



Biorefining Potential for Scotland

Mapping bioresource arisings across Scotland

Prepared by Ricardo Energy & Environment for Zero Waste Scotland

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■ The value of this piece of work as a resource for Scotland to develop the circular bioeconomy cannot be understated. Scotland is again leading the way in the circular economy and this report, and associated data, offers a plethora of opportunities to create new business opportunities for waste valorisation and value upscaling. ■

Professor Derek Stewart, James Hutton Institute.

■ This study offers a unique and comprehensive analysis of geographically available feedstocks and will be an important resource for decision makers keen to innovate in the UK bioeconomy. ■

Michelle Carter, Knowledge Transfer Network (KTN)

■ This is an important and unique piece of work which will enable Scotland to determine the best strategic use for its resources and also define and deliver the strategy for 'biorefineries' across the country. It fits well with Scotland's current European Commission Model Demonstrator Region status for sustainable high value chemical manufacturing and the ambitions in the Scottish National Plan for Industrial Biotechnology. ■

Caroline Strain, Scottish Enterprise

■ This is an excellent piece of work which allows us to accurately inform potential investors in Industrial Biotechnology exactly what feedstocks Scotland has, by volume, composition, place and value. It is unique in its detail and demonstrates our determination to make Scotland a leader for sustainable development. ■

Roger Kilburn, CEO of Industrial Biotechnology Innovation Centre (IBiolC).

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Foreword

Scotland has the ingredients for a successful circular economy

Biological resources have a crucial role to play in creating a circular economy in Scotland, and this pioneering new report from Zero Waste Scotland, *Biorefining Potential for Scotland*, reveals the scale of the opportunity for the first time.

A truly circular economy will eliminate waste as far as possible. In the context of the bioeconomy, it's about using biological resources or bioprocesses to make new products such as food, chemicals and energy as well as adding value to waste materials, for example, extracting sugars from waste bread and turning into biofuel or beer.

Moving to a circular economy contributes to the Scottish Government's aim of sustainable economic growth as laid out in the country's first circular economy strategy, *Making Things Last*, published by the Scottish Government in 2016.

The bioeconomy is identified as a priority area within that strategy. In the beer, whisky and fish sectors alone there is an estimated saving of £500m to £800m each year through better utilisation of waste and by-products.

For the first time, in this groundbreaking report, which supports the Biorefinery Roadmap for Scotland, the scale of the opportunity across these and other sectors has been studied using a pioneering approach to map bioresource arisings. The scope of the opportunity is huge: there are 27 million tonnes of bioresources arising every year in Scotland which could be turned into high value chemicals, biofuels and other renewable products across many industries.

The opportunity is greatest in our cities. Scotland's seven cities account for over half of the country's total waste, and urban bio-wastes, in particular, have enormous biorefining potential.

This report has confirmed that the bioeconomy has a key role to play in creating a more sustainable future where we use resources in the most efficient way, reduce carbon emissions and make our economy more resilient. Zero Waste Scotland and its partners stand ready to help businesses seize the opportunities it describes and we look forward to the journey ahead.



Chief Executive

Iain Gulland

Zero Waste Scotland

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Executive summary

In 2015, Scottish Enterprise published 'The Biorefinery Roadmap for Scotland'ⁱ, on behalf of the Scottish Industrial Biotechnology Development Group (SIBDG), which sets out the key actions required to identify the barriers and risks faced by companies and potential investors to enable the more established biorefinery technologies. The Roadmap aims to increase industrial biotechnology turnover to £900 million by 2025.

A key action of this Roadmap was to map the wastes, by-products and agricultural residues that are, or which could be, available as feedstock for a biorefining process. In addition, The Making Things Last strategyⁱⁱ outlines the Scottish Government's priorities for recovering value from biological waste, including mapping bioresource arisings in Scotland and investigating the potential for local biorefining hubs. The challenge for this project was therefore to establish the scale of the opportunity for the bioeconomy sector in Scotland, by quantifying and mapping bioresourceⁱⁱⁱ arisings to understand the scale and shape of a potential bioeconomy market. This report also builds on the outcomes of an earlier Beer Whisky Fish circular economy sector studyⁱⁱⁱⁱ which highlighted the need to better understand the volume and geographic arisings of by-products in Scotland.

For the first time Scotland's bioresources have been assessed in such a thorough way and the volume of resources confirms that there is sufficient feedstock to enable Scotland to be confident in developing opportunities for biorefining. Within the bioeconomy there is demonstrable scope to develop a bio-based industrial sector with the potential to significantly reduce our dependency on fossil-based resources, help meet climate change targets, and lead to sustainable economic growth. In addition, it will also help diversify and grow farmers' incomes through additional margins by valorising agricultural residues. The Making Things Last strategy brings together many of the policy areas linked to the bioeconomy, however this transition will require a greater cross-sector approach, bringing industry and academia together.

ⁱ <https://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap>

ⁱⁱ <http://www.gov.scot/Publications/2016/02/176>

ⁱⁱⁱ Bioresources are non-fossil biogenic resources which can be used by humans for multiple purposes: to produce food, substantial products, and/or energy carriers

ⁱⁱⁱⁱ <http://www.zerowastescotland.org.uk/BeerWhiskyFish>

Scotland already has a great deal of biorefining expertise including research into brewing and fermentation, the future potential for forestry and marine biomass and synthetic biology. Building on this foundation this study has shown that biorefineries have significant potential in Scotland with over 27 million tonnes of materials suitable for biorefining every year. Importantly this study has, for the first time, quantified a number of previously unaccounted for or 'hidden' resource streams including agricultural residues and by-products both of which have significant biorefining and economic potential.

The data shows a number of rural and coastal areas where bioresources arise in high volumes. This creates the opportunity for decentralised production facilities which can provide new income and employment opportunities in rural areas. Due to the fact that the raw materials arise over large areas, bio-based production favours a decentralised structure.

This report confirms that significant bioresources exist to develop technologies for biorefining to convert sustainable feedstocks into high value chemicals, biofuels and other renewable products for a range of industries. In addition, biorefining could offer significant economic benefits for the agricultural and rural industries in Scotland as well as across the food and drink supply chain.

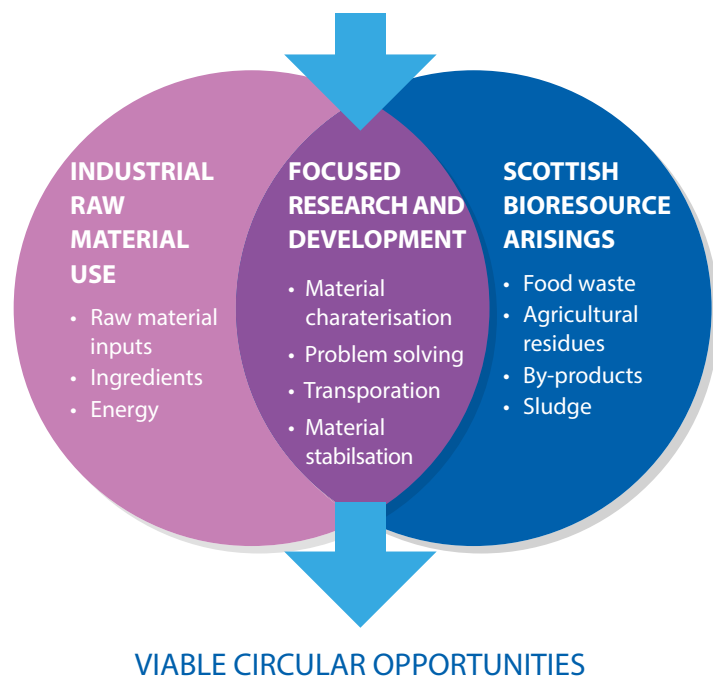
Scotland is well placed to develop biorefinery facilities given the co-ordinated approach and sufficient support from policymakers and funding bodies. Scotland has the enviable position in having world-leading centres of research excellence, a large volume of bioresources and an industrial base suited to the exploitation of the bioeconomy. The development of an industrial biorefining strategy, in alignment with the National Plan for Industrial Biotechnology, is required to encourage collaboration and focus the academic and industrial expertise. Development of a biorefining strategy will lead to a focus on the knowledge and skill gaps and reinforce the existing expertise base in Scotland.

Our view is that this study has been unique and significant for the Scottish bioeconomy and timely in gaining an understanding of one side of the equation – the supply side – bioresource arisings. There is an opportunity to undertake further work to understand the demand side – industrial resource inputs, as shown in Figure E1.

A whole system strategic approach should be considered which takes account of the demand and the supply and importantly proactively engages both sides of the equation – working with industry to understand the potential to substitute raw material inputs into their processes with available or potentially available bioresources. To facilitate this focussed research and development will be needed to identify and invest in enabling technologies like de-watering and resource stabilising techniques to aid storage and transportation of bioresources which generally have a high water content.

Figure E1: A schematic of the challenges and opportunities for bioresource utilisation in Scotland

IDENTIFY RAW MATERIALS SUBSTITUTION OPPORTUNITY



A bioresource data model was developed alongside this report which provides clear visualisation of the geographic bioresource arisings across Scotland. The bioresource data model enables a rapid assessment and quantification of the bioresource arisings helping to inform circular economy decision making and investment decisions.

Strategic opportunities:

- Industrial engagement to understand the 'demand' for bioresources.
- Identify the key bioresources that offer the greatest potential to biorefining and explore the data outputs further with stakeholders to discuss accuracy and access to further financial information.
- Use the detailed findings of specific bioresource arisings, like proteins and carbohydrates, to identify and engage with relevant stakeholders to understand their interest and appetite to develop circular opportunities
- Develop a model that serves as a national materials database that covers the complete dataset of bioresources.
- Engage with investors to showcase the opportunities and introduce the innovative companies seeking funding.

Case study – Ingenza

Ingenza use biotechnology and synthetic biology, to develop efficient, scalable bioprocesses for the manufacture of chemicals, biologics, pharmaceuticals and biofuels, from sustainable sources. Ingenza develop bio-based manufacturing routes that are environmentally sustainable in the long term, moving away from oil and using renewable resources.

Findings

The output of this project compiles a large quantity of data from the four key material groups of: waste, by-products, agricultural residues and wastewater sludge. Forestry waste and macro algae were not included within this study as these bioresources were included within the Biorefinery Roadmap. The cumulative total of these material arisings is over 27 million tonnes of potential feedstocks for biorefining which was captured within the bioresource data model.

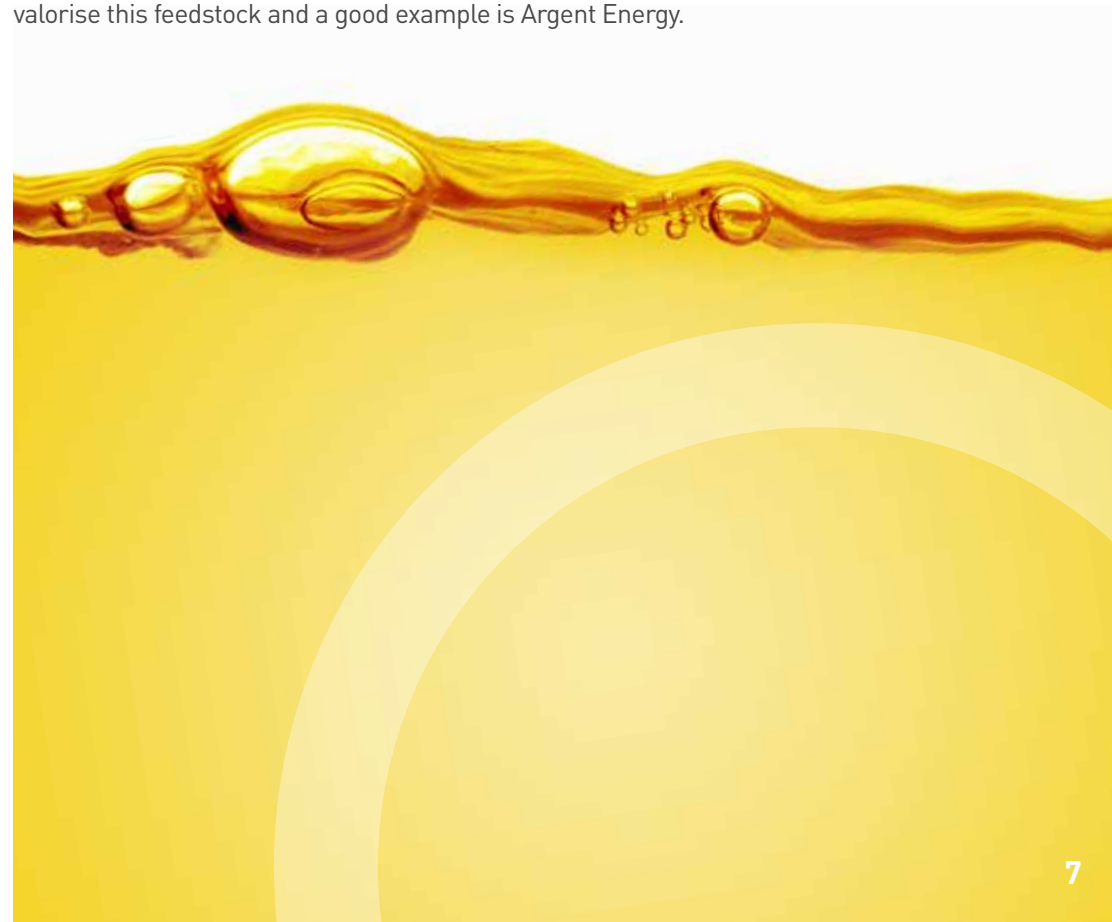
Waste

Animal and mixed food waste stands out as the key material in this stream and is of potential interest due to the quantity and also the composition. Animal and mixed food waste has been identified as an underutilised resource with over 365,000 tonnes being disposed to landfill and over 32,000 tonnes recovered through energy from waste, and therefore not being valorised in the form of composting or digestion for the production

of energy, digestate and compost. Although the food waste requirements of the Waste (Scotland) Regulations 2012 aims to divert a greater proportion of mixed food waste for composting and anaerobic digestion through household and commercial food waste collections. In addition to Animal and mixed food waste there is over 21,000 tonnes of paper and cardboard waste and over 32,000 tonnes of wood waste sent to landfill both of which could be valorised further and reduce harmful methane emissions. The most prominent concentrations of these organic materials is in residential and commercial hubs of Aberdeen, Glasgow and Edinburgh, with the key source of food waste being household and hospitality waste sectors. There are many biorefining solutions that can valorise this feedstock and a good example is Argent Energy.

Case study – Argent Energy

Argent Energy produces distilled biodiesel from waste fats, oils and greases including: food waste, wastewater fats, oils and greases, used cooking oil and tallow, oleo-chemical residues and grease trap and effluent wastes. As well as manufacturing standard diesel Argent manufacture a range of biodiesel products including B20 (with 20% biodiesel) and other high blends up to B100 (pure biodiesel).



By-products

The concentration of economic activity and Scotland's large and unique food and drink sector makes it particularly well positioned to realise the economic benefits of biorefining. The particular feedstocks that may be attractive for biorefining and the potential markets for the extracted resources are in high density and well-networked regions across Scotland.

By-products included within the study are drawn from the key sectors of brewing, distilling, cheese making, abattoir and fish processing. Of these industries the most prominent generators of by-products with potential value to biorefining are distilling (over 3 million tonnes of by-products) and cheese making with over 500,000 tonnes of material available. Some uses of by-product materials involve very limited value recovery and as such could be better utilised in a developing biorefining industry. In particular, the more remote distilleries on the coast and islands, where a small proportion of the by-products are valorised, offers greater potential for biorefining. So too do the small number of large dairy processors which have high volume of whey production – Dumfries & Galloway being a good example.

Case study – Celtic Renewables Ltd

Celtic Renewables Ltd produces biofuel from by-products of the Scottish Malt Whisky industry. The process recycles pot ale and draff which are processed using thermal hydrolysis and fermentation which convert the sugars xylose, arabinose and glucose from the waste material into ethanol, butanol acetone, as well as converting solid residues into animal feed.

Wastewater Sludge

The dataset included within the mapping process provides a good estimation of the dry organic matter available across Scotland. Although not the most abundant in terms of tonnage, wastewater sludges can have high calorific value for further use, as well as contain trace metals and other valuable bioresources. The data set used captured over 114,000 tonnes of dry matter equivalent. In relation to the regional location of these arisings unsurprisingly as with organic matter contained within the waste feedstocks the hubs of arisings are defined by areas of high population density with the cities of Glasgow, Edinburgh and Aberdeen making up over 65,000 tonnes or 50% of the overall arisings captured.



Agricultural residues

Agriculture represents by far the largest industries from which feedstocks for biorefining could be available with the key issue not being the value of the material available, but accessing these feedstocks. Similar to by-products, agricultural hubs around Aberdeenshire and Dumfries and Galloway provide potentially large quantities of material for biorefining. There are a number of agricultural resources that are of interest either as a result of their large volumes or as a result of being unused – or both. For example, farm slurry and manure arisings across the main enterprise types of: beef, dairy, poultry, pig and sheep accounts for greater than 14 million tonnes. In addition, some on-field and harvested waste material are also of interest given their volumes and biochemical composition – namely, carrots and potatoes.

The by-products from fruit and vegetable processing have been identified as another underutilised feedstock with over 140,000 tonnes of harvested fruit and vegetables currently not valorised, each year, throughout Scotland. A good example of innovation in this specific area is CelluComp.

Case study – CelluComp

CelluComp have developed a process that allows the properties of cellulose nano-fibres to be fully utilised. They have named these fibres as Curran®. Curran® is manufactured from waste streams produced by the food processing industry. CelluComp is working the food processing industry to optimise use of vegetable waste. Compared to other existing materials used as rheology additives, Curran® has a low carbon footprint due to its efficient process, uses far fewer chemicals and emits no toxic gases into the atmosphere.

Bioresource Characteristics

Within the four bioresource streams 18 characteristics of the streams were identified (as shown in Table 2 on page 21) and two of the most abundant are discussed below.

Protein

The bioresource data model also allows for specific biochemical components to be reviewed. The study calculates that over 340,000 tonnes of protein arises in Scotland each year. Key streams which contribute to the high protein arisings are distillery by-products and food waste. Biorefineries could offer not only a cheaper solution for disposal of these protein-containing bioresources, but also a lucrative avenue for value generation from feedstocks and their associated chemical components. The market value for protein for animal feed – such as fish feed can reach £400 per tonne but for more niche ingredients can reach over £1,500 per tonne^v. Horizon Proteins is currently developing a process to extract protein from distillery by-products as described below.

Case study – Horizon Proteins

Horizon Proteins have developed a process for the recovery and re-use of protein and energy from fermentation and distillery by-products. Their primary focus is to extract underutilised proteins found in brewery and distillery by-products, such as wheat, barley and yeast for use as a sustainable and nutritionally suitable source of protein for salmon feed such as fish meal.

^v <https://www.environmentalisonline.com/article/whisky-salmon>

Carbohydrates

There are over 300,000 tonnes of carbohydrate arisings in Scotland each year with the key streams being agricultural residues (potatoes), food waste and by-products (distilling and whey). Within the food waste stream one of the main bioresources is starch with the key producers being the hospitality and fast-food and quick-service establishments. A key challenge in valorising bioresources can be accessing the materials. An innovative project in Scotland has developed a technology that can capture starch from food waste. The project is being delivered by PeelTech.

