- Opportunity to achieve multiple uses of a material. e.g. integrate different new processes for any given waste such as protein extraction from pot ale (Horizon Proteins) could be integrated with fermentation of draff and pot ale (Celtic Renewables) to optimise the use of both the different components.

8.3 Limiting factors

This study did not reveal any intrinsic barriers to developing higher value circular economy opportunities for the sub-sectors. However, a number of significant factors were found that present challenges or limits to this objective, and these are described here. An indication of how they might be addressed is given in the Recommendations section.

Economies of scale
Processes involving any degree of technical complexity –such as biorefining into chemicals – tend to be commercially viable only at large scale. These processes can only provide a solution for high tonnage single sites or geographic clusters of smaller sites, as exemplified by Celtic Renewables' commercialisation plans.

Wastes and by-products produced by smaller scale and more isolated sites, such as many microbreweries and bio-based businesses in many parts of the Highlands and Islands, need a different approach to developing circular economy solutions. This is explored further in Section 8.4.

Seasonality and perishability
Many food and other bio-based production is seasonal in nature: farming and fishing especially produce their products, by-products and wastes only during certain months. This presents a commercial and technical challenge for any enterprise aimed at either supplying these businesses (e.g. distillery by-products in demand as a seasonal animal feed) or making use of wastes and by-products that are only produced during a few months of the year.

A related issue is that most bio-based materials are inherently perishable and need to be used or preserved relatively quickly. A range of preservation techniques can be used including ensiling and other forms of chemical treatment. However, drying is arguably the most important technique to not only help preserve perishable materials, but also reduce onward transport costs. Dried and milled or pelletised materials are also generally more acceptable to secondary processors such as animal feed compounders, for blending into new products.

However, drying moist by-products to a sufficient degree (5% to 10% moisture content) usually requires a high energy demand, initially as electricity for dewatering techniques such as belt presses and centrifuges and filters and ultimately through heat for final drying stages. The Renewable Heat Incentive offers a short term fix (to the cost of the UK government), as shown by the CORDe facility which uses renewable heat to convert pot ale to pot ale syrup.

Further innovations in low energy drying and preservation methods would be a significant enabler for the bio-based circular economy, and could be a future area of research for Zero Waste Scotland.

An alternative to this approach is to find a local market that can make use of a by-product in its unpreserved form at the same time of year that it is produced.

Waste regulation
The different regulatory approaches to materials deemed to be wastes and those deemed to be by-products has an impact on businesses' ability to make best use from these materials. This is explored further in Section 8.6.

Low value residues, contamination and anti-nutritional factors
Biological wastes generally comprise a mixture of components. Extracting the higher value components leaves a lower grade residue: this can present an additional cost to treat or dispose of it. The overall business model needs to allow for this and build in cascades of different uses: further processes, such as anaerobic digestion, may be possible to extract value from the residues.

The presence of contaminants such as copper in malt distillery by-products and anti-nutritional factors (components that may prevent nutritional uses of a by-product in human or animal food products) such as high phosphate concentrations in aquaculture feeds, also need to be addressed. Such components tend to get concentrated in particular outputs from bio-based processes, such as in the digestate from biogas plants. Research into dealing with these contaminants, such as through extracting them as a reusable resource, would be a valuable contribution to fully developing the bio-based economy.

Commercial motivation and anti-innovation factors
It has been pointed out that most businesses producing the wastes and by-products of interest to this study are primarily focussed on running their core business and will try to maximise income from their by-products (or more often, reduce disposal costs) only as far as can be done through quick and simple methods. In general, these businesses are not motivated to take on the numerous challenges associated with developing more innovative solutions even if this may produce a more profitable outcome. Another factor for some of the sub-sectors in Scotland is the relatively small number of players involved and their commitment to existing commercial arrangements for use of by-products or the need to continue generating income from existing capital assets used with by-products.

It is more often a new start-up company or a large business with experience in innovation who is prepared to meet the challenges of developing higher value uses of bio-based materials. These challenges can be significant and include accessing finance, finding suitable markets, and managing commercial and technical risks.

Proactive entrepreneurs are needed as at least part of a developing bio-based circular economy. A collaborative approach which shares risk, rewards and expertise, has also been shown to be successful. The Scottish Food and Drink Federation (SFDF) is already undertaking a sustainable sourcing project looking at waste from the food chain in both shortbread and bread sub-sectors.

Ad hoc development
'The Biorefinery Roadmap for Scotland'[47] details a strategy for develop a robust and vibrant outlines a range of actions required and some of the support needed to develop the bioeconomy in Scotland. This details a strategy for developing a robust and vibrant sector over the coming 10 years. Given the emerging nature of biological innovation, and based on stakeholder feedback gathered during our research, it is not unexpected to find that the higher value opportunities identified in this study are being developed in Scotland in an ad-hoc and sporadic fashion.

Stakeholders mentioned the following as particular limitations (many of which are described above):

- lack of data on quantities, sources and properties of wastes and by-products;
- better opportunities for information sharing and collaboration;
- identifying markets – and market intelligence – for innovative bio-based products;
- accessing materials at sufficient scale and consistency to use as a reliance feedstock; and
- demonstrating compliance with quality standards for use of new products – or developing new quality standards.

8.4 Small scale solutions

As explained earlier, many of the higher value options for bio-based wastes and by-products involve relatively high-tech processes which need large economies of scale to be commercial. This situation brings the need for a solution for the many wastes and by-products produced by smaller scale and geographically dispersed businesses.

Some examples have been identified in this report, such as milling scallop shells to make an agricultural lime product. It is also notable that both the Horizon Proteins process using pot ale and the CellsUnited process using salmon trimmings are being explicitly developed as processes suitable for being deployed with smaller scale distilleries and fish processors.

Two approaches are proposed here, both of which could make meaningful contributions to rural and island economies.

1. As exemplified by Horizon Proteins and CellsUnited, development of innovative processes to convert local and dispersed sources of bio-materials into high value transportable products suitable for national or international markets. This is an appealing solution, but not greatly proven yet.
2. Develop uses of the by-products specifically for local markets. Although many by-products are already used locally, this is often at low value and arisen from a need to find a simple and cheap disposal route. There does seem to be opportunities to develop processes to add value to the by-products and to develop new markets, for example:

    - pesticide and fertiliser product from crustacean shells
    - mushroom cultivation on brewers spent grains
    - use of high nutrient effluents and waste heat in hydroponics food growing enterprises
    - use of spent grains directly as a fish feed, (potentially in speciality fish production rather than conventional salmon farms)

[47] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap

These above approaches could bring other benefits compared to high tech solutions, such as a much shorter development time, the ability to be adapted to meet local needs and a strong contribution to local food economies. There is also the potential for them to form the foundation for a more ambitious integrated local or regional bio-based circular economy hub, as described in Section 7.4. It is clear that a different strategy and support mechanism is need to develop these locally adapted solutions than what is needed for the development of large scale and more complex technologies.

8.5 Market and economic factors

A number of common themes relating to economics and markets have been identified in this study. These are summarised as follows.

Growing demand for sustainable bio-based products
There is evidence of growing demand for sustainable bio-based products usually as an alternative to petrochemical-based products. This market “pull” is a strong enabler of the circular economy, complementing the ‘push’ of reducing waste disposal costs.

In the case of animal feeds, there is a growing demand for sustainable protein sources, reflected in increasing market value of recycled protein such as fishmeal and protein hydrolase.

Renewable energy generation
Using bio-based wastes to generate renewable energy, for example through combustion or anaerobic digestion, brings several benefits and is on the increase, notably amongst distilleries. These are relatively well developed and understood technologies and can be used to deal with wastes and by-products on site, avoiding the need for identifying or developing markets for onward sale of by-products. They also provide cheap heat and power for on-site use and an income from renewable energy subsidies, as well as helping meet carbon reduction targets.