Urban Bio-loops

The report has highlighted that Scottish cities are concentrators of organic material that is often landfilled at high cost which results in economic losses through landfill tax and causes a host of environmental problems not least adding to climate change through the generation of methane. This throughput is a missed opportunity. If cities could effectively recover and valorise their organic waste they could save costs, realise new revenue streams and regenerate natural capital in the process. The report highlights the huge volumes of organic waste from the organic fraction of household and commercial & industrial streams and also wastewater from sewage. Figure E1 shows that the 7 local authorities which have a city generate over 2.8 million tonnes which equates to over 50% of the total waste arisings of all 32 local authorities.

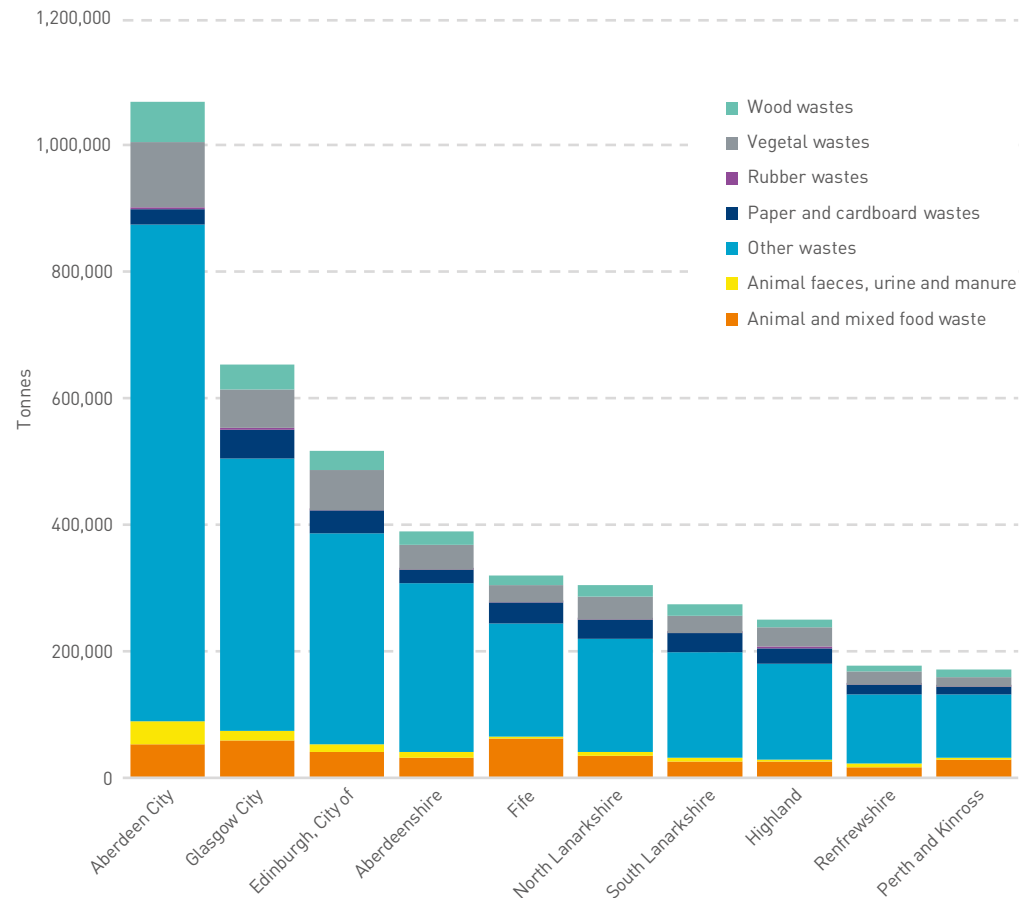
The potential opportunity is highlighted in a recent study, led by Glasgow Chamber of Commerce, looking at Circular Economy opportunities in Glasgow^{vi}. The study identified residual organic waste streams from a number of key sectors in the city, for example the manufacturing sector alone produces 8,755 tonnes of organic waste annually. Making use of these waste streams could not only lead to material savings and reductions in carbon emissions, but also represents a significant economic opportunity to the city and the wider Scottish supply chain.

^{vi} Include reference: <http://www.circle-economy.com/wp-content/uploads/2016/06/circular-glasgow-report-web-low-res.pdf>

Case study – GSK

IBioIC is working with GSK to develop a project to generate fermentable sugars from potential locally available waste stream, e.g. timber waste from nearby forestry operations or paper waste from local mills. This sugar will be used to replace corn-based glucose in GSK's processes.

Figure E1: Waste feedstock arisings by the 7 city authorities



Opportunities

Food waste

The chemical make-up of this type of waste is usually quite complex, containing various amounts of carbohydrates, proteins, fats and other minor components such as phenolics, vitamins and flavonoids. A greater proportion of food waste and by-products could be sent to existing or new anaerobic digestion (AD) plants in Scotland to produce biogas and a fertiliser as should be achieved through the Waste (Scotland) Regulation 2012. In addition, more novel applications valorising food waste could be assessed. These could include opportunities to recover protein and phosphorus and also to use as a feedstock to produce insect protein. Work could be conducted to assess the applicability and potential value of this type of approach to the Scottish economy. It would also be important to review how the existing policy and legislative landscape might impact on the commercialisation of products derived from these feedstocks; perhaps the market will not be in the UK but there is an increasing globally market.

Organic and bio-based fertilisers

According to the Agricultural & Horticultural Development Board (AHDB) 87% of the greenhouse gas emissions in the production of winter wheat comes from fertiliser production and fertiliser induced field emissions^{vii}. This could be greatly reduced through the application of organic and bio-based fertilisers and soil conditioners by avoiding the energy intensive production of chemical fertilisers.

In addition to the environmental benefits of organic fertilisers in reducing the emissions associated with producing chemical fertilisers, organic fertilisers also release nutrients, as they break down, they improve the structure of the soil and increase its ability to hold water and nutrients. The establishment of biorefineries creates the opportunity to explore options, pre and post processing, to develop organic fertiliser and soil improvers to add nutrients and improving soil structure. The opportunity exists to work closely with the agricultural sector to assess the potential to generate significantly more organic fertiliser and soil improvers either directly using raw bioresources or from the output of biorefining.

^{vii} https://cereals.ahdb.org.uk/media/176733/g57_understanding_carbon_footprinting_for_cereals_and_oilseeds.pdf

Case study – Revive Eco Ltd

ReviveEco collect used coffee grounds and recycles them to create high value bio-oils, biofuel and bio-fertiliser. The business is built upon the partnerships with large coffee chains / small independent coffee stores and garden centres. These natural bio-oils have a wide range of valuable applications across industries such cosmetics, pharmaceuticals and food and drink. The bio-fertiliser is a 100% natural soil amendment product, which can also be used as part of a compost blend, eliminating the need for the inclusion of peat. The biomass pellets produce less emissions than fossil fuels and the biochar left behind after burning can be used as a fertiliser.



Better use of environmental licensing

Most of the sources of waste and by-products are regulated under existing environmental regulations, for example The Pollution Prevention and Control regulations (PPC). The integrated nature of these regulations mean emissions to air, water (including discharges to sewer) and land, plus a range of other environmental effects, must be considered together. There is an opportunity to improve the capture and sharing of this integrated resource use data to better understand resource utilisation and opportunities for improved valorisation of wastes and by-products.

Develop a complete dataset of bioresources

There is an opportunity to include other material streams, not included within this study, to the bioresource data model to create a single data set covering all the key bioresource arisings, in particular, forestry residues and macro algae^{vi}. In addition, further biorefining opportunities were identified within the 'Waste' stream using bioresources that are not quantified separately owing to them being collected within a mixed waste stream and therefore not 'visible' in existing data sets. These 'hidden' bioresources highlighted in this report include: coffee grounds, bakery waste, by-products disposed to sea (whey, pot ale) and farmed-fish mortalities.

Another specific opportunity within food waste and also waste water processing is the capture of fats, oils, and grease (FOGs). The cost of managing fats, oils and grease in the public sewer system is significant with an estimated 60% of the overall annual sewer and pumping station cleaning expenditure resulting from FOGs. In effect this is a bioresource 'going down the drain'. The opportunity exists to gain a better understanding of the volumes of FOG arisings to inform the ability to valorise this current waste stream. Capturing FOGs before they are disposed provides a good foodwaste prevention opportunity and this is an area Argent Energy are already exploiting.

^{vi} Forestry residues and macroalgae were not included

Feasibility

With over 27 million tonnes of materials arising it is important to understand which bioresources offer the most promise from a biorefining perspective. To understand the most appropriate technologies to process the available bioresources it is suggested that feasibility studies are conducted in the main feedstock areas to build a compelling case for biorefinery construction in Scotland.

Urban Bio-loops

Zero Waste Scotland plan to explore Circular Economy opportunities in cities and regions throughout Scotland by identifying key material flows and working with stakeholders to realise opportunities. This work should further the understanding of organics material flows in cities to gain a more detailed insight into the accessibility and biorefining potential of these bioresources, and highlight the 'hidden' bioresources that will arise in high concentrations like bakery waste and coffee grounds.

Case study – Jaw Brew and Thomas Auld and sons

Making blonde beer, from waste bread. Aulds bakery supplies its bread on a sale or return basis which often leads to a large surplus of bread at the end of each day. The majority of this goes to foodbanks, however, the remainder is given to Jaw Brew. Jaw Brew use this waste bread to create beer. The Local independent micro-brewery found that the bread could be mashed without adding fermentable sugars, creating a low-alcohol beer at 2.2%, with a flavour and texture reflecting the low percentage.

Bioresources and renewables

There is a clear overlap between bioresource arisings and the areas of Scotland with high renewable energy potential. One of the challenges with renewable energy in rural and remote locations is connection to the electricity grid. There is an opportunity for biorefineries to use excess renewable energy to support novel biorefining processes in rural communities. As bioresources tend to have a high water content (de-watering requires energy) or require energy as part of the pre-treatment or for the biorefining process itself there will be value in exploring further how this energy need could best be provided by renewable power and support wider low carbon policy objectives.

Case study – Xanthella Ltd

Xanthella, a small industrial design company that is working on producing systems to grow microalgae. They are championing the use of algae as a new high value industry for remote and rural areas by using cheap renewable energy to power the photobioreactors that are used to grow the algae.

Carbon Capture and Utilisation

Carbon Dioxide (CO₂) Utilisation and Carbon Capture and Utilisation (CCU) has the potential to provide significant economic activity in Scotland by reusing its CO₂ as a feedstock for various commercial applications. Carbon dioxide utilisation is complementary to, but not a substitute for, carbon capture and storage (CCS) owing to very different scales of deployment. CCU takes CO₂ from point sources and converts it into commercially valuable products: bio-oils, chemicals, fertilisers and fuels. These technologies have the potential to transform how the world approaches CO₂ mitigation, and reduce the cost of managing CO₂. In addition to reducing net CO₂ emissions this approach brings the benefit of reducing the consumption of non-renewable resources. A recent Scottish Enterprise study^{viii} found that in 2014 there were approximately 10 million tonnes of CO₂ emissions from Scotland's large carbon emitters, (those with →10,000 tonnes of CO₂ per year), of which an estimated capture potential of around 4.3 million tonnes has been identified. Of this estimated capture potential, 3.1 million tonnes are located within 50 miles of Grangemouth, a good example of a large mixed-use industrial site. Carbon was out of scope of this study but it is suggested that carbon could be a valuable asset to the bioresource arisings dataset in the future.

Partnership working

This study clearly highlights the varied sources of bioresource arisings and therefore, for waste and by-product-fed biorefineries to develop, new 'unconventional partnerships' between traditionally separate industry sectors need to be developed (e.g. agri-food businesses and chemical companies). Organisations like Zero Waste Scotland, Industrial Biotechnology Innovation Centre, Scottish Enterprise and Highlands & Islands Enterprise will play a key role in bringing together companies generating significant amounts of waste in Scotland, potential end-users, technology providers, academia and open-access scale-up centres, regulators, policy-makers and investors to catalyse the collaborations require to build these new supply chains.

^{viii} <http://www.evaluationsonline.org.uk/evaluations/Search.do?ui=basic&action=show&id=606>

Key terms and definitions

Waste^{ix} – Defined in the Waste Framework Directive (WFD) as any substance or object which the holder discards or intends or is required to discard.

Biorefining^x – Biorefining, is the sustainable processing of biomass into a spectrum of marketable bio-based products (biochemicals, materials) and bioenergy (fuels, power heat). Convert biomass into a portfolio of biomass-derived intermediates and products that will form the base for the future bioeconomy.

Bioeconomy^{xi} – The bioeconomy comprises those parts of the economy that use renewable biological resources from land, sea and air – such as crops, forests, fish, animals and micro-organisms – to produce food, materials and energy.

Food Waste^{xii} – We define food waste in common with the FUSION's definitional framework. On this definition, food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea). Drink and liquid waste, fish discarded to sea and waste of any materials that are ready for harvest, but which are not harvested, are included in FUSIONS' definition (see below) of food waste.

Within the FUSIONS definitional framework, 'food waste' as defined above is differentiated from two distinct but related concepts:

- **'Food Loss'** – defined by Fusions as a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack of access to markets. In addition, natural disasters play a role.

- **'Food wastage'** – refers to any food lost by deterioration or waste. Thus, the term 'wastage' encompasses food loss and food waste.

It is anticipated the Fusions definition of food waste will inform future EU guidance on food measurement and for this reason it also underpins the Scottish Government's food waste prevention target.

FUSIONS – (Food Use for Social Innovation by Optimising Waste Prevention Strategies) is a project working towards a more resource efficient Europe by significantly reducing food waste. The project was funded by the European Commission Framework Programme 7 and ran from 2012 to 2016.

Bio-waste/Biodegradable waste^{xiii} – Defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste. This is a subset of the Fusion's definition of food waste and it is important to maintain this as a distinct resource stream as it is commonly referred to as biodegradable municipal waste (BMW). As an example Scotland's biodegradable land fill ban specifically mentions BMW as being banned from landfill. So too does the EU Landfill Directive.

Agricultural residues^{xiv} – materials left in an agricultural field or orchard after the crop has been harvested. These residues include stalks and stubble (stems), leaves, and seed pods. The residue can be ploughed directly into the ground, or burned first. Within the context of this report agricultural residues would not be included within the Fusion' definition of food waste.

^{ix} <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN>

^x <http://www.nnfcc.co.uk/tools/iea-bioenergy-task-42-biorefinery-biobased-chemicals-value-added-products-from-biorefineries>

^{xi} <https://ec.europa.eu/research/bioeconomy/index.cfm>

^{xii} <https://www.eu-fusions.org/index.php/about-food-waste/280-food-waste-definition>

^{xiii} http://ec.europa.eu/environment/waste/framework/bio_waste.htm

^{xiv} <https://stats.oecd.org/glossary/detail.asp?ID=480>

Animal & mixed food waste^{xv} - includes: Animal waste of food preparation and products, including sludges from washing and cleaning, Mixed wastes of food preparation and products including biodegradable kitchen / canteen wastes, and edible oils and fats. The source is generally from food production.

Recovery^{xvi} - means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Recovery covers the sub-categories of preparing for re-use, recycling and 'other recovery'.

Recycling^{xvii} - means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations. Backfilling means a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials.

Disposal^{xviii} - Defined in the Waste Framework Directive (WFD) as any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Any waste treatment operation which does not meet the criteria of the recovery definition is by default considered to be disposal. The WFD sets out a non-exhaustive list of disposal operations; these include landfilling, incineration with low energy recovery, and injection into land.

Bioresources^{xix} - Bioresources are non-fossil biogenic resources which can be used by humans for multiple purposes: to produce food, substantial products, and/or energy carriers.

^{xv} <http://ec.europa.eu/eurostat/documents/342366/351806/Guidance-on-EWCStat-categories-2010.pdf/0e7cd3fc-c05c-47a7-818f-1c2421e55604>

^{xvi} <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN>

^{xvii} <https://stats.oecd.org/glossary/detail.asp?ID=480>

^{xviii} <https://stats.oecd.org/glossary/detail.asp?ID=480>

^{xix} <http://bioresource.eu/bioresources/>

By-product – In EU waste law, notions such as by-product or secondary raw material have no legal meaning – materials are simply waste or not. However, a number of issues have arisen in relation to the interpretation of this definition. As such, the European Commission has provided further guidance addressing the distinction between waste and by-products: a Communication on waste and by-product^{xx}. Within this communication the following illustrative terms, in addition to waste as defined in the Waste Framework Directive, are used:

- **Product** – all material that is deliberately created in a production process. In many cases it is possible to identify one (or more) 'primary' products, which is the principal material produced.
- **Production residue** – a material that is not deliberately produced in a production process but may or may not be a waste.
- **By-product** – a production residue that is not a waste.

Valorise^{xxi} – Raise the price or value of a commodity by artificial means, especially by government action.

A note on terminology

It is important to note that all of the arisings discussed within this report can be described as resources or bioresources with the ability to be recovered and recycled to extract value in the framework of the circular economy. Bioresources may be classed as waste, as by-products, or as products (such as biomass deliberately grown for a specific purpose). Our primary interest here is in mapping potential future uses, not simply 'waste' reduction opportunities, and so all three sources are of interest to a future bioeconomy. Even where material has a value as a by-product, there may be greater opportunities that can be developed in future.

More widely however, the use of this terminology needs to be carefully managed as significant uncertainty and confusion can be caused by inconsistent use or different understandings by different stakeholders. This is particularly true with respect of waste and by-products and matters at several levels, including how they are accounted for within reporting systems. However, for the purposes of classifying material within this study the terms 'waste', 'by-products' and 'agricultural residues' have been used in a purely descriptive sense as defined above to help structure the bioresource data model and reporting outputs.

^{xx} <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52007DC0059>

^{xxi} <https://en.oxforddictionaries.com/definition/valorize>

1 Introduction

1.1 Background

The circular economy is an ambitious vision for a smarter way of managing resources through new business models, product redesign and new supply chain collaborations. The concept has developed against a backdrop of climate change, increasing resource pressure, and also economic uncertainty around Brexit and therefore focuses on addressing environmental and economic goals. It helps to secure businesses against risks (such as resource scarcity) and ultimately will help make supply chains more sustainable and competitive, whilst demonstrating businesses' social responsibility, and minimising the environmental impact of products and services. These opportunities are all key components of the Scottish Government's Circular Economy strategy 'Making Things Last'¹ which has a specific chapter highlighting the opportunities for a bioeconomy.

The circular economy can also offer new business growth opportunities for organisations willing to innovate. Therefore, the adoption of a new innovative circular economy business model in Scotland provides a very attractive opportunity to Scottish businesses to become more competitive and to protect themselves against future increases to resource prices.

The important role resource efficiency has in delivering economic benefits is evidenced by the fact that the Scottish Government's **Economic Strategy**² emphasises the importance of a circular economy to boost the productivity, competitiveness and resilience of the economy. The economic importance of the circular economy was highlighted in a recent study, The Beer, Whisky & Fish sector study,³ which identified potential biorefining opportunities with an economic prize to Scotland of between £500-800 million.

¹ <http://www.gov.scot/Resource/0049/00494471.pdf>

² <http://www.gov.scot/Resource/0047/00472389.pdf>

³ <http://www.zerowastescotland.org.uk/BeerWhiskyFish>



Scotland's community connectedness makes it well-suited for adopting more circular solutions. Concentration of economic activity in a few, highly networked sectors lowers the cost of collaboration and increases the viability of cross sectoral projects and resource use.

One example of how these cross sectoral projects can help maximise resource use and material productivity is that of biorefining. Biorefining offers the chance to extract as much value as possible from (usually biological) material streams via the production of chemical compounds that can be recycled directly back into industry. These compounds include materials such as proteins, carbohydrates, lipids/fats and potassium, all of which are valuable resources to feed back into industrial production loops. Advocates of biorefining make the point that turning biotic materials into energy by digestion can be inferior to re-using or recycling them in biorefinery processes.

In 2015, the Scottish Government committed to reducing per capita food waste by 33% below 2013 levels by 2025. Meeting this ambitious target will require major efficiency gains throughout Scotland's food system, however some food waste can never be physically eliminated as it is, by definition, physically 'unavoidable'. Biorefining offers Scotland a second, complementary means of reducing its food waste through a process known as 'valorisation', whereby the economic value of a waste material goes from negative (a financial liability to the producer) to positive (a source of revenue for the producer).

The concentration of economic activity and Scotland's large and unique Food and Drink sector makes it particularly well positioned to realise the economic benefits of biorefining, as the particular feedstocks that may be attractive for biorefining as well as the potential markets for the extracted resources are in high density and well networked regions.

In 2015, Scottish Enterprise published 'The Biorefinery Roadmap for Scotland'⁴, which sets out the key actions required to identify the barriers and risks faced by companies and potential investors to enable the more established biorefinery technologies. A key action of this roadmap is to map the wastes, by-products and agricultural residues that are, or which could be, available as feedstock for a biorefining process.

Therefore, **the challenge for this project was to establish the scale of the opportunity for the bioeconomy sector in Scotland**, by quantifying and mapping bioresource arisings to understand the scale and shape of a potential market.

1.2 Aims

Drawing on this background and political ambition of the circular economy this specific project was designed to meet a defined need of the industry, namely to identify the material arisings and characterising them for their biorefining potential. Therefore, key aims of the project were:

- to identify key data sources on the arisings of material streams valuable to the biorefining industry;
- to assess the quality of these data sources and critically review them to allow for opportunities to be identified on better ways of collating and managing data that would enable a better picture of the industry to be developed;
- using the publicly available data, to map the material arisings that can be quantified regionally across Scotland, to enable assessment at the level of local authorities of where key materials arise; and
- using the known fate of these arisings, to estimate the quantity of available arisings for industry when current market conditions are taken into account; and
- to generate indicative figures of available bioresource arisings regionally across Scotland.

It is worth noting that this study did not include within its scope forestry waste or macroalgae as these were being researched through other projects.

To deliver much of the above analysis, a further core output for the project was a bioresource data model that would enable industry operators to assess the viability of facilities looking to extract and exploit a given bioresource, providing clear visualisation of the density of material arisings required as a feedstock and the bioresource content that might be available for them to pursue.

⁴ <https://www.scottish-enterprise.com/knowledge-hub/articles/comment/biorefinery-roadmap>

2 Methodology

To generate meaningful estimates to allow assessment of the potential for biorefining in Scotland, a phased methodology was adopted for data collection, material characterisation, modelling of data and interpretation of outputs. This methodology was designed with the full expectation that data gaps would be encountered, and therefore that flexibility would be required to arrive at a usable data model based on the best available data. Therefore, a key aspect throughout the methodology was a pragmatic approach to project delivery, identifying weaknesses in the data where they existed, highlighting how these could be improved going forwards, but resolving to produce indicative outputs for industry use.

2.1 Overview

The methodology developed was a five-step process, as shown in Figure 1. This involved estimating the tonnage of material arising that represent feedstocks for the biorefining industry and, secondly, the potential bioresource content of each material. However, to model these arisings, several stages of data review and interpretation were required, including seeking primary studies to characterise the shortlisted material streams by their bioresource content. More detail on how these tasks were undertaken follows in subsequent sections of this report.

Utilising this methodology, data were captured, reviewed and manipulated to feed into the overarching modelling process. Consequently, a database of material arisings was created for the key material groupings of:

- waste materials;
- by-products from industrial production;
- agricultural crop residues; and
- sewage sludges.

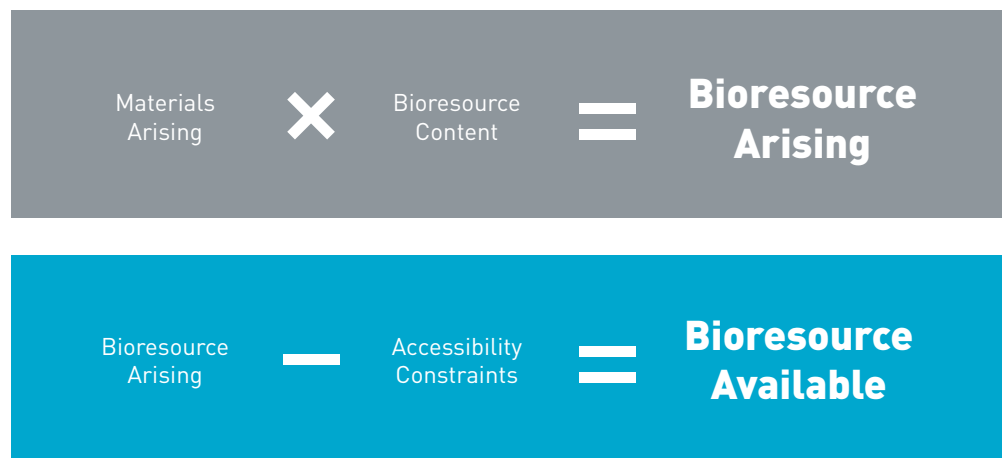
Figure 1: Overview of the methodology

TASK 1 Material Stream Arisings	<ul style="list-style-type: none">• Quantity of Material arisings acting as feedstock to biorefining• Source of Arisings with Geographic breakdown
TASK 2 Characterisation	<ul style="list-style-type: none">• Composition of Bioresources (bioresource characteristics were assessed including: carbon, calorific value, moisture content etc.)
TASK 3 Current Accessibility	<ul style="list-style-type: none">• Temporal Availability (transport)• Spatial availability - transport, storage• Existing uses and economic constraints
TASK 4 Future Accessibility	<ul style="list-style-type: none">• Market changes (price)• Future Quantities (anticipated Sector growth)
TASK 5 Biorefinery Options Appraisal	<ul style="list-style-type: none">• Commercial assessment of feedstock• Development of feedstock analysis report

Outputs from the characterisation study were compiled into an inventory of bioresource content factors, similar to that in an environmental impact assessment model. This inventory of bioresource factors formed the second half of the equation for calculating the bioresource arisings available from the feedstocks selected in the bioresource data model. Multiplying material arisings by bioresource factors yields the estimated total (maximum) quantity of bioresources should all materials streams be available for the biorefining industry.

Of course, in reality, it is highly unlikely that all material arisings would be available for biorefining, as market and economic constraints would dictate that a large proportion of the material streams will already have a pre-defined fate or destination. To account for this, a secondary 'accessibility constraint' calculation was then also overlaid in the bioresource data model. This applies a current value to the material feedstocks on a £/tonne basis depending on its current value. Some materials command a revenue, as they are put to positive use (draff to animal feed, waste paper to recycling, etc), whilst others incur a charge, as their disposal costs money (e.g. incineration or landfill). Prospective biorefineries can make use of these constraints when using the bioresource data model by determining the thresholds on the value that they are willing to pay (or be paid) for their feedstock material. The model reveals how much bioresource might be available for a given price.

Figure 2: Simple overview of bioresource data model calculation



It is important to note that one of the key strengths of this approach is that as much data as possible is captured on a regional level for Scotland. As a result, the value of materials to the operator can also include the potential impacts of transportation costs. In this way, if an operator would like to assess the potential to build a facility in one local authority, 'material values' would be adjusted for other local authorities to reflect the cost of getting that material to the processing facility.

Therefore, the overarching design of the bioresource data model is to provide a simple tool for potential operators of biorefineries in Scotland to visualise the feedstock materials available based on not just market availability, but also geospatial restrictions.

2.2 Quantifying 'material stream' arisings

To complete the level of analysis required for this project, large amounts of data have been required. This first step, the identification and quantification of material stream arisings that could act as a feedstock to the biorefining industry, was conducted using a literature review to quickly identify publicly available sources. These data sources were then filtered to select and draw out the most useful information to aid the development of the bioresource data model. Key to this was combining data sources that enabled the model to apportion material arisings across the two classifications of:

- local authority – geographically where the material arises; and
- material fate – of the materials arising, what proportion ends up in each fate.

Table 1: Example data collation template for material arising data for animal and mixed food wastes

Category	Fate	Local Authority	Material	Commercial & industrial waste	Household waste	Total (Tonnes)
Waste	RRC ⁵	Aberdeen City	Animal and mixed food waste	14,521	13,482	28,003
Waste	Recovered ⁶	Aberdeen City	Animal and mixed food waste	45	98	143
Waste	Landfilled	Aberdeen City	Animal and mixed food waste	8,046	16,383	24,429

In addition to reviewing large numbers of sources to find suitable data, there was also a need to be pragmatic in the choice of source data. Quite frequently, data appear in formats not directly applicable to the bioresource data model, and thus intermediary steps were necessary to help apportion data appropriately. Some examples where these intermediary steps have been required include:

- **Data on arisings available aggregated at the national level only**

In some cases, we have found that data on material arisings is only available at national level. In these circumstances, industry data on the geo-location of the largest producers, together with information about the frequency of smaller producers in each local authority, was utilised to apportion the national data to a regional scale.

- **Arisings appearing as product based rather than the breakdown of products available**

An example of this occurred when looking at fish waste data. Data were presented as 'fish processing waste', rather than being broken down into the granularity of data required for the bioresource data model. In these cases, industry data were used to help disaggregate this overall mass of material into individual material streams more suitable for characterisation and bioresource mapping.

⁵ Re-used, recycled or composted

⁶ Definition used by Scottish Environment Protection Agency (SEPA's) waste data strategy



2.3 Material stream characterisation

To allow transformation of material arisings into quantities of bioresources available in Scotland, each material stream included within Task 1 (Section 2.2) had to be characterised by its composition of key chemicals and characteristics important for biorefining. Working with project partners Biorenewables Development Centre (BDC), the project steering group and Zero Waste Scotland, the key characteristics and chemicals of interest to the sector were shortlisted for review and inclusion as a part of this study. The list of characteristics, and their units, are presented in Table 2.

It is this characterisation data that allows the generation of a bioresource inventory to be developed in the bioresource data model, setting out the quantity of each bioresource available per tonne of raw material arising. The starting point is the quantities of bioresources available calculated by multiplying the estimates of the material arisings by the relevant bioresource inventory factor. For example, if the biorefinery is looking for carbohydrate content, the bioresource data model outputs will multiply total material arisings by the relevant factors for each material concerning the tonnes of carbohydrate per tonne of material.

The BDC conducted a desk based assessment of the physical and chemical composition and characteristics of the waste materials (co-products and by-products) presented by Ricardo Energy & Environment in the initial mapping exercise. The bioresources identified were from the sectors below.

- commercial and industrial (C&I);
- agriculture;
- food and drink (including by-products, co-products and non-captured wastes); and
- waste water sludges.

Individual resource streams for each sector were detailed by Ricardo and shortlisted by the BDC based upon its valorisation potential (see Table 3). A literature search was carried out to populate each waste stream to individual bioresources, for example, 'paper and cardboard wastes' were broken down into feedstocks 'paper and cardboard packaging' and 'other paper and cardboard wastes' (Table 4). The individual feedstocks were then categorised based upon its chemical composition (e.g. carbon content, carbohydrates, protein and fat). In addition, high value chemicals were identified (e.g. essential oils, pectins and phenolics for some of the bioresources).

⁷ The 3-2-1 scale indicated the degree of stability where 3 is a high level of stability

Table 2: Bioresource Characteristics in bioresource data model

Bioresource characteristic	Units
Dry matter content	% wet weight (w/w)
Metabolisable energy	MJ/kg
Protein	% w/w
Fat	% w/w
Carbohydrate	% w/w
Carbon content	% w/w
Hydrogen content	% w/w
Nitrogen content	% w/w
Sulphur content	% w/w
Total dietary fibre	% w/w
Calcium (Ca)	% w/w
Iron (Fe)	% w/w
Magnesium (Mg)	% w/w
Phosphorous (P)	% w/w
Potassium (K)	% w/w
Sodium (Na)	% w/w
Zinc (Zn)	% w/w
Copper (Cu)	% w/w
Manganese (Mn)	% w/w
Selenium (Se)	% w/w
Stability ⁷	3 → 2 → 1
Potential to separate at source	Y/N
Functional ingredients for recovery	-

Table 3: Breakdown of different feeds and individual waste streams

Feed	Waste stream
C&I wastes	Paper and cardboard wastes
	Rubber wastes
	Wood wastes
	Household mixed food waste
	Animal faeces, urine and manure
	Household garden waste
Agricultural	Agricultural wastes
Food & drink (including by-products, co-products and non-captured wastes)	Dairy
	Distillery by-products
	Brewing by-products
	Coffee grounds
	Fish processing by-product
Abattoir by-product	
Sludges	Waste water sludge

Table 4: What is classified as 'Paper and Cardboard wastes'.

Paper and cardboard wastes
Paper and cardboard packaging
Paper (as received, Phyllis2, Entry: #2167)
Paper (dried, Phyllis2, Entry: #634)
Other paper and cardboard wastes
Rejects from paper recycling (as received, Phyllis2, Entry: #1878)
Rejects from waste paper preparation (dried, Phyllis2, Entry: #412)

2.3.1 Data collection

Our research around food and biomass composition is based on data extracted from a number of trusted sources including Phyllis2 database for biomass and waste, USDA food composition database, UN Food and Agriculture database, and UK food database, as well as a number of scientifically robust sources detailed in the spreadsheet.

The average of all individual bioresources was reported for each waste streams except for household mixed food waste. The Zero Waste Scotland report 'Household Food and Drink Report 2014'⁸ has detailed the breakdown of household waste and its percentage contribution by weight. Using these data, a weighted average was reported for household mixed food waste.

⁸ <http://www.zerowastescotland.org.uk/sites/default/files/Household%20Food%20and%20Drink%20Waste%20Estimates%202014%20Final.pdf>



2.3.2 Data limitations

Data from our research is limited in some cases due to the lack of literature on that specific feedstock. For some bioresources, an estimation of the carbon, hydrogen and nitrogen (CHN) composition has been calculated based upon the carbohydrate, protein and fat data available.

The calculation of CHN in each feedstock is calculated based upon the mass fractions illustrated in Table 5.

Table 5: Elemental CHN⁹ composition of carbohydrates, lipids and fats

Group	C	H	N
Carbohydrate ^a	0.444	0.062	0.000
Lipid ^b	0.776	0.114	0.000
Protein ^c	0.529	0.070	0.173

^a Represented by glycogen and starch,

^b Atomic composition of plant oil, mussel fat and fat of fresh water and marine fish,

^c No correction for Sulphur made.

It is important to note that the data above does not take sulphur or trace metal content into consideration. Therefore, predicted CHN values are likely to be an overestimate for certain feedstocks.

⁹ C- Carbon, H – Hydrogen, N- Nitrogen (Grainger & Bitterlich, 1984)

2.4 Current accessibility of material streams for biorefining

Of these total potential arisings of bioresource, some will not be accessible for use in a biorefinery. For example, there are existing uses that will continue (e.g. straw for animal bedding), some arisings will be too far from potential biorefinery sites, and some may have inappropriate composition (judged using the output from Task 2).

It is not possible for the bioresource data model to predict what any biorefinery will consider is 'too far away' for the bioresource content, or 'too competitive an alternative fate'. Therefore, a pragmatic step was taken to reduce the analysis to a question of cost.

Information was sought for the current value or cost of each material arising going to its current fate. Inevitably, the availability and accuracy of data varied according to materials and their fates, and variations in price across Scotland were excluded, but estimates were made for every combination of material and fate.

To account for the question of 'too far away', the following calculations were performed. Firstly, a centroid location¹⁰ was determined using GIS for each local authority (plotted as an X-Y scatter graph and overlaid on a map of Scotland in Figure 3). A straight-line distance was then calculated for each pair of authorities, and this was augmented by a factor (estimated to be 1.3) to account for the deviation of roads from straight-line distances. Finally, a unit price for freight was applied. These calculations yielded in a table of prices (in £/tonne) to move material between any two local authorities.

¹⁰ In effect, the 'centre of gravity' of the local authority.

Figure 3: Map of Derived Scottish Local Authority (LA) Centroids



2.5 Future accessibility

Although not part of this study it is important to comment on how these arisings and the availability of these arisings will change annually. For any given potential use of a bioresource it is important to be consider of market conditions when estimating its availability. The comments are made to highlight the uncertainty associated with bioresource arisings. When looking in to the future, multiple unknowns must be considered, on which a view must be taken, such as:

- Policy decisions – some of these can be included in the future forecasting undertaken (such as food waste policies).
- Industry growth patterns – some industries have 'future strategy' documents on which forecasts of arisings can be developed, however even in the most forward looking of sectors reasonable estimates of performance or ambition of performance are only available up to a 5-year time period. As a result, looking beyond these timeframes is somewhat more difficult.
- Market changes influencing material fates and availability – in baseline estimates, the current destination of materials and the market value of this disposal or resale into a secondary market is reasonably well understood. However, how this changes in future years provides much greater uncertainty as it represents potential changes in the transactions of multiple supply chains. For example, market changes in substitute goods could provide shifts in incentives for the purchase of by-products rather than virgin materials, this leading to greater competition and increased value of some of the material feedstocks analysed within this project. The uncertainties introduced by Brexit are a good example – this could change the flows of food and other biological materials dramatically.
- Addition of biorefining as a competitor for resources in the Scottish economy – following on from the introduction of biorefining as competitor for resources, market dynamics could shift significantly with current market value of materials now bearing no resemblance to future potential values driven by market competition.

3 Resource data availability

3.1 Waste

3.1.1 Source data and manipulation

Waste data for household and C&I waste streams are included in the bioresource data model undertaken for this bioresource mapping project. For both waste streams, the data have been extracted from Scottish Environment Protection Agency (SEPA) datasets (www.sepa.org.uk/environment/waste), with the 2015 SEPA data set downloaded for data extraction. In the case of household waste, the extraction of data is available for waste arisings at a local authority level. However, for C&I waste, more data manipulation is required to generate similarly formatted data. Gross value added data¹¹ (2012) was used to apportion C&I waste tonnages with the link being drawn between economic value generation, production and waste generation. This methodology for the apportionment of C&I waste is used regularly and is considered a reasonable estimate for apportionment. However, if the user should wish to use an alternate basis for apportioning this waste, the bioresource data model also provides the ability to do so on the basis of local share of employment, population or local authority area.