Ultimately, processing by-products with complex biochemical ingredients into high value bio-based products may bring a higher income than burning them, and may bring higher net carbon benefits. However, this is still an emerging approach and these comparative advantages are not yet widely demonstrated or accepted.

However, renewable energy generation is not necessarily wholly in competition with material uses of by-products, and there are a range of opportunities identified that could integrate both uses from a single set of by-products. The existing CORDe plant generates renewable heat which is used to produce a higher value animal feed from pot ale, and more sophisticated integrations that might extract high value chemicals, animal feeds and renewable energy from distillery by-products are highlighted earlier in the report.

Market disruptors
Unforeseen or large market disruptions can have a considerable impact on the business case for new innovative processes, both positively and negatively. Examples include:

- The Landing Obligation could lead to an increase in volume of landed fish suitable for non-human food uses, which could lead to a reduction in the value of fish processing wastes, but also presents a new supply of protein to the expanding aquaculture feeds market.
- A new bioethanol industry in the UK would lead to glut of spent grains that is likely to exceed the capacity of animal feed markets, and could offer a cheap feedstock for new biorefineries.
- In a wider context, the global market trends for oil and gas have a strong bearing on the business case for the production of biofuels and other bio-based products.

Lost value in exports
Some Scottish bioresources are exported before being processing into higher value products, for example fish by-products processed in Norway, and whole fish exported for onward processing in other countries. This represents a loss of value to Scotland and offers an economic opportunity in principle for carrying out this processing in Scotland.

Competing in commodity markets

Accessing higher value markets for products extracted from bio-based materials often necessitates generating a reliable supply of easily transportable products manufactured to consistent standard. Producing a dry and stable product as described above is one part of this challenge. Meeting existing or new quality standards (such as Femas, for animal feed products) is another.

Accessing international markets in particular involves needing to compete with other suppliers: both long established industries producing conventional (e.g. petrochemical-based) products and in some cases, international suppliers of the same bio-based products (e.g. the multi-billion dollar chitosan market dominated by China and India.) This puts pressure on a new bio-based enterprise to operate at large scale and with efficient manufacturing techniques.

This situation is not necessarily a barrier for Scotland in the long term, but significant support will need to be available to allow an emerging bio-based industry to develop at scale.

8.6 Policy implications

Waste regulation
In common with many other countries, Scotland has a well-established framework for regulating how wastes are managed. This brings robust requirements on how wastes are stored, transported, processed and disposed of, or used, as well as planning requirements for waste facilities. In the case of wastes of animal origin, the Animal By-Products Regulations (ABPR) impose further limits on treatment and use (as described in Section 5.3).

These extensive regulatory limitations for wastes emphasise the importance of the decision of whether a material is a waste in the first place. A material that can be agreed to be a by-product rather than a waste in the eyes of the regulator can access higher value markets much more easily than one that is regulated as a waste even where ‘end-of’-waste’ status can be demonstrated at the end of the process. The whisky sector has enabled pot ale to be used as an animal feed and fertiliser by successfully agreeing ‘by-product’ status with the regulator. Similarly, a fish waste processing plant cannot extract selected fish parts (e.g. fish heads) for sale to the human food chain, if their feedstock is already classified as waste and subject to the ABPR.

The Landings Obligation
The European Landings Obligation being introduced in Scotland will require non-quota bycatch caught by fishing boats to be brought to port rather than disposed of to sea. In order to prevent intentional overfishing as a consequence, the regulations will however limit the use of the bycatch for human consumption. Implementation of the Landings Obligation could potentially result in increased tonnages of fish landed, the fish sector seems unclear on the expected scale and implications. It is possible that it will cause saturation of the fishmeal market and cause fish waste prices to drop significantly. There is an opportunity for expansion of the existing fish waste processing sector and at least one processing company has indicated that they are prepared for this. The situation also offers an opportunity for new or existing businesses in the sector to develop new higher value solutions such as extraction of high value chemicals and proteins.

Renewable energy subsidies
As described earlier, the subsidies provided by the Renewable Heat Incentive, Feed in Tariff and Renewables Obligation scheme directly incentivise using bio-based wastes and by-products to generate heat and power, and this may be at the expense of a more circular option of processing these materials into high value products. An appropriate policy intervention need not involve reducing the subsidies but could instead focus on identifying and promoting economic and environmental benefits of processing into products (where this is the case) and highlighting the opportunities to integrate both approaches.

8.7 Waste heat

Two common sources of waste heat in the food and drink sector are heat lost from cooking or similar process heating and heat ejected from refrigeration condensers. Large quantities of waste heat are generated in whisky production due to the high heat requirement for distillation; breweries and fish waste processing also generate significant amounts of waste heat.

In many cases waste heat can be reduced (e.g. through improved insulation) or recovered from waste gases, heated products and effluents and reused within the factory. This is particularly the case for the higher temperature waste heat typically available in flue gases of boilers. However, the majority of waste heat tends to be in the form of large volumes of warm (<100oC) water or air. Generation of this low temperature heat is widespread in the food and drink manufacturing sector. There are opportunities to recover it using heat pumps and exchangers and use it for example for pre-warming of process feedstocks, and this should be promoted as good practice within industry. However, it is clear that even an efficiently run distillery, brewer or other food manufacturer will inevitably still generate significant quantities of low temperature waste heat.

Potential options for using this waste heat include:

- Drying. Large volumes of warm dry air are suited for drying many types of products. This could present a solution for adding value to otherwise moist wastes and by-products such as spent grains or spent hops. Alternatively, drying could be offered as an add-on service for other food products or for biomass fuels.
- Enhanced food production. Most forms of protected food production – and innovative bio-production techniques such as algaculture or aquaponics – benefit from additional heat. The large volumes of warm air or water typically produced by manufacturers as waste heat are very suitable. A limitation is that the seasonal demand for this heat compared to typically year-round generation. However, the business case may be strengthened if the bio-production also uses waste CO_2 and wasted biological nutrients available in effluents produced by the factory, such as demonstrated in the M Power case study.

A promising opportunity that this reveals is the potential economic and environmental gains available from integrating new bio-based enterprises adjacent to existing food and drink factories to make productive uses of their wastes and effluents. This bio-based industrial symbiosis approach will need innovation and support as much on developing the business models required as on the technological aspects.

8.8 The economic prize for Scotland

This study has revealed a range of opportunities for processing waste and by-products into higher value products than current uses. It has not been possible to calculate comprehensive figures on the additional economic value to Scotland that would accrue from implementing these opportunities across the three subsectors, due to the complexity involved in modelling these figures and the shortage of reasonable data. However, some reasonable assumptions can be made, and indicative economic figures are given for some of the new circular economy solutions being developed.
It can be assumed that Scotland would win considerable economic benefits from any by-product that is currently used in low value applications that can instead be processed into high value products, particularly if the high value product replaces a resource currently imported to Scotland.
Figures provided by some of the innovators developing such examples, as shown in the relevant case studies in this report, gives an indication of the scale of the economic prize:

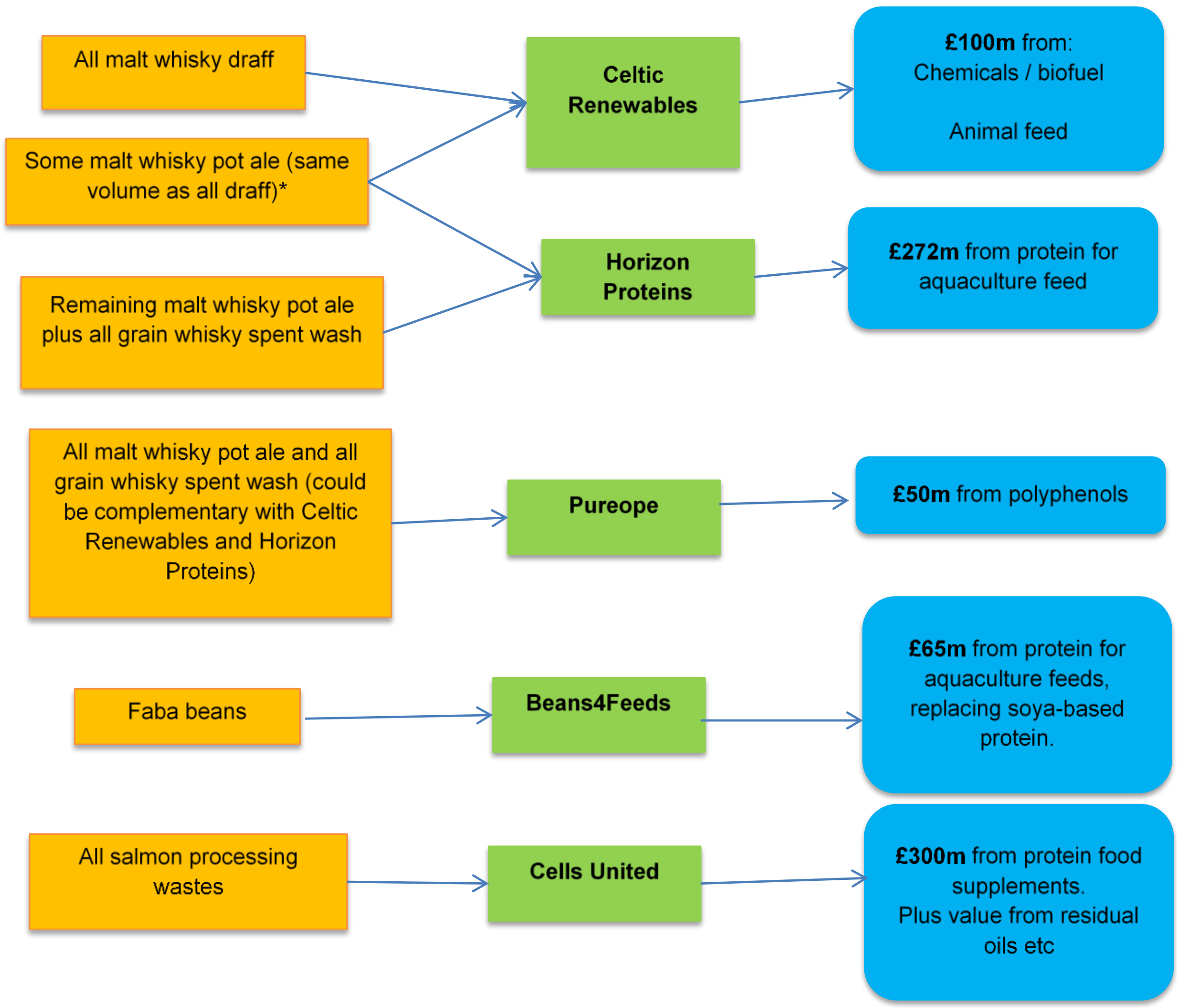
- **Celtic Renewables** technology applied to all malt whisky draff would generate an estimated **£100million** of value from the various biofuel and chemical products including the residue suitable for animal feed.
- **Beans4Feeds** has indicated a total value to Scotland of £65 million (of which an estimated **£9.5 million** would accrue to Scottish farmers) from replacement of imported soya products with Scottish grown bean protein for aquaculture feeds and provision of other animal feeds.
- The **PUREOPE** project team has estimated that the polyphenols content of all the malt and grain distillery by-products in Scotland would have a market value of at least **£50million**.
- **CellsUnited** has estimated that if all Scotland's salmon waste could be processed using their technology, the added value would exceed **£300 million** from sales of the protein food supplement alone, plus additional value for the separated salmon oil and the residue used as fertiliser.
- **Horizon Proteins** - The total potential value of protein in pot ale and spent wash in Scotland is estimated at £272 million per year, including the residue suitable for animal feed. In theory, this assumes, that all these by-products could be captured across the sector (although it more

realistic to anticipate around **£80million** of value could be realised). This is based on 181,000 tonnes of protein in these by-products: almost twice as much as is needed by Scotland's salmon farms. Further details are given in Section 4.2, under 'Protein available for Scottish aquaculture from Scottish whisky distilleries'

Further explanation of the above opportunities and their economic value is provided in Table 11 and Figure 12.

#	Organisation	By-product	Opportunity	Potential savings	Technology readiness	Timescale	Additionality	Confidence *(High, Medium, Low)*
1	**Celtic Renewables**	**Draff**	Apply technology to all whisky draff to extract biofuel and chemical products, with residual material going to animal feed.	**£100 million**	~7	**Short**	Complimentary process to that of 'Other extraction (inc. Horizon Proteins) (6) as not extracting the protein content in draff. Savings figure includes savings from animal feed. Initial by-product would come from distilleries near pilot facility (Grangemouth), no further detail at time of writing.	**High** Pilot at commercial stage with small group of distilleries in central Scotland.
2	**Beans4Feeds**	**Faba Beans**	Replace soya products with Scottish-grown faba bean protein for aquaculture feeds and provision of other animal feeds. Also potential to save significant CO2 savings from displacing fertiliser use.	**£9.5 million**	~7	**Medium**	No overlap with by-products in sectors as utilises virgin crop. Output of process should displace imported soya content currently used.	**Medium** Pilot at commercial stage
3	**PUREOPE**	**Pot ale and spent wash**	Extraction of polyphenols from malt and grain distillery by-products.	**£50 million**	~5	**Medium**	Competition with Celtic Renewables (1) and other processes not listed.	**Medium** Commercial demonstrator to be built in Republic of Ireland in 2015.
5	**CellsUnited**	**Salmon process wastes**	Extraction of purified amino acid supplements from salmon heads, tails and viscera. Use of amino acids in dietary supplements (hospitals and aid programmes).	**£300 million**	5 to 6	**Medium**	Competition with existing routes to fish meal processing (i.e. United Fish Industries). However, this produces higher purity protein to use in different markets.	**Medium** Pilot being built in Dingwall in 2015 to run limited capacity trial.
6	**Horizon Proteins**	**Pot ale**	Recovery of protein from pot ale. Potential recovery of protein from pot ale £272 million, but unrealistic to capture all by-product nationally.	**£80 million**	~7	**Short**	Horizon Proteins process complimentary to that of Celtic Renewables (1). However, will be competing for protein in the animal feed part of the process. Pot ale would come from distilleries near pilot plant (unknown at time of writing).	**High** Horizon Proteins pilot at commercial stage with malt distilleries (unknown due to commercial sensitivities). Breakdown of savings not available at time of writing.
	TOTAL	*n/a*	*n/a*	***£595 million***	*n/a*	*n/a*	*n/a*	*n/a*

Table 11 Summary of economic value of previously costed circular opportunities in Scotland



Overlaps within the above*

- Protein in malt whisky pot ale: output as both Celtic Renewables animal feed and in Horizon Protein's products.

Competition with existing uses

- Draff: animal feed, fuel for renewable energy
- Pot ale: Pot ale syrup animal feed
- Salmon processing wastes (e.g. Ross Yew)

Additional value

- M Power: Algae from pot ale: should be compatible with protein and polyphenol extraction
- Higher value / complementary uses of brewery spent grains and other by-products (including extraction of proteins and polyphenols).
- Landings Obligation: short term potential for additional proteins and oils.
- Chitin extraction from crabshells.
- Chemicals / nutraceuticals extraction from fish wastes.

Figure 12 Explanation of overlap and competition between previously costed circular opportunities in Scotland

The figures shown in Table 11 add up to a potential economic benefit to Scotland of **£595 million** per year. As previously described, some caution needs to be allowed for in this figure, as the above values do not allow for the value of current uses of the by-products in every case and the Celtic Renewables estimate includes a value of protein in pot ale which is also included in the protein calculation for aquaculture feeds. However, there are further potential high value uses of beer, whisky and fish by-products that could be integrated with the above examples whose economic value it has not been possible to calculate. In addition, there is an opportunity here to develop new bio-based circular economy networks in Scotland that once established other sectors and businesses could take part increasing the overall economic benefit. On this basis it seems reasonable to suggest a total economic prize for Scotland of between **£500million and £803million** per year from full implementation of the high value bio-economy opportunities identified in this report.