Once household and C&I waste data are available in the same format by local authority region, they are then combined using a simple seven-stream categorisation of waste:

- paper and cardboard;
- rubber waste;
- wood waste;
- animal and mixed food waste;
- vegetal waste;
- animal faeces, urine and manure; and
- other wastes.

These waste streams are then mapped against bioresource factors to establish the quantity of bioresource available in each local authority region of Scotland.

¹¹ <https://www.sepa.org.uk/media/125421/2012-waste-data-quality-report-final-rev2.pdf>

3.2 Waste data

Caution should be used when assessing bioresource arisings as they can be challenging areas to quantify and different studies can reach different conclusions either due to the year source data originates (with variation reflecting actual change, or changes to the way some sites or sectors record information) or the way in which system boundaries are defined for a specific study purpose.

One area where differences between studies has been identified in the current work relates to food and organic material. SEPA waste data records material by waste stream – only where food and organic fractions are separated in collection and management can they be counted in isolation. This will also usually align with the food waste's suitability to be used as biorefining feedstock, where separation is essential to productive future use. However, a large amount of food waste arises in mixed waste streams; this is still counted in bespoke studies focused on food waste even though, at present, it may not all be available for biorefining applications.

As an example, at the household level, Zero Waste Scotland estimate¹² around 600,000 tonnes of food waste was generated in 2014. This covers food waste in residual collection, separate food waste collection, food waste in mixed collections, and an estimate of disposal to sewer, based on a number of dedicated studies. However, SEPA data captures information on separately collected 'food waste' which is therefore more selective than this, and only shows 144,000 tonnes as being generated.

Crucially, for the biorefining sector, which needs material to be separated for it to be available as feedstock, treatment data may be a better guide to what can be used than estimates of waste generation or arisings, as it will be a better guide as to the extent to which material is already separated and available.

¹² <http://www.zerowastescotland.org.uk/content/how-much-food-waste-there-scotland>

4 By-products data availability

4.1 Brewery by-products source data and manipulation

The brewing sector in Scotland is a significant contributor to employment and value added of the food and drink sector. Due to the large scale there are also significant by-products generated associated with production which could potentially be utilised for biorefining.

The sector study on beer, whisky and fish¹³ compiles the results of a study undertaken specifically in to reviewing the circular potential of the three key sectors. Therefore, this study included reviewing the sector inputs, outputs and by-products to further identify potential circular economy opportunities. This source therefore provided the best available basis for this study's estimates of the material arisings available for biorefining. Data provided in the beer, whisky and fish sector study summarises the key by-product arisings for the Scotland wide scale as presented in Table 6. To refine this data to local authority level the proportional split of this data then had to be calculated taking into account the number and scale of breweries in each local authority region.

For example, >75% of the total barley, hops and yeast consumed by the sector were used by two key breweries: Belhaven Brewery (Green King) (approx. 12.3 million litres per annum) and Tennent & Caledonian Breweries (T&C) (approx. 200 million litres per annum). The rest of the sector comprises relatively small, independent craft brewers (approx. 31.2 million litres per annum in 2013). It is estimated that the total Scottish beer production is at least 243.5 million litres per year. Belhaven and (T&C) produce 5% and 82% of the estimated production per year across Scotland, respectively with the remainder produced by up to 80 smaller craft breweries.

Table 6: Annual brewery by-product tonnages (Scotland-wide)

Output type	Output quantity (tonne)	Approximate weight of by-product per litre of beer produced	Approximate weight (tonne per annum) of by-product at Brewery		
			Belhaven Brewery	Tennent Caledonian	Small breweries
Spent grain	48,700	100-200g	1,845	30,000	16,855
Spent hops	428	85% input volume	22	352	54
Spent yeast	3653	15g	185	3,000	469
Spent kieselguhr	414	1.7g	21	340	53
Trub	487	No data			

To apportion these arisings of materials across Scotland, location and postcode data was then sourced for all breweries. For the two large producers with known material arisings these could then be plotted directly into local authority regions. The remainder of the material was then apportioned within local authorities. First calculating the arisings per small brewery based on the known Scotland wide arisings/number of small breweries. Then apportioning this based on the number of small breweries present in each local authority identified in location and postcode datasets available.

¹³ Zero Waste Scotland, (2016), Sector study on beer, whisky and fish 2015, available online from <http://www.zerowastescotland.org.uk/BeerWhiskyFish>

With data manipulated in this way the bioresource data model is populated with by-product arisings data for the key product groups of, spent grain, hops, yeast and Kieselguhr. Trub (the remaining sediment left after fermentation) remains a data gap in the model however with limited data available on arisings per brewery and therefore its distribution across Scotland. Although this does not represent a large data gap in relation to the tonnage of material available, the nature of Trub and its composition of heavy fats, proteins and spent yeast means that it could contain high proportions of valuable materials for biorefining. Should feedback from industry represent significant interest in this material stream despite its relatively small scale, then further work should be taken to more robustly quantify this by-product stream so that it can be estimated based on either inputs to the brewing sector, or outputs from the sector as is the case for the other materials covered in this study.

4.2 Whisky distillery source data and manipulation

Data on distillery by-products was extracted from the following study:

- Zero Waste Scotland, (2016), Sector study on beer, whisky and fish 2015¹⁴. This study provides the most robust review to date of the distillery sector with a focus on quantifying the material flows through the industry process. This includes an assessment of the reported by-product outputs versus the potential outputs calculated based on the industry benchmarks for outputs from known source input materials such as the dry matter utilised. Importantly the report also demonstrates the true potential value of the sector with all by-products estimated to be high in valued bioresources such as protein and carbohydrates.

However, the key data extracted from this were the target material tonnage arisings from the sector as represented in Table 7.

Apportionment of this data was undertaken utilising data received from SAC estimating the distillery by-product by distillery and local authority region. Combining the proportional data from this study and overlaying it on the calculated potential by-products arising then provides the basis for the data uploaded into the model.

¹⁴ Zero Waste Scotland, (2016), Sector study on beer, whiskey and fish 2015, available online from <http://www.zerowastescotland.org.uk/BeerWhiskyFish>

Table 7: Annual by-product arisings from the whisky distillery sector (Scotland-wide)

By-product	Quantities (Tonnes)
Draff	684,000
Pot ale	2,016,000
Spent lees/wash	361,000
Pot ale syrup	32,000
Distillers dark grain	254,000

4.3 Fish processing source data and manipulation

Three key studies were used to extract data on fisheries by-products and apportion these by-products from fish processing arisings:

- Zero Waste Scotland, (2016), Sector study on beer, whisky and fish 2015¹⁵;
- Ghaly et al (2013) – Fish Processing Wastes as a Potential Source of Proteins, Amino Acids and Oils: A Critical Review¹⁶; and
- Pascal et al (2013) – By-products from Fish Processing: Focus on French Industry¹⁷.
- Secretariat of the Pacific community (2014) Adding value to fish by-products¹⁸

¹⁵ Zero Waste Scotland, (2016), Sector study on beer, whisky and fish 2015, available online from <http://www.zerowastescotland.org.uk/BeerWhiskyFish>

¹⁶ <http://www.omicsonline.org/fish-processing-wastes-as-a-potential-source-of-proteins-amino-acids-and-oils-a-critical-review-1948-5948.1000110.php?aid=20794>

¹⁷ <http://archimer.ifremer.fr/doc/00148/25916/23949.pdf>

¹⁸ https://www.researchgate.net/profile/Jean-Pascal_Berge2/publication/262808270_Adding_value_to_fish_processing_by-products/links/02e7e538ecacd000cf000000.pdf

Core arisings data for the Fish and Aquaculture sector was sourced from the Zero Waste Scotland sector study on beer, whisky and fish, with aquaculture representing farmed fish and 'fish' representing sea caught varieties. However, classification of this material required further manipulation to transpose these data from raw material arisings for Scotland, into by-product arisings for each local authority. Firstly, key by-products for the fish sector could not simply be classified as fish processing waste as each element of this process waste could have significantly different bioresource content. As such, key by-products from fish processing were identified as being:

- skin;
- trimmings;
- bones;
- viscera (internal organs and entrails); and
- shellfish waste.

To split out this homogenous fish processing waste into these categories, three additional sector studies previously mentioned were utilised to calculate an estimated average split of each material stream.

Table 8: Annual breakdown of fish processing waste to key by-product streams (Scotland-wide)

By-product	Source 1	Source 2	Source 3	Estimation for model	Estimated tonnage
Skin	8%	4%	4%	5%	8,013
Trimmings	41%	47%	64%	55%	88,138
Bones	41%	23%	16%	20%	32,050
Viscera	0%	26%	16%	20%	32,050

With these by-products then broken out apportionment of these material tonnages was then undertaken using the Aquaculture Scotland site database¹⁹ as a reference for which local authorities are likely to produce the largest quantities of each material. A count of aquaculture sites in each local authority region was developed with the share of sites in each local authority then acting as the apportioning factor for by-product material streams.

¹⁹ http://aquaculture.scotland.gov.uk/data/site_details.aspx



4.4 Abattoir source data and manipulation

Abattoir data required a similar approach to fisheries data to combine several data sources to transform key data on material arisings and disaggregating it into the wastes streams of:

- carcass;
- blood;
- bone;
- fat;
- hide/skin; and
- viscera.

To do this, livestock numbers were first reviewed to identify the total potential weight of material available in Scotland apportioned by key region multiplied by the average weight of each livestock typology.

Table 9: Number of livestock slaughtered in Scotland by region²⁰

Regions	Abattoirs – annual livestock throughputs				
		Cattle	Sheep	Pigs	Totals
North west – Highland (Orkney, Shetland and Western Isles)	Number of livestock	15,791	16,834	19,169	51,794
	% of total	3.30%	1.20%	6.30%	2.40%
North east – Grampian (Moray, Aberdeen, Aberdeenshire)	Number of livestock	148,379	626,261	36,049	819,689
	% of total	31%	46.10%	11.90%	38%
South west – Argyll-Bute, East Central, Clyde Valley, Ayrshire, Dumfries & Galloway	Number of livestock	76,090	2,852	182,381	261,323
	% of total	16%	0.20%	60.30%	12.20%
South east – Tayside, Fife, Lothian & Borders	Number of livestock	234,098	712,895	64,708	1,011,701
	% of total	49%	52.50%	21.40%	47.40%
Scotland	Number of livestock	474,358	1,358,842	302,307	2,135,507
	% of total for each animal category	100%	100%	100%	100%

Table 10: Calculation to transform number of livestock to tonnage of material arisings²¹

Average weight of each animal (tonnes)		
Cattle	Sheep	Pigs
0.35	0.031	0.081

Transforming this tonnage of material into the key by-products of interest for this study then required further data breaking down the full mass of the animal into the by-products for reprocessing. This split of these by-products is then multiplied by the tonnage of livestock slaughtered to generate the potential tonnage of by-products generated by the industry.

Table 11: Assignment of waste stream to by-product output²²

Waste stream	Pigs (estimated by-product)	Cattle (estimated by-product)	Sheep (estimated by-product)
Carcass	68%	50%	58%
Blood	3%	14%	2%
Bone	7%	2%	2%
Fat	3%	3%	3%
Hide/skin	5%	5%	14%
Viscera	15%	26%	22%
Total	100%	100%	100%

²⁰ <http://www.resourceefficientscotland.com/sites/default/files/5th%20Quarter%20Blood%20Management%20Report.%20Red%20Meat%20Sector.pdf> Resource efficient Scotland 5th Quarter Blood management project. 2014

²¹ http://www.qmscotland.co.uk/sites/default/files/red_meat_industry_profile_2015.pdf – based on carcass weights

²² K. Jayathilakan et al (2012) Utilization of by-products and waste materials from meat, poultry and fish processing industries: a review

4.5 By-product data gaps and opportunities

4.5.1 General data issues

In compiling the data required for the bioresource mapping process large quantities of source data have had to be accessed to try to understand by-product arisings, fates and current market values. In conducting this review, frequent data gaps have been uncovered with overarching difficulties that could be better overcome to ensure future work in this area is more complete.

The first of these general issues is the classification of by-products as a material stream. As they do not as a material fall well into either categories of waste or resource, it is not always the case that their arisings are captured in standard reporting systems. This is especially the case when potentially valuable materials, are disposed of to land, sea or standard drainage systems. Key examples of this within the data captured for this study include:

- Whey production – many of the potentially valuable resources from the cheese making sector are disposed of to sewer or to sea. Having this material then combined into waste water material means that either the tonnage is captured as a homogenised waste water material, or in the case of disposal to sea or not captured at all.
- Fisheries and abattoirs – in the case of fisheries and abattoirs the issues with the data are slightly different. In these cases the value of the individual by-products is not yet truly realised and as such only very high level aggregated data is available on the tonnage of fish waste or carcasses produced as a waste product. Therefore, in these cases, the problem lies not in the records of the quantity of material available for biorefining, but in the classification of this waste in relation to its constituent parts. This is another key factor for the production of data for mapping the bioresource potential of the sector. Not only is the overall quantity of material key but also specific material typology and its corresponding bioresource content. Without accurate classification of materials available accuracy of bioresource factors applied is limited and results delivered with unknown margins of error.

Therefore, the second general issue with the management of data is the requirement to overcome issues of limited data. Many different data sources have to be used in combination to calculate just one material stream arisings and subsequent bioresource availability. In undertaking this process although all due care can be taken to ensure compatible data are used, it is not always best practice and less-than-ideal data can be used to generate the first estimates of material arisings. Therefore, this study

acknowledges this fact in that attempting to generate first estimates of bioresource availability, challenging data issues have been overcome that, when refined, could produce different results.

The final issue frequently uncovered is that of the lack of data at a regional or local authority level. In the case of this study, numerous methodologies have been used to overcome this barrier with industry data reviewed and used to again produce the first estimates of regional scale arisings. Should industry operators wish to engage in the market and look to develop treatment facilities with sustainable feedstocks, more work will be required to ensure that not only the quantities of data are accurate, but also the destination of their arisings. However, this first attempt is a significant start towards addressing this.

4.5.2 Opportunities

To overcome these known barriers and to better understand the arisings and fate of by-products there is an opportunity to develop an industry reporting system for all material waste streams including by-products. Firstly, this will require clear classification of all by-products as a potentially valued material stream. Secondly, it will then require mandatory reporting to produce quarterly figures on the quantity of these materials being produced and where these materials then go. In most industries this should not be a large barrier to overcome, administrative burden should not be high, and data management systems at a local scale (in business) are probably already in place. The solution is a central reporting system to enable better management of this data at a regional and national scale so that the potential value of by-product materials can be maximised through the use of all avenues available, including that of biorefining.



5 Agricultural data availability

Agricultural arisings data has been estimated for a wide range of potential material streams ranging from animal slurries and on farm digestate through to cropping tops and straw products. Estimates of these material arisings have been generated from a range of source data:

- agricultural survey data – Scottish Government's June Agricultural Census 2015;
- Scottish livestock numbers – Scottish Government's June Agricultural Census 2015;
- a network of expert opinion from regional advisors – SRUC – SAC Consulting's network of regional agricultural consultants spanning 23 offices in Scotland provided estimates of local practices in livestock housing and manure management; and
- industry best practice or benchmark data – SRUC/SAC Consulting specialists, a range of industry reports.



6 Sludge

Scottish Water is the principal service provider in Scotland for waste water and water treatment. However, several of its schemes are part of the private finance initiative, with Scottish Water delivering wastewater treatment and sludge management operations, particularly for some large conurbations, through private sector partnerships. The bulk of Scotland's sewers are combined surface water and foul water sewerage systems, taking dirty water from domestic, trade and commercial customers and also runoff from road and roof. Sludge is primarily the organic by-product of the biological treatment of wastewater, formed by the settlement of the breakdown products of the treatment process.

While the drive to improve wastewater treatment standards has led to a significant improvement in the quality of Scotland's streams, rivers and coasts this has in turn resulted in Scotland producing more sludge. As this drive for improvement is continuing and the population increases, it is expected that Scotland's sludge quantities will continue to increase for the foreseeable future.

6.1 Sludge management options

Wastewater sludge has a number of potential outlets and applications such as recycling as a fertiliser and soil improver to agricultural or non-agricultural land and more recent approaches such as using as a fuel in energy production. There are also disposal options such as landfill and incineration. There are few options in Scotland for the re-use or recycling of water treatment sludge, and management options have traditionally centred on treatment within wastewater works or disposal to landfill. In early 2005²³, the key outlets used for Wastewater Sludge in Scotland were:

- recycling to agricultural land (approximately 23%);
- land reclamation (40%);
- energy from waste/power generation (35%); and
- other (2%).

²³ http://www2.scottishwater.co.uk/portal/page/portal/SW_PAGE_GROUP_PS_ADMIN/SW_PUB_SCHEME_ADMIN_HOLDING/TAB65572/Scottish%20Water%20Draft%20National%20Sludge%20Strategy%2025-01-06.pdf

The key outlets used for water treatment sludge were:

- landfill (approximately 64%); and
- treatment at wastewater treatment works (36%).

6.2 Strategy for wastewater and water sludge

Scottish Water were supportive of the study through the provision of sludge data across Scotland which totalled 114,725 tonnes. The largest arisings being in the central belt and with the single largest site being in Glasgow with over 45,000 tonnes. Given the acceptance that sludge arisings are likely to rise in the future there is a strategic opportunity to explore new innovative circular opportunities. The approach to sludge management over recent years has been to seek value recovery from sludge. Most recently this has been through energy recovery from digestion or thermal hydrolysis processes. Thermal hydrolysis is a two-stage process combining high-pressure boiling of waste or sludge followed by a rapid decompression. This combined action sterilizes the sludge and makes it more biodegradable, which improves digestion performance. It also produces a potentially attractive fertiliser or soil conditioner used on non-agricultural land.

Between 2021 and 2040 all of the private finance initiatives (PFI) contracts, which manage circa 80% of all sludge arisings in Scotland, will come to an end. This creates an opportunity to explore further value-add opportunities for sludge treatment and following discussions with Scottish Water biorefining could provide some innovative solutions. A particular opportunity could be the co-digestion (anaerobic) of sludge with other bioresources – the by-product of macro-algae processing for example. Co-digestion offers potentially the dual benefits of establishing a process that utilises waste/by-products creating energy and also with an output that could be developed into an effective agricultural fertiliser and soil improver. Alternatively, or additionally, a biorefining approach could take the chemical rich feedstock and develop high value chemicals for target sectors such as lubricant, complex chemical scaffolds, etc.

7 Other material streams

Through the research and stakeholder engagement in delivering this project, a number of interesting resource streams, which could have a biorefining solution, were identified and are described in the following sections.

7.1 Bakery waste

The bakery sector in Scotland is one of the largest within the food and drink sector employing over 20,000 people. Little is known about the raw material inputs or wasted resources from this sector. However, the bakery sector is an interesting sector from a biorefining perspective for a number of reasons. Firstly, the wasted resources resulting from the bakery process are generally consistent and homogenous in composition. Secondly, the location and number of bakeries generally reflect the size and location of the population which means that the a risings are concentrated in the areas with the highest population density making them more accessible. The downside being that generally the volume of wasted resources will be small per given site.

The potential value of waste materials from bakeries has been highlighted in a recent report: Glasgow Circle Scan²⁴

Through this study a specific project was highlighted which turns bread into beer – ‘beer utilises unused bread in the beer brewing process, saving 1/3 of the resources utilised in the brewing process. Food waste is also reduced’ (www.jawbrew.co.uk/hardtack-launches-blonde-beer-made-bread).

It would be helpful therefore to have a better understanding of the wasted resources across the bakery sector in Scotland – especially the populous city regions. Zero Waste Scotland is conducting work to better understand the raw material inputs and waste resource outputs.

²⁴ Located at: – <http://www.circle-economy.com/wp-content/uploads/2016/06/circular-glasgow-report-web-low-res.pdf>



7.2 Coffee grounds

The UK coffee industry (cafés and instant coffee factories) produce approximately 485,000 of UCGs (used coffee grounds) per year, of which over 90% are landfilled or incinerated, costing the UK coffee industry £79.8 million per year (Fairtrade, 2012). Of this, it is estimated that 40,000 tonnes of used coffee grounds is generated in Scotland alone²⁵.

Coffee grounds have interesting properties which may have biorefining potential. Similar to bakeries, cafes and coffee shops map against the population and so our cities and towns have concentrated arisings of used coffee grounds (UCGs) making collection easier. Further work would need to be done to understand the attractiveness of UCGs as a biorefining feedstock.

7.3 Forestry waste

Forestry waste and residues (not including domestic garden waste which is included within the household waste data) were out of scope of this study but it is worth providing a short commentary on this stream as it is potentially attractive as a biorefining feedstock. A recent study estimates that wood fibre potential²⁶ availability is approx. 2 million tonnes per annum greater than forecast demand for at least the next 20 years in Scotland. A proportion of the 2 million tonnes will be in locations that are expensive to harvest either due to difficult ground and/or lack of infrastructure. Wood availability does start to drop around 2030 and demand is forecast to exceed availability by 2040-ish, hence the current political direction of demand to plant additional productive forests.

Another study was undertaken to look specifically at wood fuel. This found that the quantity of wood-fuel used in Scotland amounted to 1,098,000 oven dry tonnes (odt) in 2014, compared with 775,000 odt in 2013 and 737,000 odt in 2012. The rate at which wood-fuelled boilers have been installed is expected to slow over the next few years because of the changes in the way the UK Government encourages and supports the renewables sector and the recent major drop in the price of oil. The present indications are that total use of wood-fuel may increase by a further 268,000 odt per year by the end of 2018.

The most widely used type of wood-fuel in Scotland in 2013 was virgin wood fibre in the form of chips, sawmill co-products and process residues, and this accounted for 59% of the total wood-fuel used. Recycled wood was the next most widely used fuel type and

accounted for 38%, with wood pellets being the third most widely used fuel type at 2% of the total. In 2014, virgin fibre, sawmill co-products and process residues accounted for 53% of the total wood-fuel used, recycled wood 42% and wood pellets 4%. Recycled wood is a very important fuel type for the largest boilers, more than 1,000kWth, while pellets are the most important fuel type for boilers less than 200kWth in size.

There is no single report that clearly identifies the available biomass from the forestry sector. However, the available reports for wood-fuel and wood fibre suggests that there are investment and growth opportunities in the short to medium term in the wood fibre supply chain in Scotland. There is an opportunity for wood fibre and forestry co-products such as bark, branches, stumps and roots etc and their potential to create value chemicals such as tannins, antibacterials and lubricants to be investigated in greater detail given its potential relevance to biorefining.

7.4 Fats oils and grease

Another specific opportunity within food waste and also waste water processing is the capture of fats, oils, and grease (FOGs). The cost of managing fats, oils and grease in the public sewer system is significant with an estimated 60% of the overall annual sewer and pumping station cleaning expenditure resulting from FOGs. In effect this is a bioresource 'going down the drain'. The opportunity exists to develop a better understanding of the volumes of FOG arisings to inform the ability to valorise this current waste stream. Capturing FOGs before they are disposed provides a good food waste prevention and biofuel opportunity and this is an area which Argent Energy (page 7) are already exploiting.

7.5 Macro algae

In the UK, macro-algae are a traditional crop. They have been wild-harvested and used for food, feed and as fertiliser in coastal communities for centuries. Therefore, a core of commercial activity is well established: Companies such as the Hebridean Seaweed Company Ltd, Mara Seaweed, Wild Irish Seaweed and Seagreens Ltd and Seagreens, harvest seaweeds (2,000-3,000 dry tonnes total harvest per year in the UK²⁷) from the wild, and produce food and feed products and speciality chemicals and fertilisers. Fulfilling the wider potential will require increased production capacity, through wild harvest, but mainly through cultivation, for example on long-lines. Sustainable wild harvest is close to maximum capacity at the locations with current activity; expansion may be possible in some new geographical areas²⁸.

²⁵ <http://www.gd-environmental.co.uk/blog/business-waste-how-keep-coffee-grounds-out-ground/>

²⁶ Wood Fibre availability & demand 2015-2035, Confor.

²⁷ https://connect.innovateuk.org/documents/3312976/3726818/AB_SIG+Roadmap.pdf

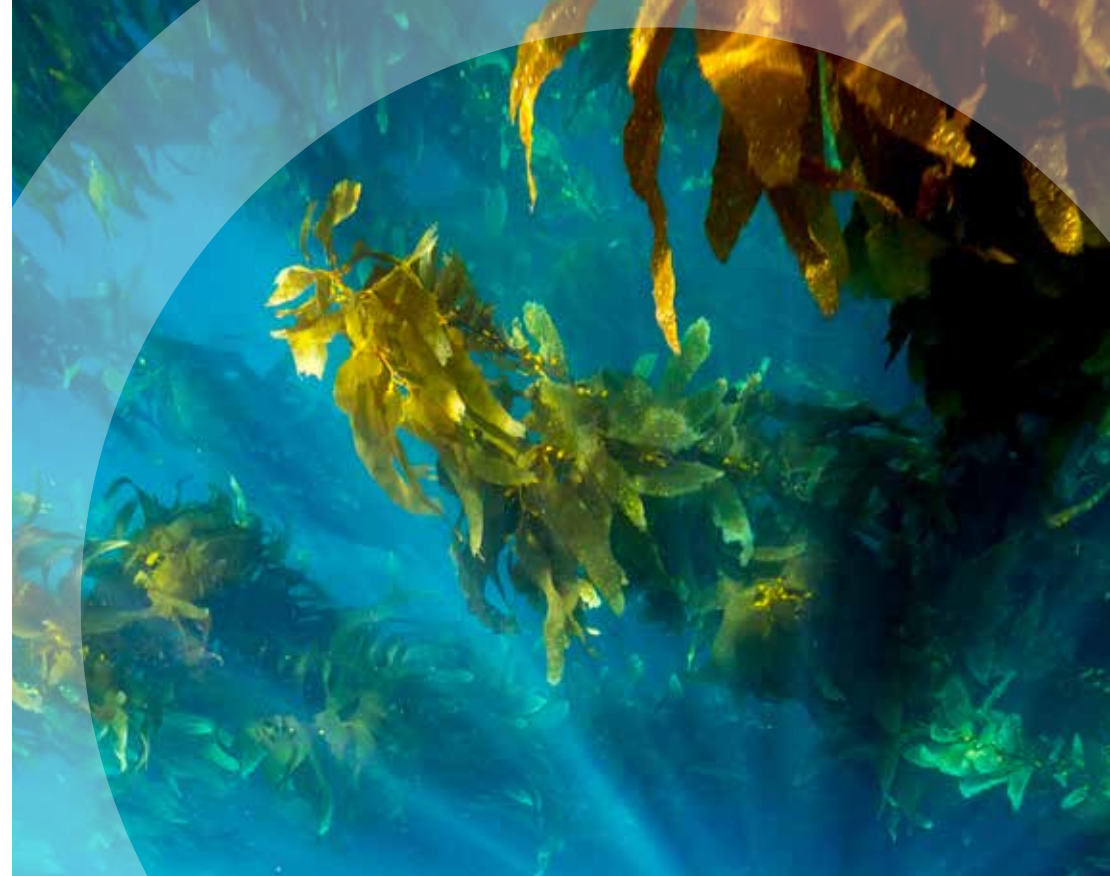
²⁸ Current data seems to indicate that large-scale and sustained harvesting of natural stocks of most (possibly all) seaweeds in most locations is unsustainable. (Pers. comm., Prof Michael Cowling, The Crown Estate, May 2013)

Cultivation does not have a long-standing history in the UK; however, pilot scale seaweed cultivation using long-lines is underway (e.g. at Scottish Association for Marine Science (SAMS), Queen's University Belfast, Hebridean Seaweed Company and through The Crown Estate). Establishing how seaweed cultivation can be done at scale in an environmentally and economically sustainable manner is of paramount importance for developing this industry. The Norwegians will harvest 170,000 wet tonnes of kelp annually. This is done in a strict five-year rotation between the different areas which are licensed to ensure the minimum amount of environmental impact. Bioenergy Technology Innovation Needs Assessment (TINA) estimates 'up to 0.6Mha of sea would need to be used to grow macro-algae for energy production (10 TWh), in line with the department for Energy & Climate Change (DECC - which is now Department for Business Energy & Industrial Strategy) 2050 pathways analysis. Future detailed analysis from The Crown Estate is expected to offer further insights into the area of the UK seabed which macro-algae could be farmed on. Initial insights from this indicate that significantly greater production might be possible, by a factor of two or three. However, increased production will not necessarily mean greater use as an energy source, owing to the higher profitability of macro-algae in pharmaceutical, chemical and food markets.'²⁹

An industry source estimated that there is 40–50 million tonnes of Kelp seaweed available around Scottish coastal water with 8–10 million tonnes of harvestable Kelp available per annum.

Macro-algae was out of scope for this study but there is growing interest from a biorefining perspective. The 8–10 million tonnes of harvestable biomass could not be included as it does not 'arise' and it would need to be harvested. Future work should focus on the waste arising from processes using macro algae (e.g. the cellulose waste arising from production of alginates). However, it is recognised that at present the macro-algae processing levels are very small but as detailed in section 6 above there is growing interest in exploring the co-digestion (anaerobic) of macro-algae biorefinery by-products. It is also worth noting that that Centre for Process Innovation (CPI) is running a project aimed at assessing the potential of using seaweed in anaerobic digestion (AD) – <https://www.uk-cpi.com/blog/seeing-the-potential-in-seaweed>.

²⁹ TINA Bioenergy Summary Report, September 2012, LCICG, page 11; available at carbontrust.com/media/190038/tina-bioenergy-summary-report.pdf



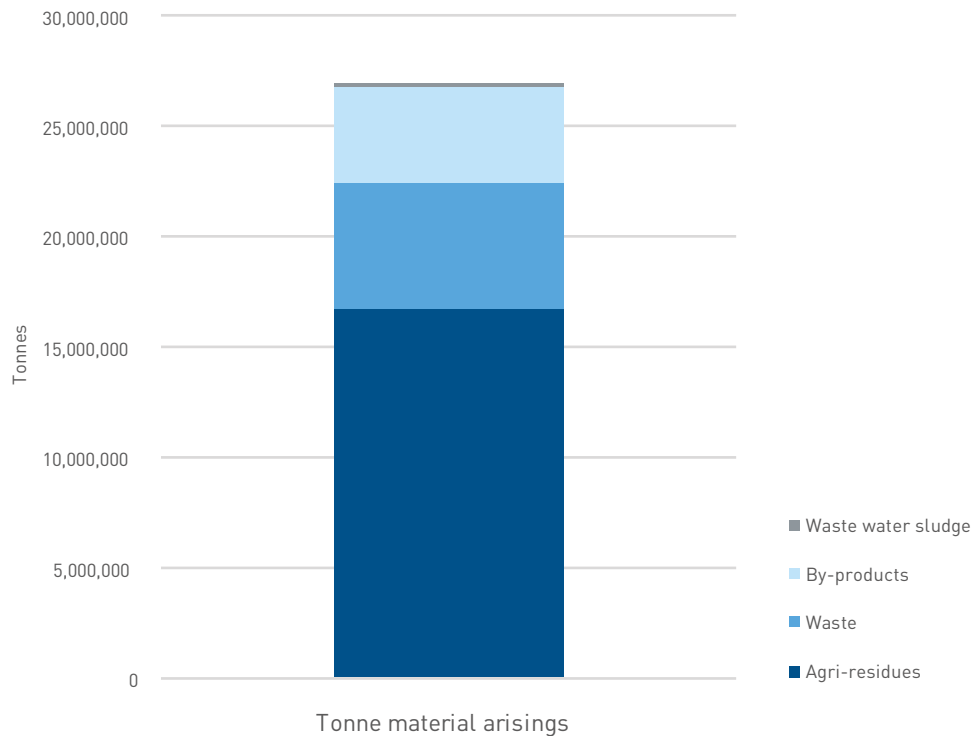
Case study – Hebridean Seaweed Company

The Hebridean Seaweed Company processes the raw seaweed, Knotted Wrack (*ascophyllum nodosum*) into animal feed supplements, soil enhancements, alginate and for application in the nutraceutical sectors. The company works closely with Scottish Natural Heritage and Scottish Environment Protection Agency (SEPA) to ensure that the seaweed harvesting is sustainable and environmentally friendly. Harvesting takes place all year round and the cutting is carried out either manually using a sickle or mechanically using a seaweed harvesting boat.

8 Results

The bioresource data model produced for this project compiles a large quantity of data from the four key material groups of agricultural, waste, by-product and sludge. The cumulative total of these material arisings is over 27 million tonnes of potential feedstocks for biorefining which was mapped within the model. Using these data, the following sections first explain the way in which these data can be accessed from the model, then take in turn each key material group to highlight key areas of potential value for the biorefining sector and, as a result, areas of interest for further research to be undertaken.

Figure 4: Summary of total material arisings captured within the model



8.1 Overview of resulting metrics from the model

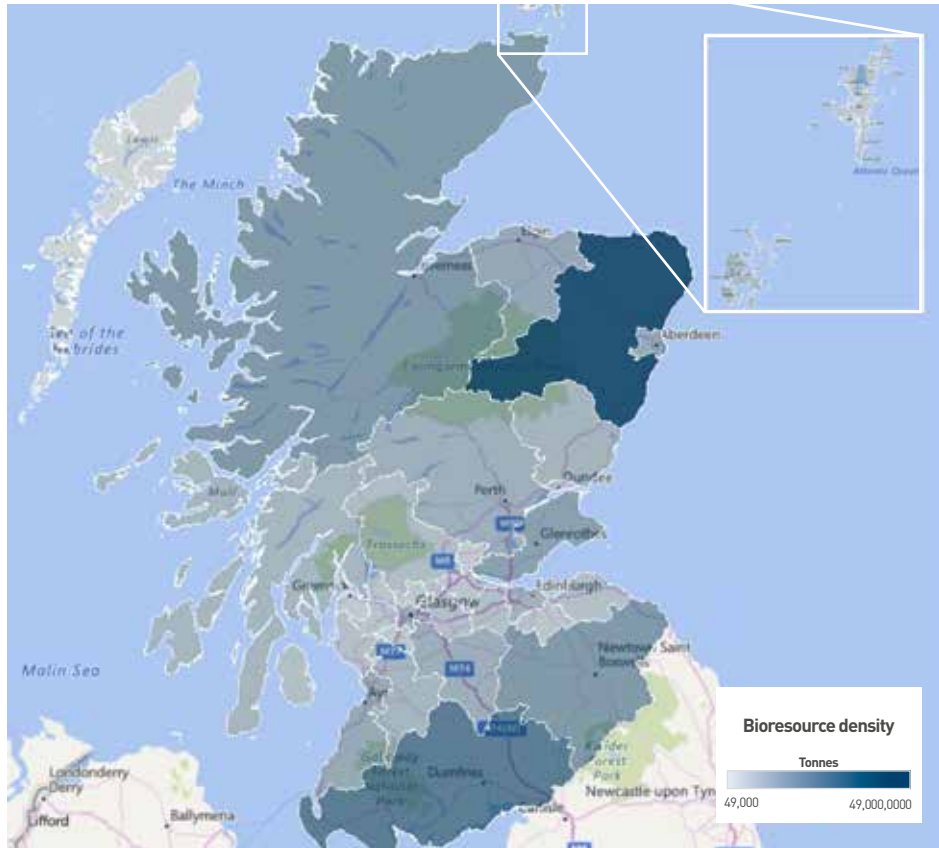
The outputs from the modelling process are designed with the industry operators in mind and are thus two-fold in their presentation.

Primary outputs of the model will consist of material density maps presented for the user to quickly identify the areas of highest density bioresource arisings. These output maps enable the user of the model to select the core bioresource of interest. Using the model's control system the user will be able to choose from a drop down menu any single bioresource assessed in this project. In addition, the user will also be able to filter between arisings maps should they be interested in looking at alternate resources simultaneously. It is considered that this first level of data will allow initial high level assessment of technology feasibility in Scotland.

Figure 5 details the geographical arisings of the 27 million tonnes of materials potentially suitable for biorefining across Scotland. The figure highlights the concentration of bioresources in particular geographical areas. It clearly demonstrates the importance of the rural areas which highlights the importance of agricultural and by-products as key resource streams.