9 Recommendations

This study has identified many examples of bio-based circularity in the three sub-sectors and revealed the scale and variety of opportunities of higher value and wider circularity. Some of these opportunities are being developed sporadically, but a more strategic approach and leadership is needed if Scotland is to fully develop a bio-based circular economy.
The recommendations below are proposed by many of the stakeholders interviewed in the study as well as by the report authors. They include both strategic support and action oriented projects, and could form a specific action in the roadmap. The core recommendation is for Scottish Government and its partner agencies to work with stakeholders, not only in the beer, whisky and fish sectors, but also the wider bio-based sectors, to develop a robust and extensive bio-based circular economy in Scotland. This will involve various elements including better data provision, information sharing and collaboration, and a strategic approach to supporting innovation of both high tech processes as well as locally-adapted new bio- enterprises.

1. **Cross-sector awareness raising.**
   This study revealed that knowledge of the opportunities for potential new uses of wastes and by-products and potential circular economy approaches to bio-production amongst the food and drink sectors is sporadic and often anecdotal. A more robust effort to raise awareness, share information and provide opportunities for collaboration is recommended. This should focus on identifying and developing new valorisation processes and business models, although solutions that are already commercially available could also be promoted.

   Representation from research and innovation organisations, potential entrepreneurs, government, technology providers and potential markets should be included as well as the food and drink sector businesses themselves. Specific opportunities that can be promoted include:

   - Small-scale approaches to service the dispersed spread of small scale and craft breweries
   - New uses for draff and pot ale beyond the current uses for cattle feed to meet future management needs of outputs from increased distilling outputs across Scotland
   - Higher value uses of fish and shellfish by-products through both small scale and large scale solutions

   This information sharing function could be provided through different channels including workshop events, webinars and knowledge sharing hubs. Amongst other organisations, Zero Waste Scotland, Scottish Enterprise, Highlands and Islands Enterprise (HIE), the Industrial Biotechnology Innovation Centre (IBIOIC), the Biosciences Knowledge Transfer Network (KTN) and Scotland Food & Drink could contribute to delivering these activities.

   It is important to recognise the opportunities to share information and make new connections across different sectors as well within established networks and sector organisations. There is an opportunity here to develop new bio-based circular economy networks in Scotland, using both traditional and new networking techniques. The Ellen MacArthur Foundation Disruptive Innovation Festival is suggested as one model for this.

Recommended action-oriented project: Build on and complement the work being undertaken by the IBioIC by runnning a bioresources awareness-raising programme that addresses circularity and helps build new networks and collaborations, business models and enterprises.

2. **Co-ordination of support, analysis and innovation.**
Scotland already has various organisations and initiatives that contribute to the development of the bio-based circular economy, including ZWS, Scottish Enterprise, HIE, IBioIC and various University-based programmes. However, it is suggested that a more extensive and overarching approach is needed to help Scotland become an international leader in circular economy approaches for bioresources. This might best be provided through one of the existing agencies acting as a focus for circular economy bio-economy activities and should cover policy research, strategy development, technology innovation, market development, skills and knowledge transfer and funding.

Some specific requirements identified by stakeholders are:

- Better data on sources, quantities and destinations of waste and by-products (see Recommendation 4).
- Expertise to identify optimal integration of processes and cascades for wastes and by-products across a whole sector or from a single facility.
- Further research to identify markets for new products (made from by-products) and assess how these a markets can be accessed.
- The provision of open access commercial scale testing facilities, for processing bio-wastes into products, similar to those provided by the Biorenewables Development Centre. It is understood that such facilities are being developed by Heriot-Watt University, for fermentation processes for polysaccharide containing wastes such as spent grains. There is a need for similar facilities for at least biomarine resources.
- A co-ordinated approach to supporting the development and commercialisation of new enterprises and processes, including identifying, assessing and accessing markets for new products made from wastes: this is commonly identified as the biggest stumbling block to developing these innovations.
- Determine the commercial case for a suitably located spent grains biorefinery fed by the outputs from a cluster of brewers and distillers.
- Review of regulatory approaches to definition of waste and end-of-waste criteria. This is aimed at simplifying and streamlining how the environmental and quality control of bio-based resources is applied and might consider a merging of the approaches currently used for wastes and for by-products. This would review not only the use of waste regulations and Animal By-Products Protection regulations, but also quality standards such as Femas, PAS standards and food quality standards.

Recommended action-oriented project: Examine the potential for one or more existing agencies to become a focus for circular economy bio-economy activities, covering policy development, strategy, technology innovation, market development, skills and knowledge and funding.

3. **Support for technical innovations**
This report has revealed many circularity opportunities for the three sub-sectors, at least two of which will need strategic support if they are to develop into a full scale high impact commercial reality:
   - Marine biorefining technologies to extract high value chemicals from aquaculture fish, caught fish and shellfish wastes and by-products.
   - Integrated technologies suitable for distillery and brewery wastes and by-products.

In both cases support is need to better understand the relative costs, logistics and environmental benefits of different processes, and how they can best be integrated. Collaboration between industry, research organisations, investors and government is also key. Recommendation 2 provides further details on these requirements.

There is also a need for investment in Scottish development of the technologies themselves, through industry-scale testing facilities and making good use of Scotland's research and development organisations. The IBioIC is well placed to help deliver these types of technical support and has indicated its willingness to do so.

There are also technical solutions applicable across almost all bio-based industries that could be key enablers for widespread valorisation of biological wastes. Two specific solutions needing further development, suggested by some stakeholders are:

- Low energy drying techniques to reduce costs and carbon emissions of producing dry and hence marketable and transportable products.
- Techniques to convert mixed organic wastes into specific products (such as platform chemicals) with consistent properties. This might be through extracted particular molecules, leaving a residue requiring further processing, or through breaking down to short chain molecules then using chemical or biological techniques to build up particular high value chemicals.
- Technologies to use common food processing liquid effluents as substrate or nutrient supply for new on site bio production (e.g. algae production, horticulture); combined with use of CO_2 emissions and waste heat.

Recommended action-oriented project: Support investment in R&D and innovation that increases circularity and helps to develop and commercialise processes which address technical barriers for valorising bio-wastes [48].

4. **Bioresource mapping.**

Bioresource mapping refers to quantifying and characterising bioresources of current or potential value or importance. This includes identifying the sources, quantities and properties of bioresources for a particular resource, supply chain or geographical area. Bioresource mapping can usefully include indicating the data using geographical maps although other data visualisation tools are also useful.

Some bioresource mapping work has already been produced for Scotland, including *'The Biorefinery Roadmap for Scotland'*[49] and data analysis given in this report (See Section 4 and Appendix F), and also work previously undertaken focussing only on potential sources of biofuels in Scotland. However, a more comprehensive approach is recommended, which could include some or all of the following and which would allow a co-ordinated approach to logistics serving dispersed sources of wastes and provide a foundation for future policy development.

- A top level analysis of all bioresources currently (or potentially) available in Scotland, quantified in terms of potential uses. This can build on work previously undertaken focussing only on biofuels.
- A focus on the wastes and by-products from specific bio-based sectors. The data gathered in this report for the three sub-sectors provides a foundation for this (see Section 4 and Appendix F), while also highlighting the need for more formal data gathering.
- A stocks and flows assessment of key resources of strategic importance to Scotland, such as: protein, nitrogen and phosphate. A 'protein inventory' for Scotland, identifying future demand and potential sources of protein for human and animal needs would be a useful tool for policy-makers.