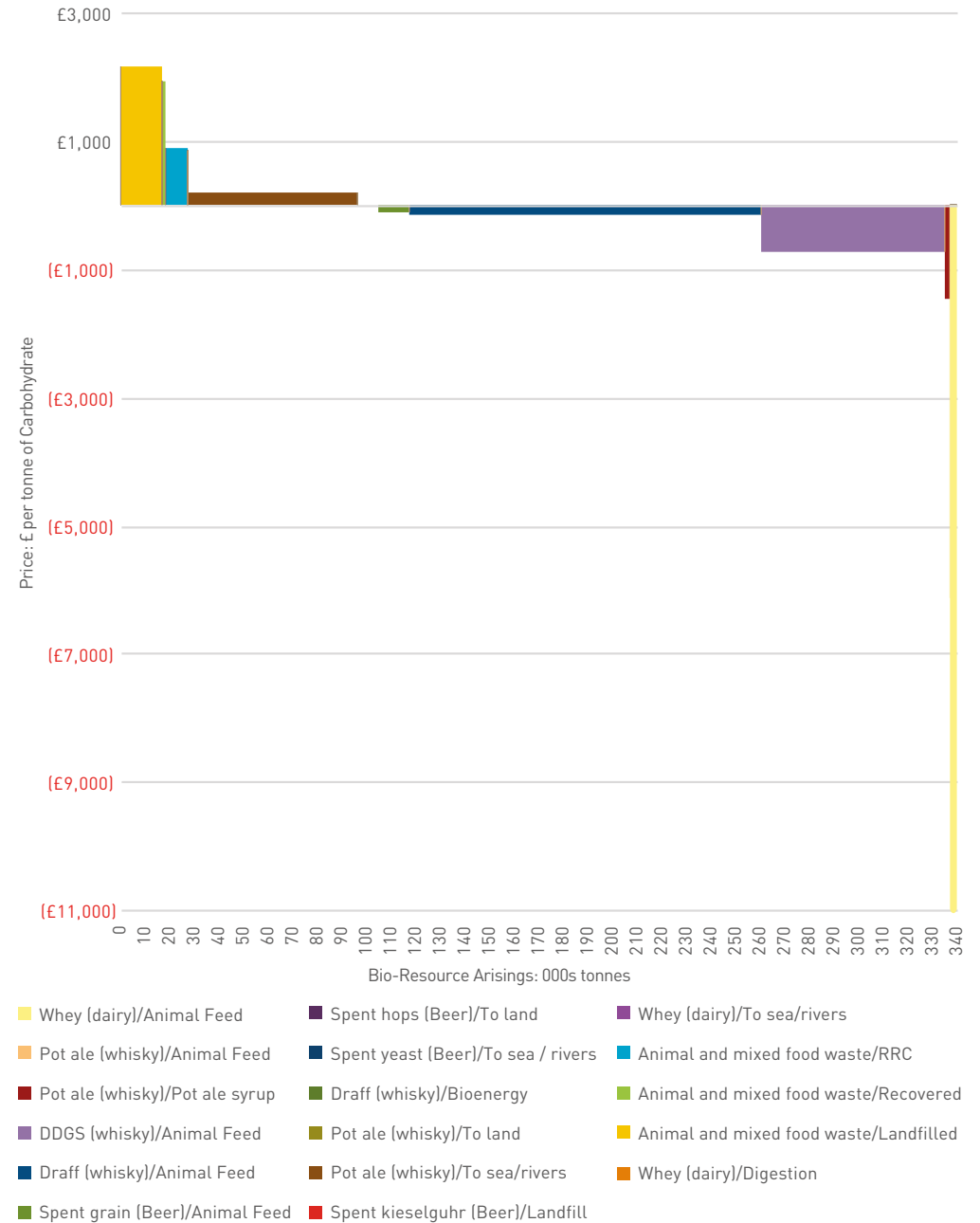


Figure 5: Geospatial mapping of bioresource arisings



The second tier of data presentation looks at the commercial viability of the bioresource selected. This element of the bioresource data model will apply the economics constraints over the material arisings data to present the quantity of material available at a given market constraint. If the operator wishes to vary their potential market operating value, they can therefore be used to quickly re-assess the economic viability of their business model when entering the Scottish market.

Figure 6: Example of value assessment output from the model



For the purposes of this report we have not produced large amounts of these data outputs as these can be generated on a case by case basis using the model. It has the ability to produce a wide range of potential outputs relevant for different operators wishing to enter the market. To produce the full range of these outputs would be difficult in the context of this report. The outputs in this report however will provide the high level arisings data by material stream and local authority area, and provide commentary on what this potentially represents.

8.2 2014 baseline outputs from bioresource data model

As stated above the bioresource data model developed for mapping bioresources across Scotland can produce a wide range of results and outputs useful for industry operators. The aim of the results presented below, however is to provide a high level overview of the market potential with key material arisings, and current utilisation of these materials presented. In addition, current estimates of the destination of these arisings will also be produced so that key areas for development can begin to be identified alongside potential technologies best suited to the material availability.

8.2.1 Material or feedstock arisings

The first key data output which the study has enabled is the production of estimates of the material arisings, or in other words, potential feedstocks available for use in a biorefining process. These are defined as the raw material arisings that are available and suitable for feed into a biorefining process. The materials captured are categorised by two key parameters. Firstly, their quantity split by current fate or end destination. This allows clear representation of which potential feedstocks are well managed or already valorised in other industry sectors. Understanding this metric allows quick interpretation of which materials might be most readily available for biorefining. The second categorisation is arisings by local authority region. As the transportation of materials is a costly element of any process this metric allows geographical reference for the feedstock arisings meaning siting of potential biorefineries can also be undertaken. These two metrics in tandem then provide an overview of the most prevalent feedstocks available, but also, the most efficient siting of a plant to take advantage of them.



8.2.2 Waste material feedstocks

Waste material feedstocks are defined as available material collected as part of current household and C&I waste collection regimes. These are classified down from a long list of material typologies into seven key resource streams appropriate for the study as detailed in Table 12. Of these key streams it is the **animal and mixed food waste** which stands out as the key material of potential interest due to the amount and also the composition. It is worth noting that despite waste policy requiring that source segregated food waste collections are now mandatory, there is still a significant quantity of material still being landfilled and recovered, and therefore not being valorised in the form of digestion or composting for the production of energy, digestate and compost. This is furthered by the fact that food waste represents a good source of bioresources such as proteins, carbohydrates and fats as well as more trace resources such as potassium, iron magnesium and phosphorous. This situation is of even greater interest given the Scottish Government's estimate that food waste arisings across the household and C&I sources is in excess of 1.35 million tonnes. However, the amount of food waste actually going into AD is only 125,000 tonnes³⁰ of the 183,980 tonnes which is re-used, recycled or composted (RRC). This indicates that the potential for biorefining is even greater given the volume of material that is not valorised.

³⁰ <http://www.zerowastescotland.org.uk/content/organics-reprocessing-industry-survey-2014-0>

Table 12: Waste material feedstock arisings

Material stream	Landfilled (Tonnes)	Recovered ³¹ (Tonnes)	RRC ³² (Tonnes)	Total (Tonnes)
Animal and mixed food waste	365,400	32,862	183,980	582,242
Animal faeces, urine and manure	156	117,431	9,615	127,203
Other wastes ³³	2,103,843	211,216	1,391,331	3,706,389
Paper and cardboard wastes	210,427	17,846	226,491	454,764
Rubber wastes	111	16,183	796	17,090
Vegetal wastes	55,670	5,101	574,148	634,918
Wood wastes	29,957	125,109	189,907	344,973
Grand total	2,765,564	525,748	2,576,268	5,867,580

³¹ Energy from waste

³² Re-used, recycled or composted

³³ Refers to all other waste that cannot be classified as wastes of interest to this project (e.g aggregates, metals and dense plastics)

Figure 7: Waste material feedstock arisings by local authority

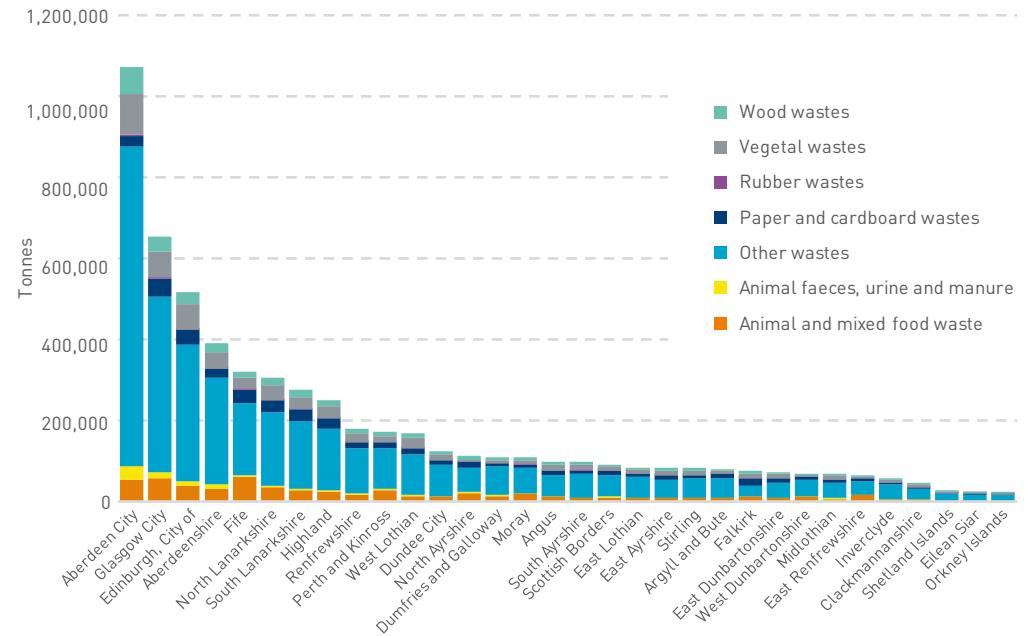
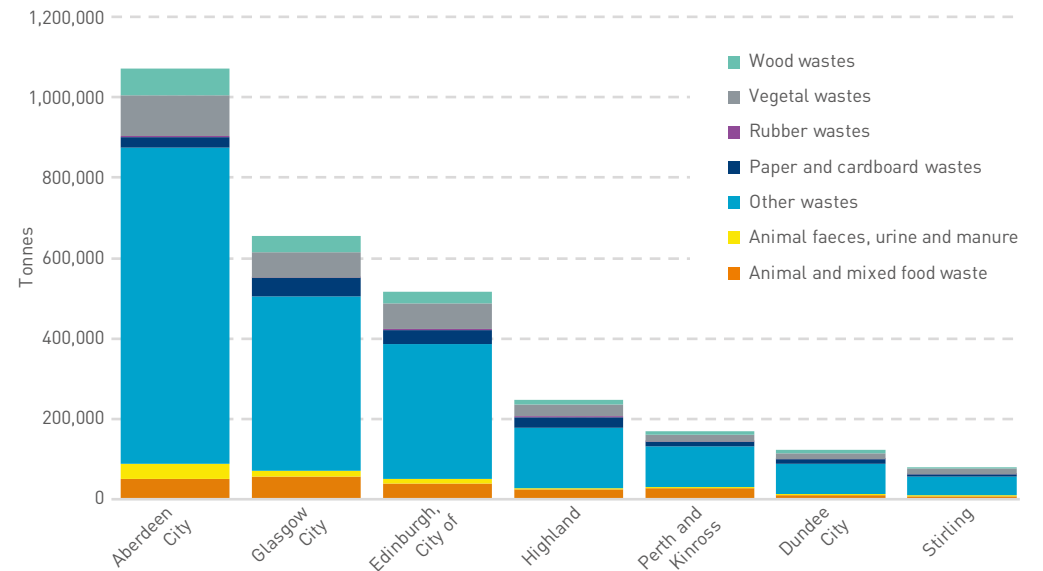


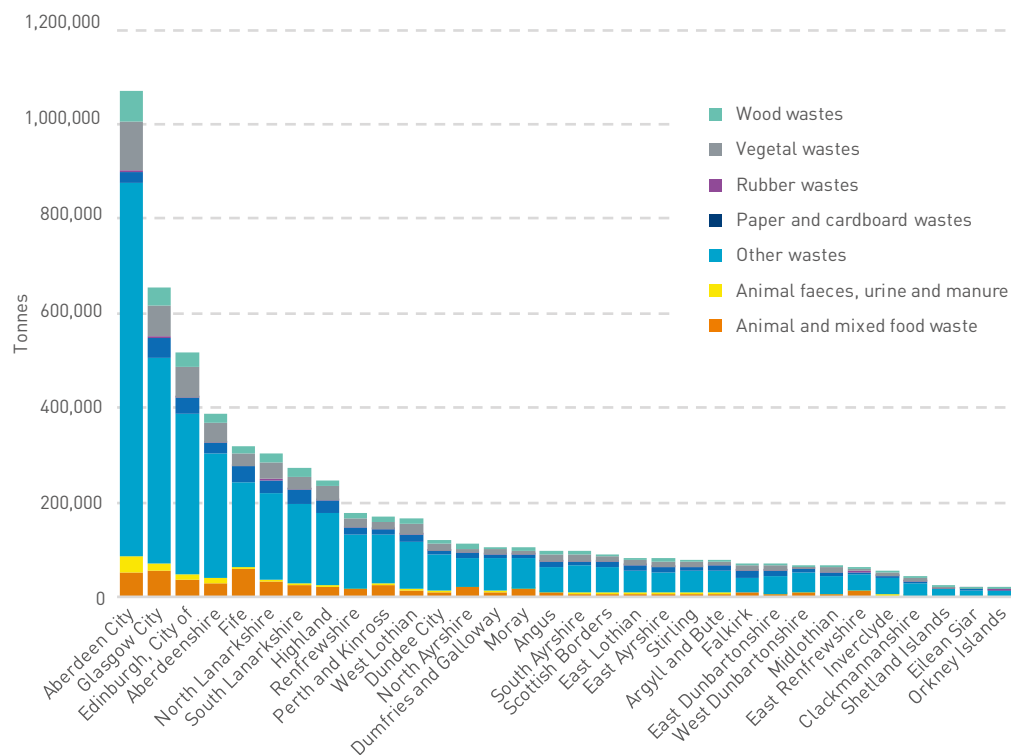
Figure 8: Waste material feedstock arisings by the 7 city authorities



The most prominent focussed arisings of these organic materials is in residential and commercial hubs of Aberdeen, Glasgow and Edinburgh, with the key driver of food waste being household and hospitality waste sectors. In these three hubs alone there are over 500,000 tonnes of organic materials available for use in biorefining should the process of extraction make economic sense.

A note from the graph above however is that the basis for apportionment of C&I waste is key in determining the ranking of interesting local authorities for assessment. In the case of the analysis above apportionment of C&I waste is based on Gross Value Added (GVA) value produced from each local authority which in the case of Aberdeen City is skewed by the value generated by the oil and gas industries. As a result of this 28% of C&I waste is apportioned to Aberdeen City with nearly a million tonnes of material added to the 97,000 tonnes of household waste. If C&I waste is apportioned by either employment or population then as expected Glasgow City and the City of Edinburgh would rank more highly as illustrated in Figure 9.

Figure 9: Re-apportioned C&I waste for waste arisings by local authority



8.2.3 Wastewater feedstocks

Wastewater material arisings or 'sludges' are defined as organic dry matter remaining after the de-watering process has been undertaken to reduce the moisture content of raw waste water. The dataset included within the modelling process provides a good estimation of the dry organic matter available across Scotland. Although not the most abundant in terms of tonnage, sludges can have high calorific value for further use, as well as contain trace metals and other valuable bioresources. The data set used to populate the model captured over 114,000 tonnes of dry matter equivalent, but only covers 19 of the 32 local authority regions and further assessment would be needed to ascertain whether the arisings are actually relate to the arisings of the wastewater or the sludge itself (i.e. is the wastewater transported for treatment). It is also suggested within this dataset that material recovered is spread to land as a cheap disposal option, but with limited value recovery. Only Glasgow City operates a recovery process sending dry matter for incineration.

Table 13: Sewage sludge feedstock material arisings

Material stream	To land (tonnes)	Incineration (tonnes)	Grand total (tonnes)
Sewage sludge	64,731	49,994	114,725
Grand total	64,731	49,994	114,725

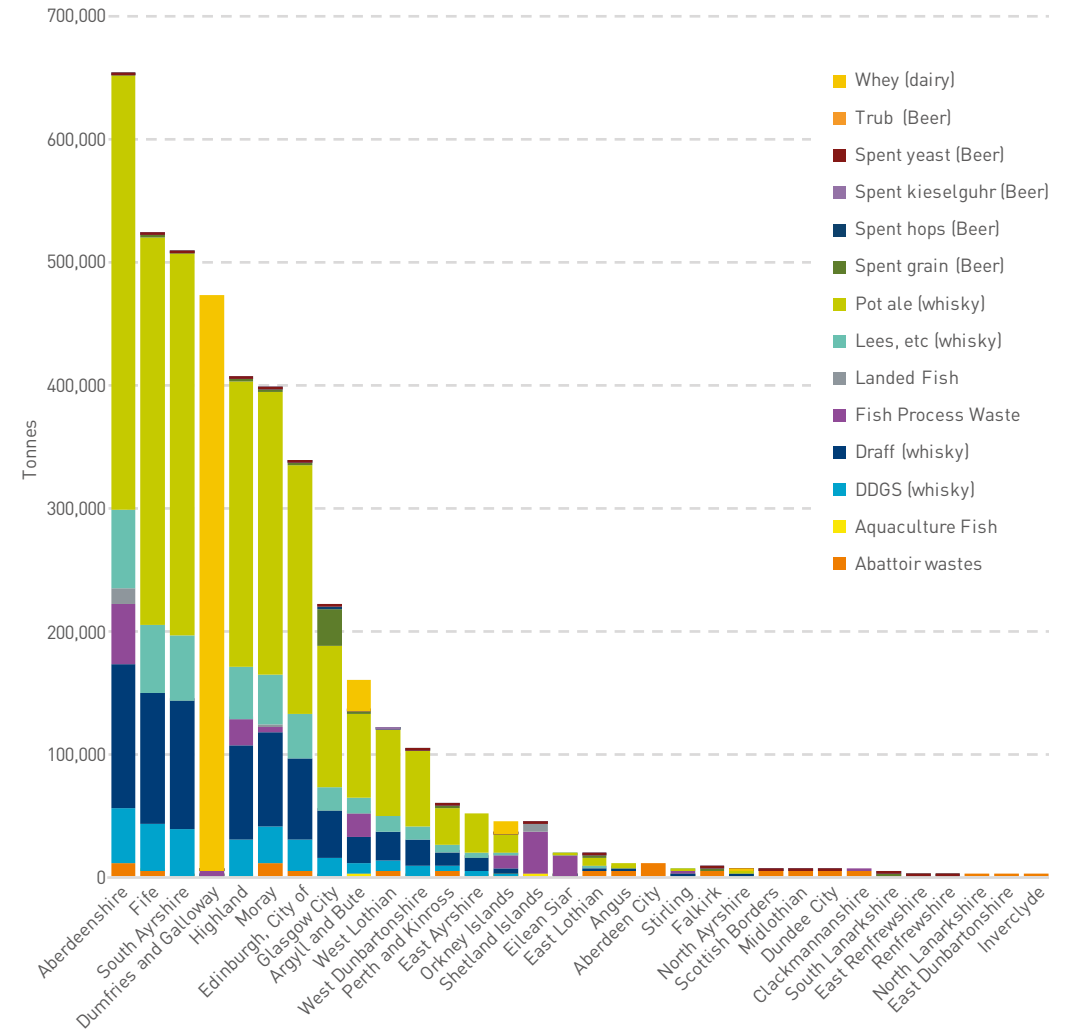


Table 14: By-product feedstock materials arisings

Material stream	Grand total (tonnes)	Valorised used (tonnes)	Unused or landfilled (tonnes)
Abattoir wastes	108,269	108,269	–
Aquaculture fish	2,811	2,811	–
DDGS* (whisky)	254,000	254,000	–
Draff (whisky)	684,001	684,001	–
Fish process waste	160,250	160,250	–
Landed fish	24,400	24,400	–
Lees, etc (whisky)	361,001	–	361,001
Pot ale (whisky)	2,048,003	32,000	2,016,003
Spent grain (beer)	48,700	48,700	–
Spent hops (beer)	428	428	–
Spent kieselguhr (beer)	414	–	414
Spent yeast (beer)	3,653	–	3,653
Trub (beer)	–	–	–
Whey (dairy)	505,486	493,000	12,486
Grand total	4,201,416	1,807,859	2,393,557

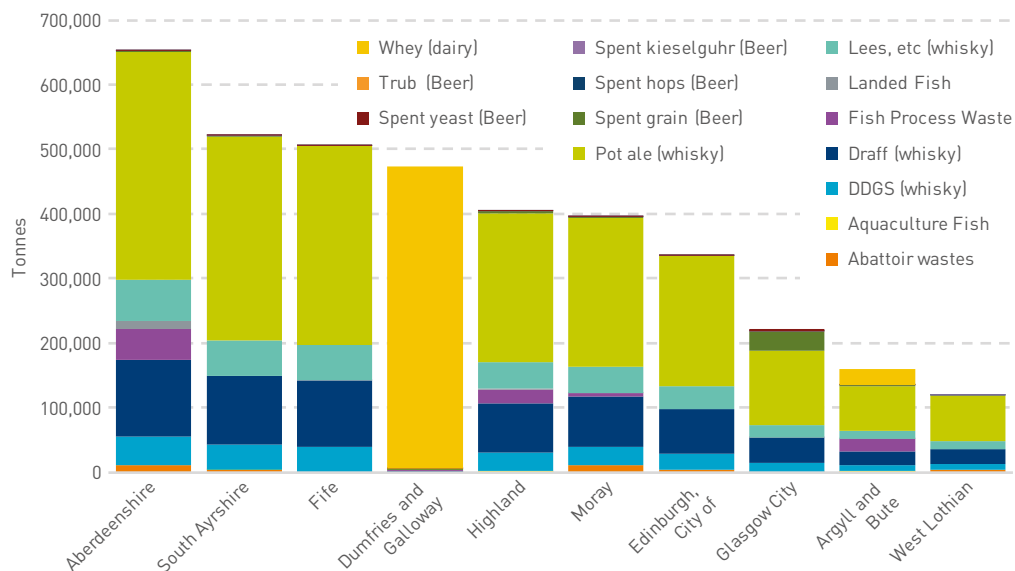
*Distillers Dark Grains Soluble

Figure 11: By-product feedstocks by local authority



At a local authority scale, the mix of regions with large by-product arisings is different to that of waste materials and sludge materials with commercially productive hubs becoming the focus of material arisings rather than population being the key driving force. Data presented this way also uncovers interesting potential locations for biorefining, with processes linked to particular sectors such as brewing and distilling (in Aberdeenshire, Fife and South Ayrshire) or whey production (Dumfries and Galloway).

Figure 12: By-product feedstocks by local authority (focus on the top ten authorities)



8.2.5 Agricultural feedstocks

Agricultural feedstocks represent the largest industries from which feedstocks for biorefining could be available with the key issue not being the value of the material available, but accessing these feedstocks. Most material arisings are used for alternative functions, such as animal feed and soil improver products, or are not captured/collected (e.g. ploughed back).

Table 15: Agriculture feedstock materials arisings

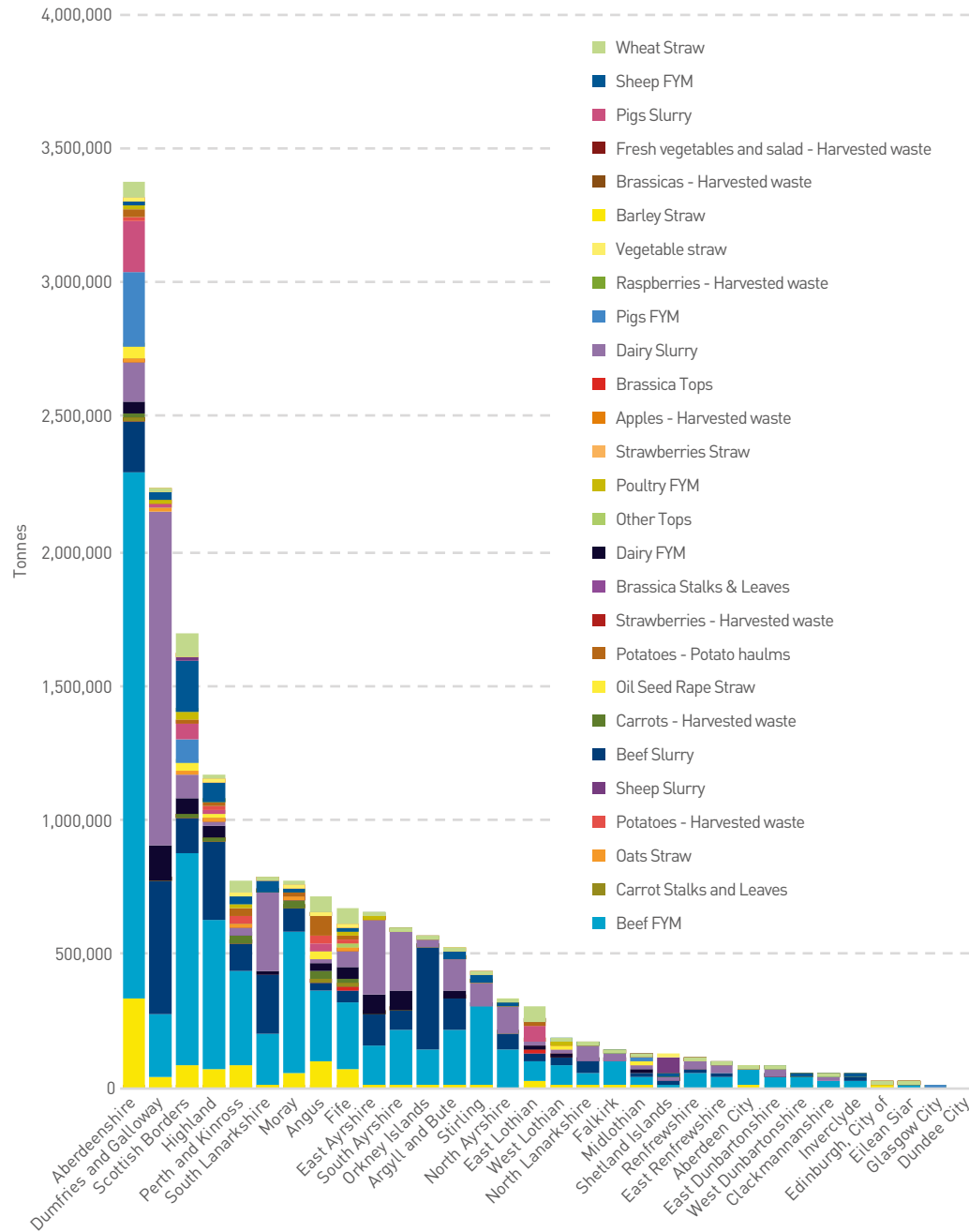
Material stream	Grand total (tonnes)	Valorised used (tonnes)	Unused or landfilled (tonnes)
Apples – harvested waste	448	224	224
Barley straw	957,417	916,723	40,694
Beef farm yard manure (FYM)	6,827,085	6,827,085	–
Beef slurry	2,568,163	2,568,163	–

Table 15 (continued): Agriculture feedstock materials arisings

Brassica stalks and leaves	3,626	3,626	–
Brassica tops	38,496	38,496	–
Brassicac – harvested waste	4,880	2,440	2,440
Carrot stalks and leaves	47,475	47,475	–
Carrots – harvested waste	136,671	68,336	68,336
Dairy FYM*	560,069	560,069	–
Dairy slurry	2,994,603	2,994,603	–
Fresh vegetables and salad – harvested waste	170	85	85
Oat straw	89,741	53,340	36,402
Oilseed rape straw	152,961	75,934	77,027
Other tops (turnip etc)	5,979	5,979	–
Pig FYM*	378,652	378,652	–
Pig slurry	357,426	357,426	–
Potatoes – harvested waste	132,062	66,031	66,031
Potatoes – potato haulms	203,538	203,538	–
Poultry FYM*	133,834	133,834	–
Raspberries – harvested waste	557	278	278
Sheep FYM*	528,182	528,182	–
Sheep slurry	59,682	59,682	–
Strawberries – harvested waste	4,104	2,052	2,052
Strawberries straw	3,758	3,758	–
Vegetable straw	69,055	69,055	–
Wheat straw	460,162	277,809	182,352
Totals	16,718,795	16,242,874	475,921

*FYM = Farm Yard Manure

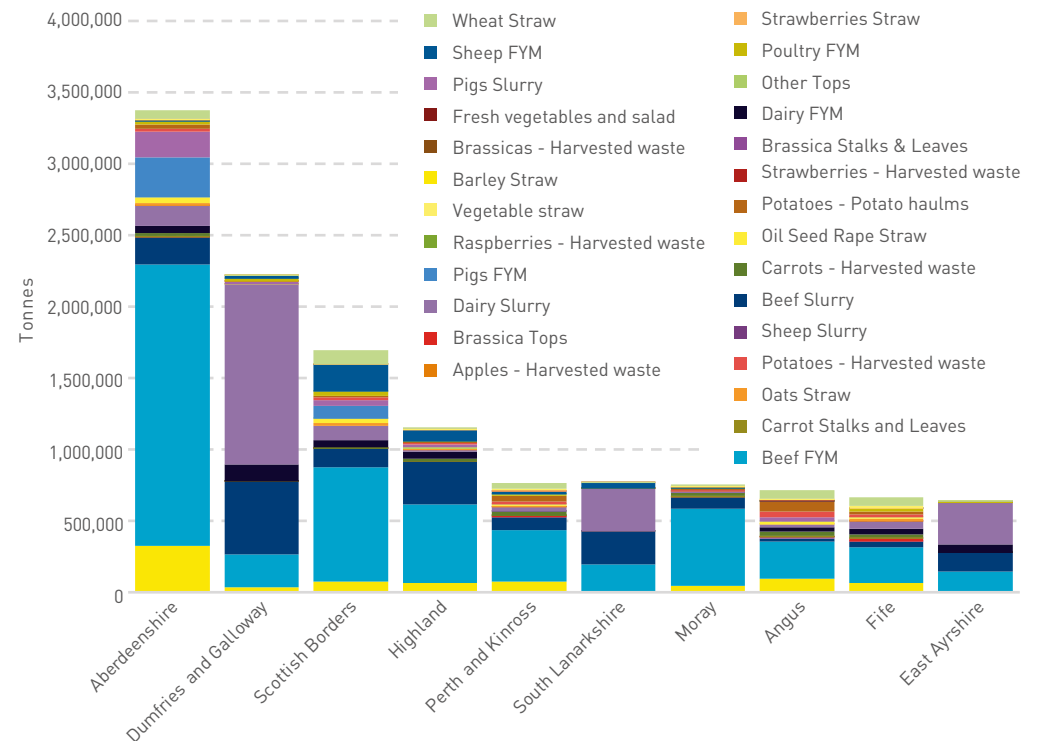
Figure 13: Agricultural feedstocks by local authority



Similar to by-products, agricultural hubs around Aberdeenshire and Dumfries and Galloway provide potentially large quantities of material for biorefining. There are a number of agricultural resources that are of interest as a result of their large volumes or as a result of being unused – or both. For example, farm slurry and manure arisings across the main enterprise types of: beef, dairy, poultry, pig and sheep accounts for more than 14 million tonnes. In addition, some on-field and harvested waste material are also of interest given their volumes and biochemical composition, namely carrots and potatoes (136,000tonnes combined).

In addition, there is the potential that some of the material arising from the agricultural sector, although ‘valorised’ - utilised for uses such as soil improver on farm or used as a substitute for animal feeds, will achieve a low value and a higher value could be achieved through biorefining opportunities. Again, the bioresources data model provides the ability to explore these bioresources with regards to not just the material arisings, but also the potential current use value, to see if biorefining could support greater value generating activities.

Figure 14: Agricultural feedstocks by local authority, focus on top ten





8.2.6 Bioresource arisings – example of protein

The bioresource data model also allows for specific biochemical components to be reviewed. Table 16 gives a summary of protein arisings across Scotland. Key in the presentation of this data is that the model provides the ability to rank the bioresource arisings not only by its material source but also on its current market value (based on the value paid for feedstocks). This proxy value generated by the modelling process therefore should allow biorefining industry entrants to high level analyse which feedstocks would be cost effective to refine and which are not.

Table 16: Summary of Protein arisings from current material feedstocks within the model (shortened to materials with protein arisings of greater than 200 tonnes)

Material feedstock/current destination	Protein arisings (tonnes)
Draff (whisky)/animal feed	142,956
Distiller's dried grains with solubles (DDGS) (whisky)/animal feed	75,375
Pot ale (whisky)/to sea and rivers	69,552
Animal and mixed food waste/landfilled	16,906
Spent grain (beer)/animal feed	12,159
Animal and mixed food waste/RRC*	8,512
Whey (dairy)/animal feed	3,763
Potatoes – potato haulms/to land	3,502
Spent yeast (beer)/to sea and rivers	1,786
Animal and mixed food waste/recovered*	1,520
Pot ale (whisky)/pot ale syrup	1,104
Carrot stalks and leaves/to land	817
Brassica tops/to land	662
Carrots – harvested waste/animal feed	636
Carrots – harvested waste/landfill	636
Whey (dairy)/digestion	205
Grand total	340,858

* Re-used, Recycled Composted

This analysis of current market values of feedstocks is illustrated in Figure 16 for protein materials. From this analysis we can see that due to high costs of landfilling food and organic material, this is the most cost effective feedstock to target first, with the current value of protein set at over £1,500 per tonne (depending on type, function and nutritive value). What this analysis suggests therefore is that if a biorefinery can pay for food waste material, refine it for a price of less than £1,500 per tonne of the protein content within it, then they should be able to overcome economic barriers to securing this feedstock. Clearly biorefineries should not only be able to provide a cheaper solution for disposal, but also a lucrative avenue for value generation from feedstocks and their associated chemical components. However what the analysis also demonstrates is that feedstocks with low economic barriers such as food and organic material currently landfilled, incinerated or digested are also lower in arisings with only an estimated 25,000 tonnes of protein available from these feedstocks (shown by the width of the bars in figure 16). As a result the opportunity exists to produce large quantities of chemical components by biorefining lower value material, such as pot ale which is currently disposed of to sea, will also need to be reviewed. It is worth bearing in mind, however, that the biorefining process, for example for protein will, by default, also enrich the remaining component and therefore potentially generate two (or more) higher value components.

Figure 15 provides a geospatial overview of the protein arisings mapped across Scotland. The map clearly highlights a number of the geographical 'hot spots' where there are high concentrations of protein arisings, namely: Aberdeenshire, Fife, Ayrshire, Highlands and Islands and to a lesser extent across the central belt.

Figure 15: Geospatial mapping of Protein arisings from current material feedstocks across Scotland

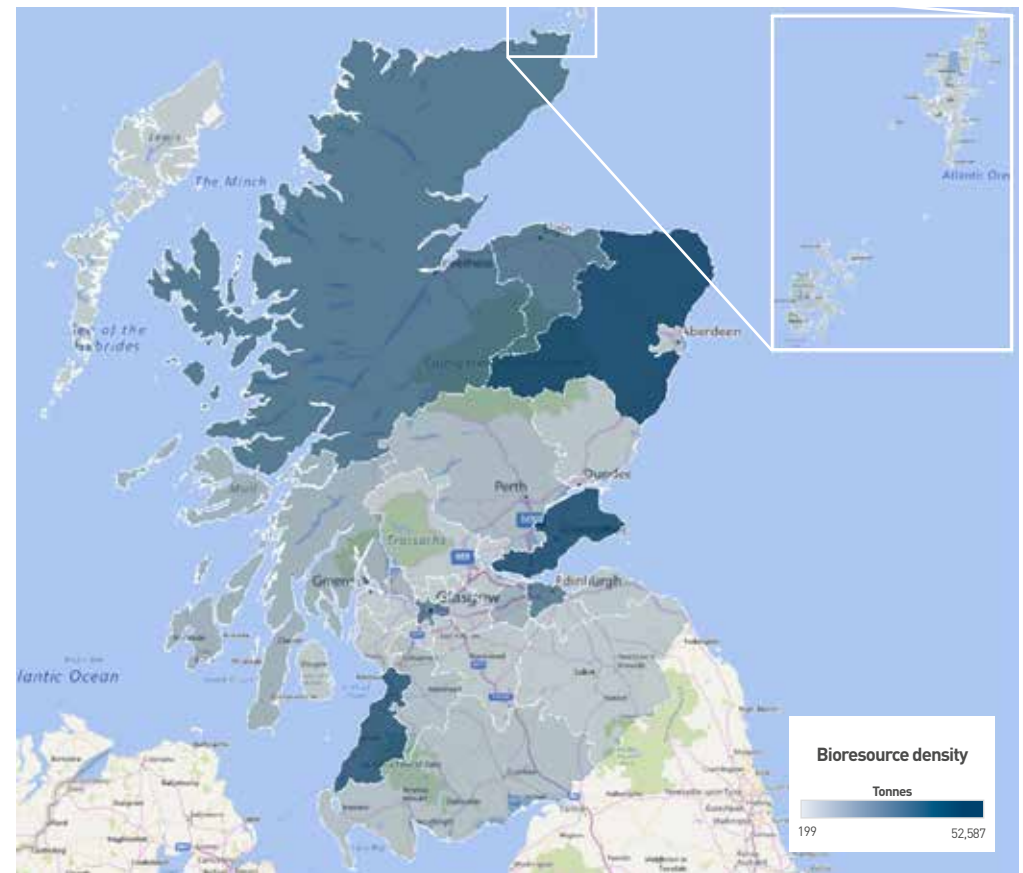
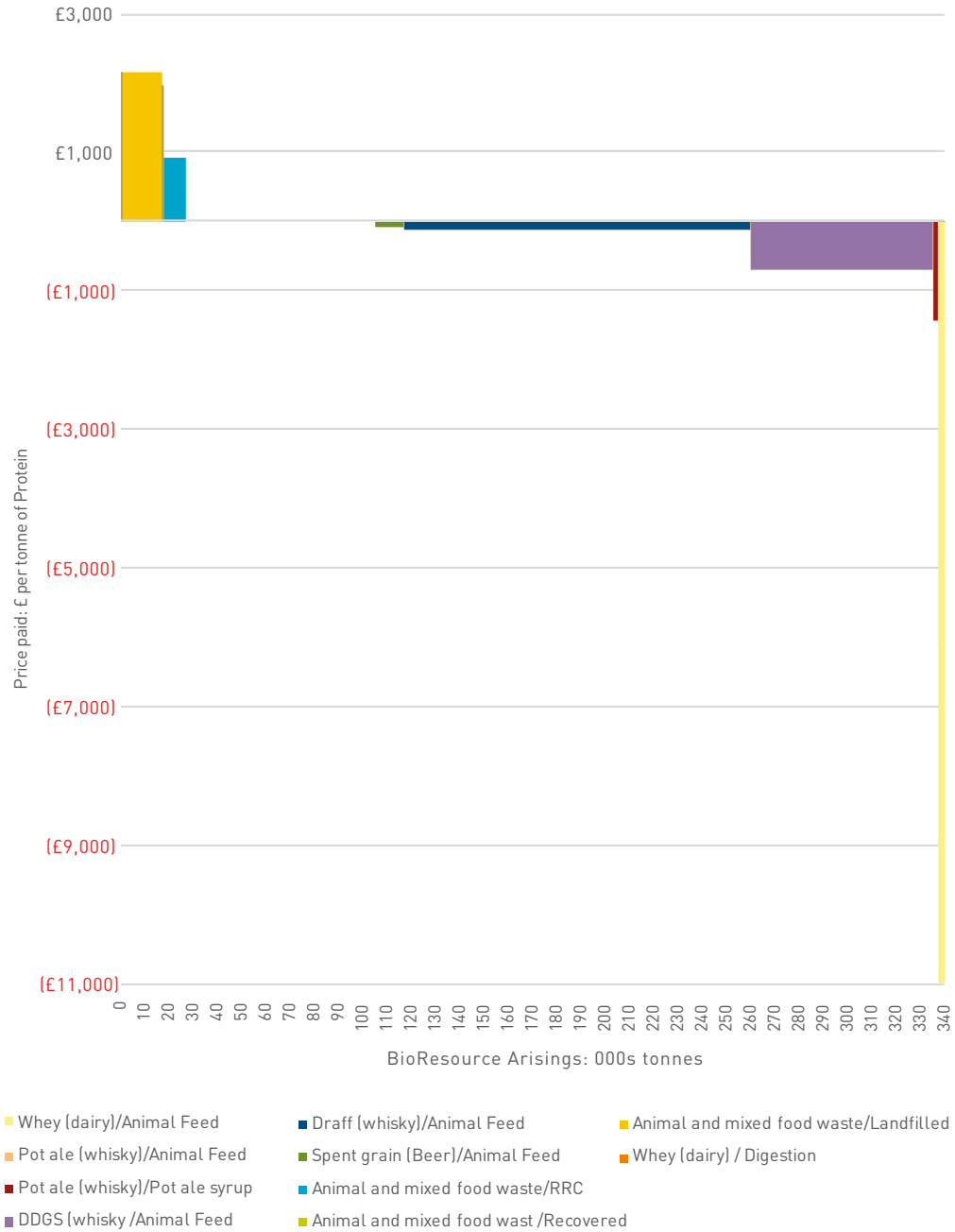