A distinction can be made between one-off bioresource mapping studies which give a snapshot and bioresource mapping derived from ongoing data collection systems such as the Edoc records of waste transfers. A challenge for bioresource mapping (and for wider resource data for circular economy development) is that the production of many bioresources (notably liquid effluents and

[48] It is noted that the Norwegian Food Safety Authority have recently developed a new processing/disposal method for fish mortalities. This process is called the Fish Silage Processing Method and has been approved by the European Commission. There is potential to use this processing method in Scotland but consideration should be given to existing facilities before deciding whether it would need investment to build a new facility and investment at a fish farm level.

[49] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap

by-products not regulated as wastes) are not formally quantified or characterised. An investigation into how a suitable data reporting system could be established is recommended.

Recommended action-oriented projects

1. Carry out a suite of bioresource mapping analyses for specific wastes and by-products and/or for specific bio-based nutrients and products which complements the feedstock mapping undertaken in *'The Biorefinery Roadmap for Scotland'*[50].
2. Investigate the potential for formal ongoing data collection systems for specific sectors or bioresources as a circular economy enabler.

5. **Rural bio-economy strategy and support.**

Provide support to develop bio-economy solutions suitable for small scale and dispersed Highlands, Islands and rural businesses. These are likely to involve low tech processes with relatively low capital requirements and that may result in new by-product derived products for local or niche markets boosting regional food economies. Examples include speciality flours from brewers spent grains and agricultural products from shellfish wastes.

The approach taken to support such innovation will be of a different nature to that needed to support more technical processes that need large economies of scale, and would be more focussed on supporting new ideas, enterprises, and making use of local resources.

Making use of both existing support programmes such as Scotland Food and Drink and technical expertise from Scottish Universities and others will be needed.

Recommended action-oriented project: Establish a programme to support new ideas and enterprises that contribute to rural economic growth through use of appropriate technologies and processes which valorise local and dispersed bioresources.

An initial step may be an open innovation festival or competition designed to attract a wide range of stakeholders, entrepreneurs and practical experts, aimed at highlighting opportunities and exemplars and fostering new collaborations.

6. Assess opportunities of regional bio-based circular economy hubs.

There may be economic and environmental benefits from a regional bio-based circular economy hub approach for particular regions. This would involve an integrated approach to the main bioresources of that region. Two examples are suggested:

- A biorefining hub for industrial areas or areas with large volumes of suitable bio-based wastes. A cluster of sources of wastes would serve one or more biorefineries in the region, producing a range of products which might be further processed or used by other businesses in the same region. The Kalundborg Symbiosis (see Section 7.4) is one model for this. Grangemouth has been suggested as suitable site for this approach, with significant quantities of commercial biowastes available alongside a major chemical manufacturing sector. Speyside is also a potential site specifically for higher value uses of distillery wastes and by-products.
- A rural or island bio-based circular economy hub is a more novel concept and would be characterised by local 'recycling' of the region's available bioresources, with varying degrees of processing. The support described in Recommendation 5 would contribute to developing such regional hubs. However, the concept would be best developed tailored to a particular region's situation and resources and an assessment of suitability of different islands and regions is suggested as an initial step. Two regions that are suggested as initial candidates for this approach are Orkney and Islay, both of which have a significant food and drink sector including distilleries, breweries, fish and shellfish businesses as well as strong agricultural and hospitality sectors.

[50] http://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap

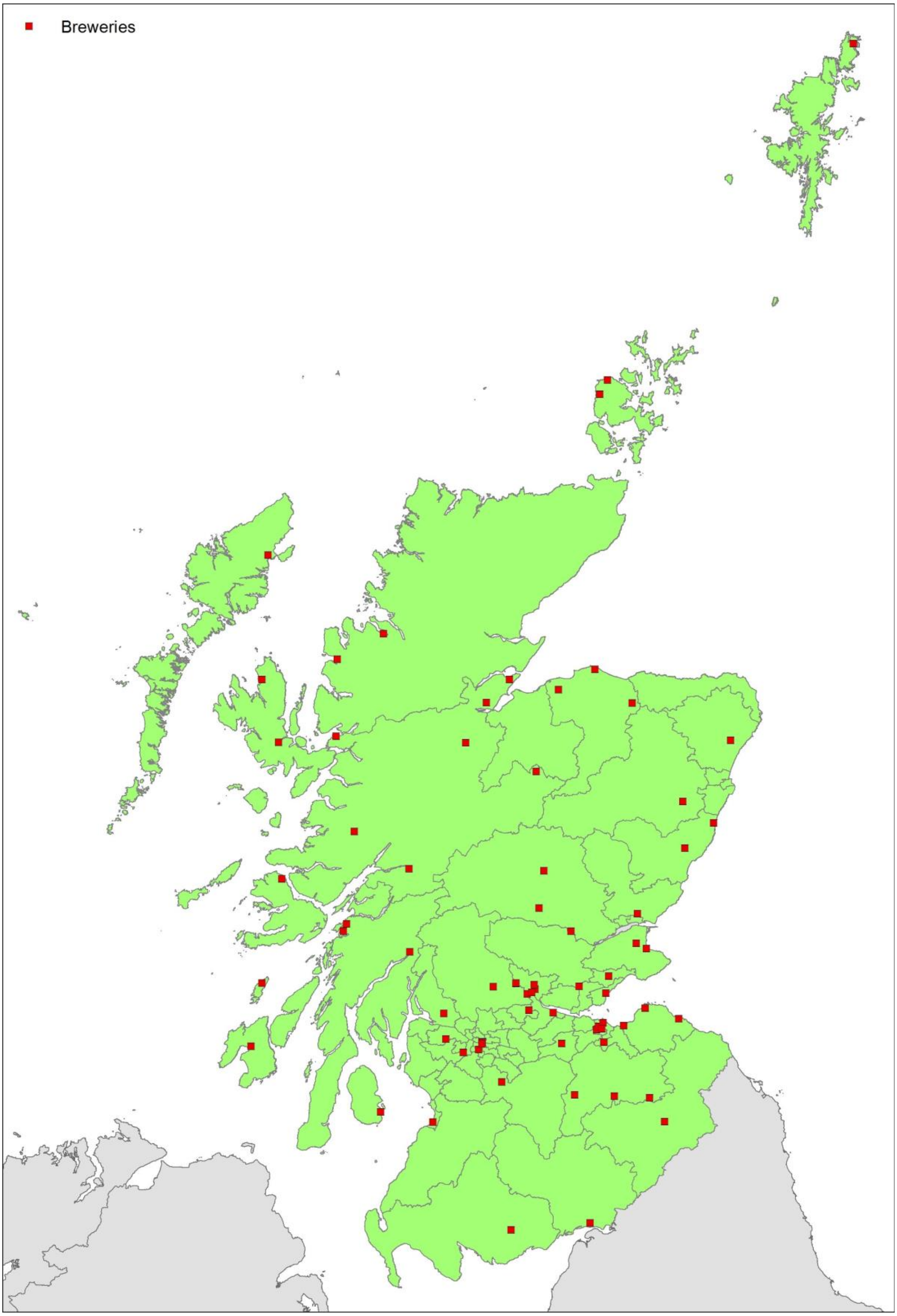
Recommended action-oriented project: Carry out assessments of the best locations for initial urban and rural / island bio-based circular economy hubs. Assessment for an urban hub should build on early work carried out by various agencies on optimal locations for biorefineries. Assessment for a rural or island hub should allow not only for a range of dispersed bioresources but also the interest and potential involvement of key stakeholders in that community.

Appendix A - Stakeholder list / acknowledgements

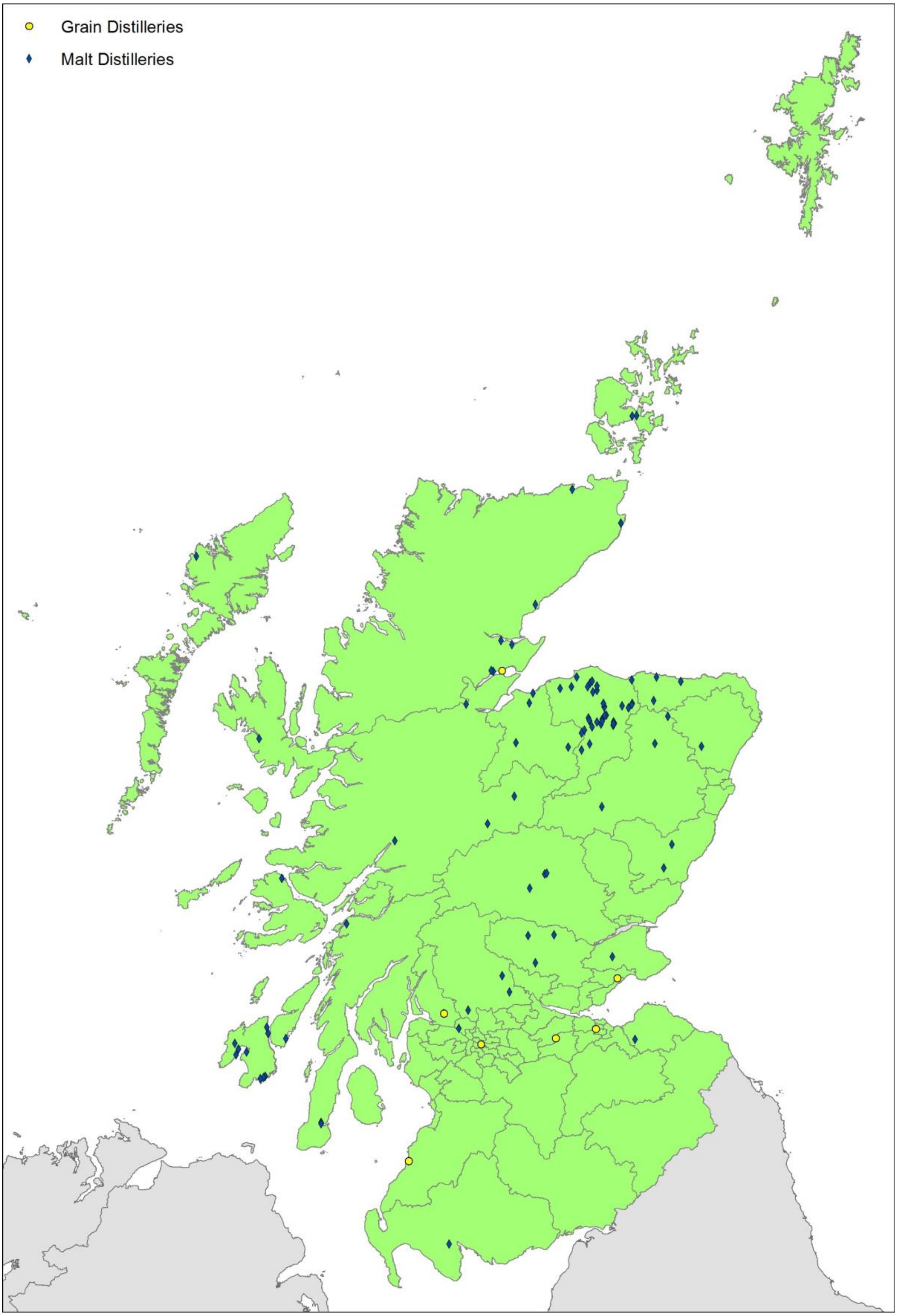
#	Organisation	Contact
	Tier 1 Stakeholders	
1	**Association of Scottish Shellfish Growers (ASSG)**	Dr Nick Lake (Chief Executive)
2	**Brewing, Food & Beverage Industry Suppliers Association (BFBI)**	Ruth Evans (Chief Executive)
3	**Highlands and Islands Enterprise**	Donald Fowler
4	**Institute of Brewing and Distilling (IBD)**	Simon Jackson (Executive Director) and Keith Lugton (Scotland Chair)
5	**James Hutton Institute**	Dr Pete Iannetta
6	**Scotch Whisky Association (SWA)**	Morag Garden (Environment & Scientific Affairs Manager)
7	**Scotland Food and Drink (SF&D)**	Amanda Brown (Industry Development Director)
8	**Scottish biofuel programme**	Jim Purves
9	**Scottish Enterprise**	Chris Corden
10	**Scottish Food and Drink Federation (SFDF)**	Mary Lawton - business liaison manager
11	**Scottish Salmon Producers Organisation (SSPO)**	Jamie Smith (Technical Officer)
12	**Scottish Seafood Association (SSA)**	John Cox (Chief Executive)
13	**Seafish**	Hazel Curtis (Chief Economist) & Chris Middleton (Marketing Officer)
14	**Seafood Scotland**	Graham Young (Chief Executive) & Jess Sparks (Technical Officer)
15	**SSMG (Scottish Shellfish Marketing Group)**	Douglas Watson (Secretary) on behalf of Stephen Cameron (Chief Executive)
16	**Stirling University Institute of Aquaculture**	Prof Rachel Norman
17	**The Scotch Whisky Research Institute**	Gordon Steel (Director of research)
18	**University of Nottingham Biosciences**	Greg Tucker
19	**University of York**	Avtar Matharu, Peter Hurst, Mark Gronnow
	Tier 2 Stakeholders	
20	**Agriprotein**	Jason Drew
21	**BASF Pharma (Callanish)**	Angus Morrison
22	**Beacon Project, Aberystwyth University**	Kirstie Jones
23	**Biosciences KTN**	Michelle Carter
24	**Bridgend Consultancy Services Ltd**	Allen Scobie, Independent Consultant
25	**Caledonian Solutions**	Alan Wolstenholme

26	**CellsUnited**	Tim Mott
27	**Celtic Renewables**	Martin Tangney
28	**Chivas/Pernod-Ricard**	Ronald Daalmans (Environment Manager)
29	**Eminate**	Dr Sarah Gaunt
30	**FDT Consulting (PUROPE)**	Michael Clancy, Aoife Hamill
31	**Glycomar**	Charlie Bavington
32	**Harviestoun**	Stuart Cail, head brewer
33	**Horizon Proteins**	Nik Willoughby
34	**Industrial Biotechnology Innovation Centre**	Roger Kilburn (CEO)
35	**Inveralmond Brewery**	Fergus Clark
36	**James Hutton Institute**	Dr Pete Iannetta
37	**M Power**	David Simpson
38	**National Farmers Union of Scotland**	John Sleigh
39	**Nordlaks**	Tor Anders Elvegard
40	**Salmar**	Alf Jostein Skjaervik
41	**Scanbio**	Knut Hjelt
42	**Scottish biofuel programme**	Jim Purves
43	**Skretting**	Phillip Gallimore
44	**UK CPI / Biomega**	Campbell Tang, Daniel Noakes
45	**United Fish Industries**	Andy Giblin
46	**Useful Simple Projects / RSA**	Dan Epstien, Fred Labbe

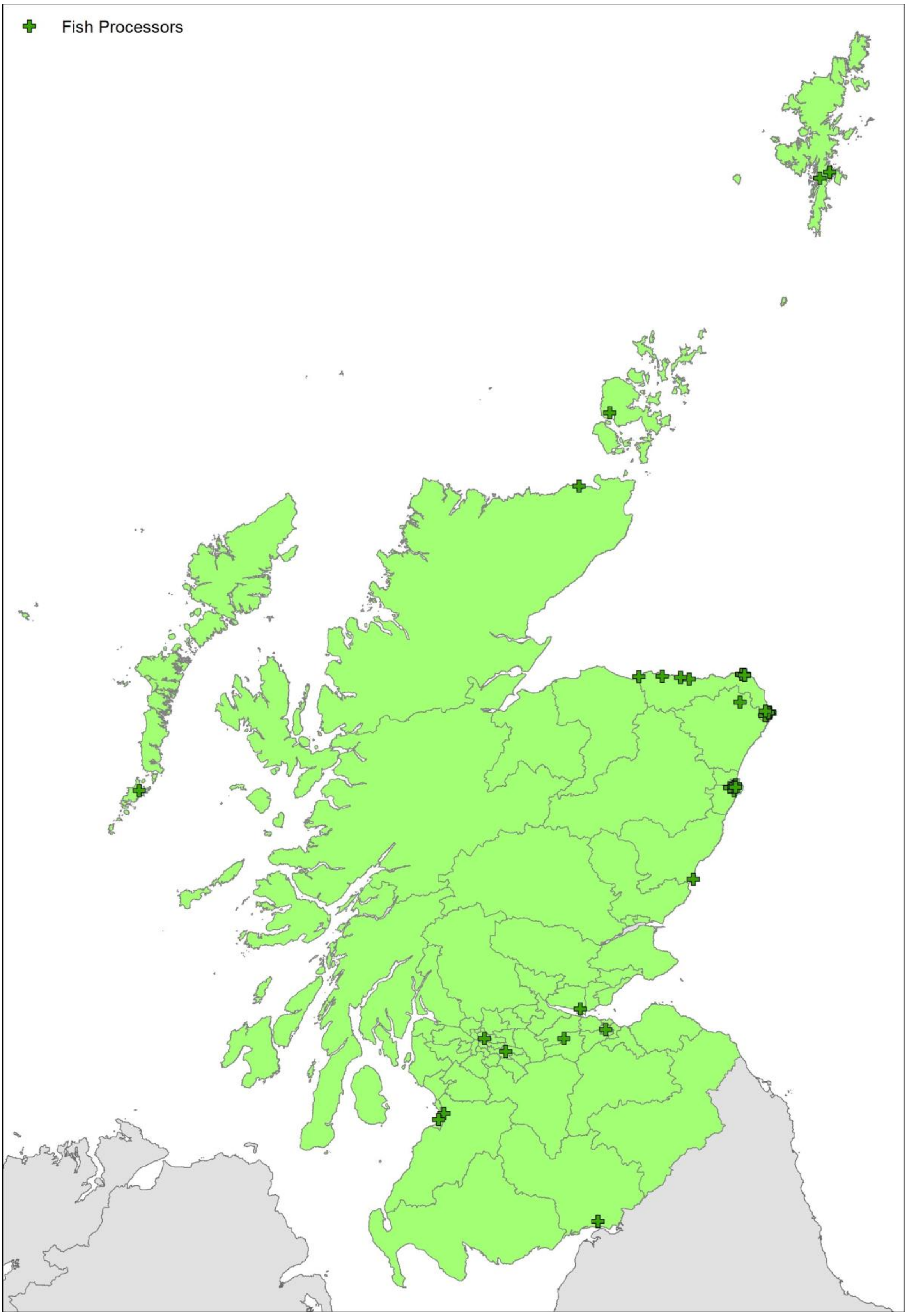
Appendix B – Map of breweries in Scotland



Appendix C - Map of distilleries in Scotland

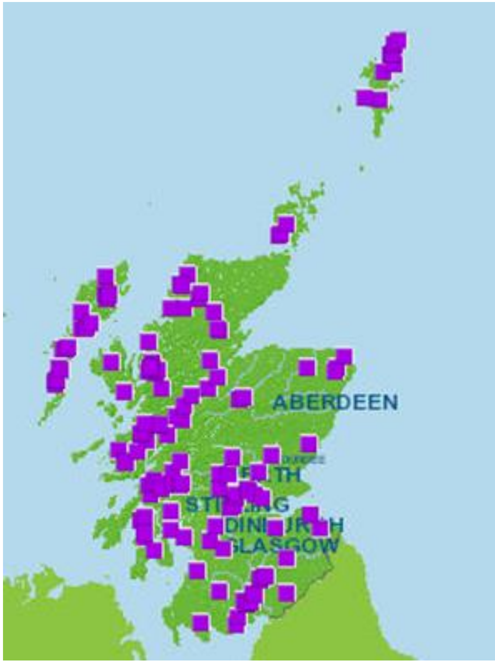


Appendix D – Map of fish processors in Scotland

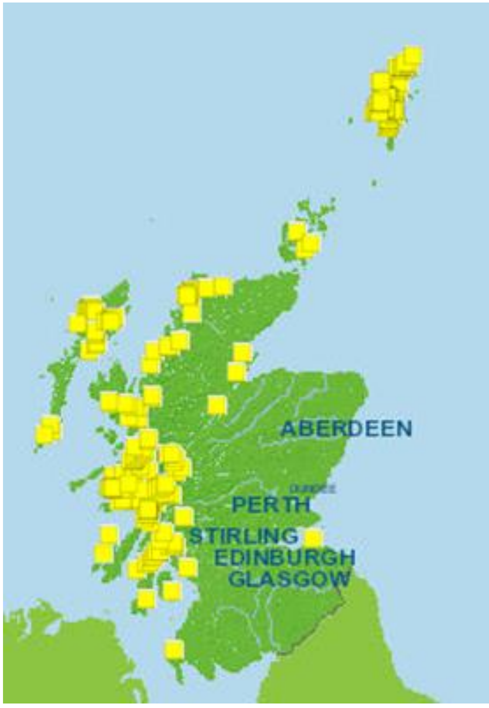


Appendix E – Map of active aquaculture sites in Scotland (finfish and shellfish)

Active Seawater Finfish Sites



Active Freshwater Finfish Sites

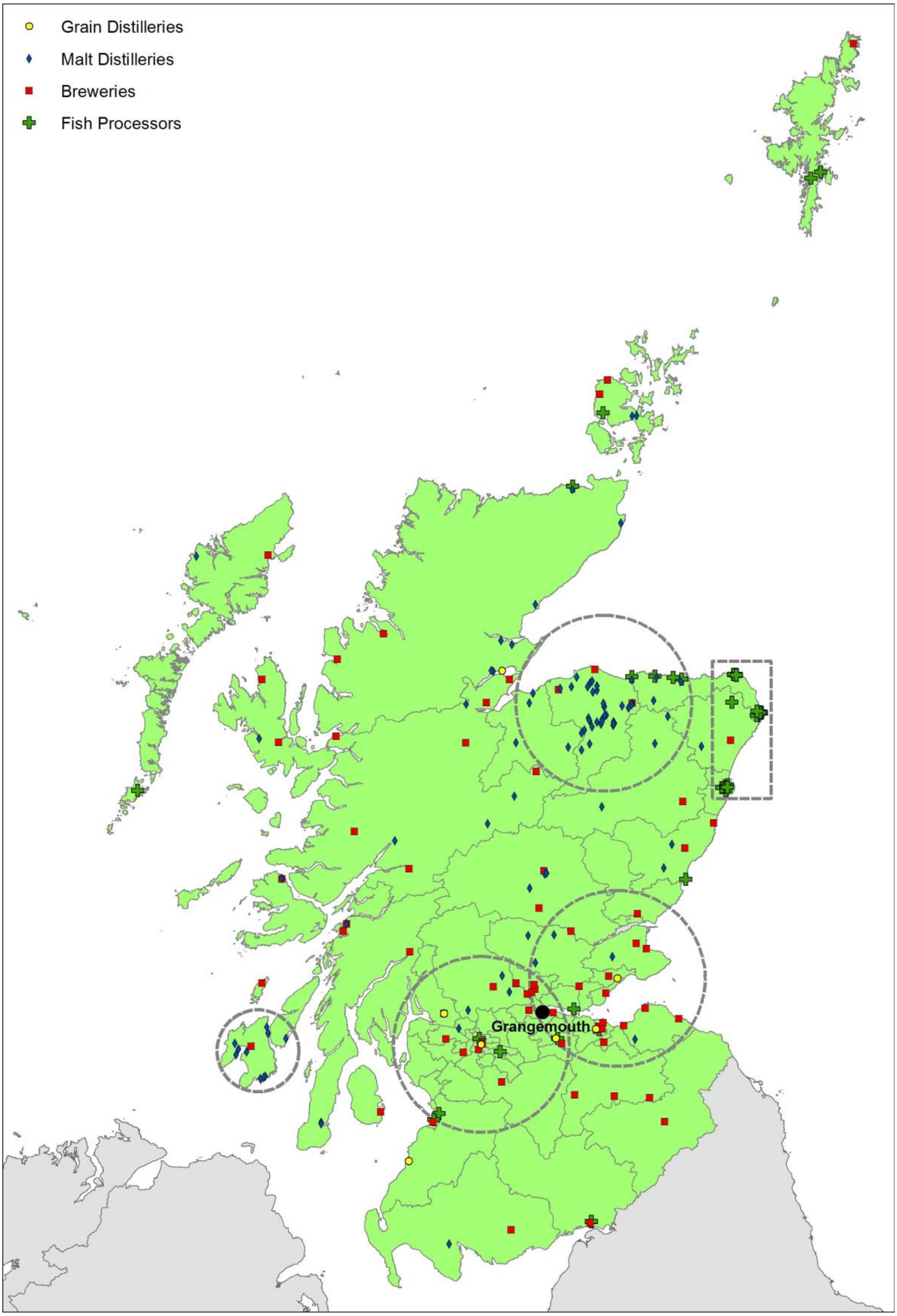


Active Shellfish Sites

Active Combined Seawater and Freshwater Finfish Sites

Source: Aquaculture Scotland at - http://aquaculture.scotland.gov.uk/map/map.aspx

Appendix F – Map of breweries, distilleries and fish processors with potential hotspots of by-products indicated



Appendix G - Supporting calculations

Index	Description	Malt	Grain	Total	Units	Source
A	2013 arisings of whisky	275	350	625	MLPA	SWA Statistical report
B	Spirit yield of distilling	408	380		LPA / t grain	SAC Report 2013: Annex 5
C	Implied grain used	674	921	1,595	kt	C = A / B x 1000
D	Conversion rate: grain to DG	0.3114	0.3272		t DG / t grain	SAC Report 2013: Annex 5
E	Max DG Potential	210	301	511	kt DG	E = C x D
F	Actual DG			254	kt DG	SWA Statistical report
G	DG not produced	106	152	257	kt DG	G = F - ΣE
H	Equivalence factor: DG:draff			2.7	t draff / t DG	Ricardo-AEA calculations
I	Equivalence factor: DG:pot ale			9.1	t pot ale / t DG	Ricardo-AEA calculations
J	Total potential draff (after DG)	281	403	684	kt Draff	J = Σ (G x H)
K	Total potential pot ale (after DG)	959	1,377	2,336	kt Pot Ale	K = Σ (G x I)

Appendix H – Beans4Feeds calculations

The benefits of using faba beans for sustainable protein production in Scotland can be calculated.

Iannetta, James, Hawes, Begg, Young, Karley & Squire - The James Hutton Institute

Approximately 500,000 hectares (ha) of Scottish farmed land is arable, but only a small proportion (<3%) is used to produce plant protein despite national and EU recommendations to increase plant protein productions. Seed harvested from the grain legume crop faba-bean (*Vicia faba* L.) can be fractionation into protein- and starch-enriched components, and the former is desired by farmed-salmon feed manufacturers: the non-protein fraction has the utility as a feed and beverage component for animal feed and human consumption. Current demand for faba beans by aquaculture is estimated at 160,000 tonnes of beans *per* year. With an average faba bean crop of 4 tonnes *per* hectare (ha) *per* year, 40,000 hectares or just less than 1/12th of Scottish arable land. Put another way, this would mean that faba beans would need cropped one year in twelve.

Faba beans are also a major net contributor of nitrogen (N) to the production system (Iannetta et al., 2013). They do not require N-fertiliser since they derive N from biological nitrogen fixation - a process that converts atmospheric di-nitrogen gas (N_2), into biologically useful forms of nitrogen. Also, faba bean delivers between 60 - 100 kg N *per* ha in their post-harvest residues (stems and roots) which are left in-field. Account should also be made of the other significant positive environmental impacts of faba bean cropping. Perhaps of greatest significance is the fact that residues left in-field post-harvest are most effective at forming soil due to their high nitrogen-to-carbon ratio - and this benefit is delivered throughout the soil profile due to the deep tap-roots produced by faba beans. This can ***offset*** the N-fertiliser requirements of crops which follow beans in the rotation - for spring cereal by up to 90% and winter cereals by up to 60%. Therefore, given that: 75% of the arable hectarage is sown with barley, and that 5.2-fold more spring barley is sown annually than winter barley (2014 ratio), and that fertiliser prices are currently average £30 *per* ha - this translates into an annual cash saving of between £0.75 and £1.25 million for Scottish farmers if 40,000 ha of faba beans sown was annually before a following crop of barley. Of course, at least a comparable financial saving is also made when faba beans are cropped since N-fertiliser application is ***avoided***. There is also a direct relationship between the amount of N manufactured and applied as fertiliser and the Carbon Footprint or CF (expressed as 'kg carbon dioxide equivalents' or [CO_2e] *per* year), such that fertiliser application that is ***offset*** and ***avoided*** would allow a reduction in CF by almost 73,000 tonnes CO_2e for a two year bean-to-barley cropping sequence on 1/12th of Scottish arable farmland. This is not insignificant - especially in consideration of the fact this reduction in CF is a function of altering only one in-field activity.

It should also be noted that an assessment of yield and N-fertiliser use over successive years of a crop rotation has shown that highest yields and greatest fertiliser off-set/displacement is achieved when grain (and forage) legume inclusion is 25% of the rotation, and often when cropped alongside a non-legume - an agronomic approach termed 'intercropping' (Brooker et al., 2014). Intercropping is the cultivation of different species on the same land at the same time and means that faba bean need not displace other crops from the crop-rotation.

In terms of monetary value - the 160,000 tonnes of beans considered here is valued at £215 *per* tonne, or a total farm-gate value of almost £9.5 million. The value of the starch and protein component varies depending upon which of two different methods are used for their fractionation. Both methods demand the use of beans which are dehulled (skins removed) - hulls account for almost 20% of the bean weight and are typically used to feed ruminants at a purchase value of around £70 *per* tonne, or a total value of £2.4 million. The dehulled beans, or kernels, are then milled into flour that can be fractionated into protein and starch components using either a "dry" or "wet" method. The resultant purchase price of the protein component is around £600 *per* tonne, or just over £19 million pounds, regardless of the fractionation processed used. The starch is valued at around £300 or £500 *per* tonne (a total of £22 million or £44 million) for the dry and wet processes respectively. Collectively, fractionating the bean starch and protein components allow the total value to be increased by almost five- or seven-fold that of the farm-gate grain price for the dry and wet processes, respectively.

In addition, unprocessed faba beans can also be used in grower and finisher pig diets to completely replace soya bean meal (Houdijk et al., 2013). In a landscape of ever increasing soya prices, looming soya shortage on the world market, and CAP reform measure that stimulate home grown faba bean production, this provides another incentive to increase the production of faba beans as home-grown alternatives to enhance sustainability of UK pig production.

There is of course an important human-related value that remains to be taken into account. Faba bean starch is characterised as a 'health-promoting' food component, and if sourced from the dry fractionation process still presents a balanced food-stuff as protein is retained at relatively high levels (ca. 18%), and possesses a high essential-mineral content. Dry fractionated faba bean starch would be very well placed in the human food chain. However, there are current restrictions within the Scottish supply chain, including a lack of processors who mill *and* dehull beans in Scotland; there is no dry process fractionation plant in Scotland. Further, there is a need to develop the market for foods with high faba bean (starch) inclusion.

The farmed salmon industry is ready to take faba bean protein. Farmers and the environment are also set to benefit. Is the Scottish food supply chain ready to process these beans and deliver a variety of health-promoting faba bean starch based foods?

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www.beans4feeds.net
www.legumefutures.eu

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