Figure 16: Price curve for protein refined from a range of feedstock materials

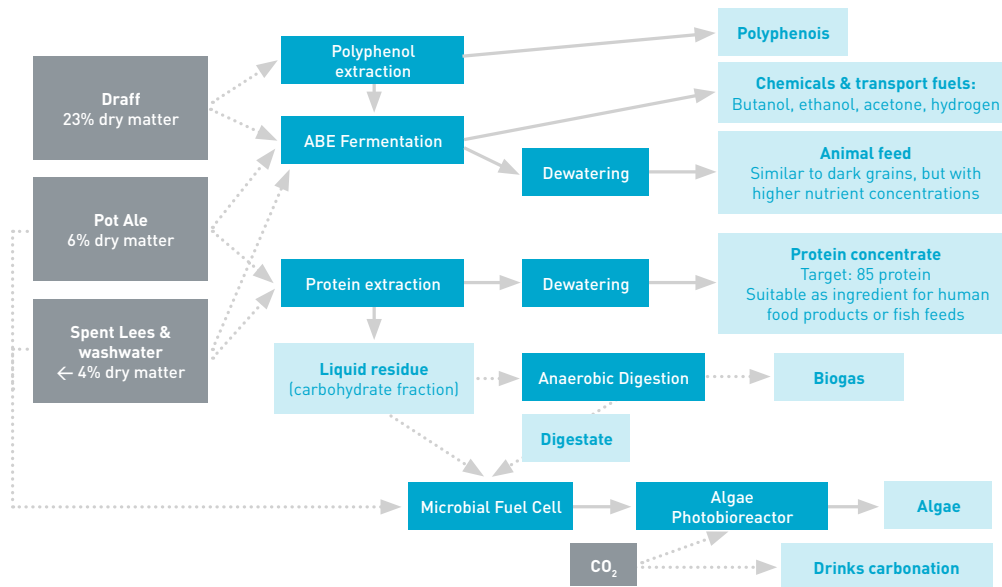


9 Opportunities for biorefining technologies

9.1 By-products from whisky production

The by-products from the whisky making industry, namely draff, pot ale and spent lees have been identified as underutilised value streams, with over 2 million tonnes being disposed of to sea/land and 684,000 tonnes used as animal feed in Scotland (2015). These materials contain an abundant source of proteins and carbohydrates, which could be used in a variety of products. Potential higher value applications for the utilisation of distillery by-products are well documented and illustrated in Zero Waste Scotland's sector study; Beer, Whisky and Fish (see Figure 17).

Figure 17: Future uses for distillery by-products³⁵



Against the background of an increasing global protein shortage, one of the priorities for Scotland should be to help the sector develop opportunities to recover a significant proportion of the proteins within the 2 million tonnes that are disposed of to sea/land and loop them back into the food and feed supply chain. Horizon Proteins³⁶ is conducting pilots to refine the process of extracting proteins from the distillery sector to use in high value applications.

Another important opportunity for the sector would be to convert the carbohydrates present in significant amounts in these resource streams into higher value chemicals through fermentation. Celtic Renewables – for instance, is in the process of commercialising a process to convert the sugars contained in draff and pot ale into acetone, butanol and ethanol using a strain of bacteria from the Clostridia Class. Celtic Renewables has demonstrated its technology and is now in the process of building a commercial-scale demonstration plant in Grangemouth with capacity to process by-products from a cluster of six distilleries in the area³⁷.

³⁵ Zero Waste Scotland, (2016), Sector study on beer, whisky and fish 2015, available online from <http://www.zerowastescotland.org.uk/BeerWhiskyFish>

³⁶ <http://www.horizonproteins.com/>

³⁷ Zero Waste Scotland, (2016), Sector study on beer, whisky and fish 2015, available online from <http://www.zerowastescotland.org.uk/BeerWhiskyFish>

In addition to acetone, butanol and ethanol, other higher value chemicals and products could potentially be produced from the carbohydrates present in the by-products from the distillery sector. GlaxoSmithKline (GSK), Croda and Ingenza and a number of academic centres in the UK are actively looking for opportunities to produce existing and new products from alternative sugar sources. However, some of these opportunities are still at an early stage of development so significant public and private sector support would be required to help industry, and in particular small and medium-sized enterprises (SMEs)/start-ups de-risk the development, demonstration and deployment of their innovations at commercial scale in Scotland.

As outlined in Figure 17, the major waste streams from a cluster of distilleries could in theory be converted into a variety of products at a central processing plant or biorefinery. This is exactly what Celtic Renewables are planning to do at their plant in Grangemouth, which will not only produce acetone, butanol and ethanol from a group of closely located distilleries but also a high-grade animal feed from the protein-rich by-product of their process. As part of their Courtauld 2025 initiative, the Waste and Resources Action Programme (WRAP) is funding a couple of projects in England and Wales aimed at helping companies in specific food and drink sectors in the UK identify and develop biorefining opportunities for some of their waste streams. Specific engagement with large food and drink manufacturers in Scotland could also be conducted to identify possible biorefining opportunities.

9.2 Fruit and vegetable waste

The by-products from fruit and vegetable processing have been identified as another underutilised feedstock with over 181,000 tonnes of harvested fruit and vegetables sent to landfill, each year, throughout Scotland. These losses occur at a number of stages in the pre- and post-harvest value chain including mechanical damage during harvest, spillage and spoilage during storage.

Fruit and vegetable by-products represent an abundant source of valuable bioresources including carbohydrates/fibres and low volume but higher value compounds such as flavours, colorants and vitamins (Prado et al., 2015). Using carrot waste as an example, Scottish company Cellucomp has successfully developed and commercialised a material called Curran® from the fibre/carbohydrates present in carrot and other root vegetable waste and is raising finance to build its first commercial plant. In addition, global suppliers of natural ingredients such as Diana Food and FMC Health and Nutrition sell colourings and health products derived from carrot and other vegetables.

However, fruit and vegetable tend to have a low bulk density and a relatively high water content, which makes transport in their raw state expensive. Another issue associated with fruit and vegetable waste is its perishable character or susceptibility to degradation. The development of localised (and perhaps mobile) pre-processing technologies capable of converting cost-effectively this type of waste into higher-density, aerobically stable, easily transportable material would therefore be critical to developing a sustainable infrastructure capable of working with significant quantities of such materials at a national level. This type of enabling research and Development (R&D) would be needed as part of a biorefining/industrial strategy as described in Section 10.

One opportunity would be to help companies in this sector identify and develop biorefining opportunities for some of their waste and by-products. The learnings of this study would suggest that support of this type would be most beneficial to the fruit and vegetable sector and specific food and drink manufacturing businesses in Scotland. In the meantime, what this study clearly highlights is that, for waste-fed biorefineries to flourish, new 'unconventional partnerships' between traditionally separate industry sectors need to be developed (e.g. agri-food businesses and chemical companies). Organisations like Zero Waste Scotland, Scottish Enterprise and the Industrial Biotechnology Innovation Centre already play a key role in bringing together companies generating significant amounts of waste in Scotland, potential end-users, technology providers, academia and open-access scale-up centres, regulators, policy-makers and investors to catalyse the collaborations require to build these new supply chains.



9.3 Animal and mixed food waste

Animal and mixed food waste has been identified as an underutilised waste with over 365,000t being disposed to landfill. The chemical make-up of this type of waste is usually quite complex, containing various amounts of carbohydrates, proteins, fats and other minor components such as phenolics, vitamins and flavonoids. Separating the most valuable components from this waste cost efficiently is therefore a major challenge. In addition, the chemical composition of animal and mixed food waste is unavoidably variable, making it a very challenging feedstock to biorefine.

A greater proportion of this waste could be sent to existing or new AD plants in Scotland to produce biogas and a fertiliser. A number of relatively well-established extraction, thermo-chemical and biological technologies could potentially be used to biorefine (a) mixed food waste and (b) mixed food waste combined with garden waste. However, because of the complexity of these waste streams, their high water content and the variability of their chemical composition, there are not any technologies at present that are likely to make economic sense at commercial scale. Targeted R&D could be utilised to investigate the potential to extract higher value components from this stream using innovative and novel processes like microwave technologies to break down cell structures.

Nevertheless, there is growing interest from industry and academia in developing new AD processes that will produce volatile fatty acids (VFAs) and/or alcohols (intermediates formed during the AD process) instead of biogas from various different types of organic waste including mixed food waste. For instance, Veolia have developed a new patented process at pilot scale to produce VFAs from organic waste through AD and convert them into polyhydroxyalkanoates (PHAs) while the University of Aberdeen is developing a process at lab scale to produce and isolate VFAs, alcohols and hydrogen from various organic waste streams. More work and public support would, however, be required to prove that this technology could be used to convert food waste into higher value products at scale. A next step could be a feasibility study looking at the potential of using this technology to biorefine mixed food waste in Scotland.

Alternatively, food waste could potentially be used to rear insects, as an alternative source of proteins for the feed and food sector. This concept is attracting growing interest from the academic world (e.g. PROteINSECT³⁸ project involving, amongst others, the University of Stirling) and the private sector (e.g. Ynsect in France, Millibeter in Belgium). However it is important to note the regulatory barriers. Since the BSE crisis, Europe enforces the TSE legislation (Regulation EC 999/2001), which prohibits the use of insects as a source of protein for animal feed for animals raised for human consumption.

However, several insect producing companies and stakeholders across Europe (including the PROteINSECT project consortium led by FERA) have been lobbying to make an exception for insect meal for the last few years and it is understood that changes to the EU legislation are being considered. Dutch bank ABN Amro, for instance, have recently published a report³⁹ in which they claim that the European Commission is preparing a vote on the introduction of insect meal in aquaculture diets through the regulation 56/2013 and a new legislation is expected to come into force in the third quarter of 2017. An interesting opportunity for Scotland given the size of the aquaculture sector in the country and the known shortage of protein globally (even though the impact of Brexit on such legislation remain unknown). Also opportunities exist to utilize insect protein and oils in other applications not including food for human consumption. The growth of the insect rearing sector is best reflected in the growth of the Black Soldier Fly which has increased from 7,000 tonnes wet weight in 2014-2015 to 14,000 tonnes in 2016.⁴⁰

However, more work would be required to assess the applicability and potential value of this type of approach to the Scottish economy. It would also be important to review how the existing policy and legislative landscape might impact on the commercialisation of products derived from insects; perhaps the market will not be in the UK but there is an increasing global market. It is worth mentioning that, the Woven Network was recently established in the UK to connect entrepreneurs, researchers and others working in the role of insects in the human food chain across the UK.

³⁸ <http://www.proteinsect.eu/>

³⁹ <http://www.allaboutfeed.net/New-Proteins/Articles/2016/12/Insect-meal-allowance-expected-in-2020-68992E/>

⁴⁰ <http://www.allaboutfeed.net/New-Proteins/Articles/2016/12/Insect-meal-allowance-expected-in-2020-68992E/>

9.4 Organic and waste-based fertilisers

More and more manufacturers in the EU are developing innovative fertilising products including nutrients or organic matter recycled from bio-waste. The existing Fertilisers Regulation⁴¹ ensures free movement for traditional inorganic fertilisers typically made of mined or synthetic raw materials but it does not include a clearing procedure for organic fertilisers. As a result, around half of all fertilisers produced stay in the country where they were produced. This is the case for virtually all fertilisers produced from organic materials, such as animal by-products or other agricultural residual products, or recycled bio-waste. Inorganic fertilisers have therefore a competitive advantage which hampers innovation and investment in the circular economy. Considering that processes for producing traditional inorganic fertilisers are often energy consuming and CO₂-intensive, easier market access for organic fertilisers can also bring environmental benefits. As such, the European Commission is planning to bring organic fertilisers within the scope of the Fertilisers Regulation and grant access to CE marking⁴². By affixing the CE marking to a product, a manufacturer declares that the product meets all the legal requirements and it can be traded freely across the EU. The Regulation will create a level playing field for fertilising products. At the same time, new common requirements for quality, safety and labelling will guarantee a high level of safety and environmental protection of all CE marked fertilising products.

Given the environmental benefits of reducing the emissions related to producing inorganic fertilisers, organic fertiliser release nutrients as they break down improving the structure of the soil and increase its ability to hold water and nutrients. The opportunity exists to work closely with the agricultural sector to assess the potential to generate significantly more organic fertiliser for domestic and international use.

⁴¹ <http://ec.europa.eu/growth/sectors/chemicals/legislation/>

⁴² <https://www.gov.uk/guidance/ce-marking>

9.5 Other waste streams

Other waste streams that were either not covered in this study (forestry waste) or 'hidden' within a mixed waste stream are worth investigating are described in the following sections.

9.5.1 Forestry waste

Scotland generates significant quantities every year of this type of waste, which could be valorised. With the global demand for paper decreasing, the forestry industry is actively looking for alternative outlets for their products and by-products. This is an area where Scotland could learn from the experience of countries like Sweden and Norway where the concept of biorefining wood has been developed for decades with companies/clusters like Processum and Borregaard. This is also an area where continuous support for the development, demonstration and deployment of new technologies being developed by academia and the private sector could also have a significant impact.

9.5.2 Bakery waste

Bakery waste represents a substantial untapped source of starch and, to a lesser extent, proteins, which is going into feed and AD, but could be converted into higher value food and non-food products through fermentation. The Jaw Brewery Limited and Thomas Auld and sons Ltd (Aulds bakery)⁴³ in Glasgow, for instance, have recently started to produce beer from surplus bread while GlaxoSmithKline (GSK), Veolia and the Biorenewables Development Centre are assessing the potential of producing one of GSK's pharmaceutical actives produced in Scotland from bread by-products instead of wheat grain. Some technologies to convert sugar-rich by-products into higher value products through fermentation are being developed at laboratory and pilot-scale, but more work (and public support) would be required for these technologies to be proven and deployed at scale.

9.5.3 Coffee grounds

Coffee grounds are particularly rich in oil and nitrogen and are attracting a growing interest from industry. Glasgow based Revive Eco Ltd are developing a process to extract oil from coffee waste (grounds) collected in Scotland while, in London, Bio-bean Ltd have entered into a partnership with Costa Coffee, which will see 3,000 tonnes of Costa Coffee's waste coffee grounds from 800 different stores across the UK be turned into biofuels, biochemical and new solid fuel. More work would be required to assess the accessibility of coffee grounds in Scotland and how similar initiatives could be implemented across the country.

⁴³ <http://www.glasgowlive.co.uk/news/glasgow-news/award-win-glasgows-pioneering-project-12461326>

9.5.4 Mixed food and garden waste

With more local authorities opting to provide a mixed garden and food waste collection service more of the mixed organic stream will become available. Because garden waste is very varied in its composition it is mostly used to produce compost, even when combined with food waste. However, there is growing interest from councils and waste management companies in using dry Anaerobic Digestion (AD) as a way to turn high-solid organic waste such as garden waste into biogas. Unlike wet AD (process used by most AD plant in UK), dry Anaerobic Digestion is a relatively new technology and, although more than five dry AD plants have been built in the UK to date to enable co-mingled collection of food and garden waste (including one by Fife Council), more R&D work would be required to improve the performance and encourage the more widespread uptake of this technology in Scotland. Similarly to traditional liquid AD technologies, dry AD systems could also potentially be modified to produce higher value Volatile Fatty Acids (VFAs) and alcohols instead of biogas from food and garden waste. Again, more work would be required to assess the potential of dry AD to generate higher value products and bring the technology to market. To improve the performance of such a process, new pre-treatment technologies might also need to be developed, in parallel, to increase the digestibility of garden waste. Much could be learnt from the farm AD sector in this respect, as a number of technologies are being developed across Europe to pre-treat (recalcitrant) straw. A possible project could be to conduct a feasibility study looking at the potential of using dry AD to biorefine garden and food waste in Scotland.

9.5.5 Sewage sludge

The water industry in Scotland generate substantial quantities of this type of waste every year. Its recycling/valorisation is a major challenge for the sector, which is actively looking for new technologies to add value to this resource. A number of initiatives in Scotland and in the UK are aiming to catalyse knowledge exchange between academia and the industry and technology transfer between small to medium sized enterprises (SMEs)/technology providers and the main water and wastewater industry. A review of how these different initiatives might complement each other, develop better links and common strategies to boost their impact and share best practice with similar projects/initiatives across the world could be beneficial.



10 Observations and opportunities for Scotland

10.1 Data and terminology

It is evident that there is some confusion across stakeholders around definitions and terminology. As examples: co-product versus by-product, which waste processing options count as prevention as opposed to treatment and when materials is considered a by-product and when is it a waste. To help promote the concept of the bioeconomy we have provided consistent terms throughout this document. To support this aim we have included a glossary of terms and definitions within this report.

Individual sites, or point sources with large bioresource arisings ('hot spots'), are difficult to identify because at present sites are not required to provide information relating to their waste arisings (or raw material use), including by-products, in a way that is consistent or accessible. A good example is the data captured from regulated industrial sites (e.g. PPC licensing arrangements) which are really designed to capture emissions or pollutants to air or water rather than understand raw material inputs or waste arisings. This became apparent following a review of the Scottish Pollutant Release Inventory (SPRI) where it is generally not possible to gain a good understanding of the wastes generated at a particular site.

Opportunity: Regulated sites could share more detail on the amounts and types of raw materials used and wastes/by-products arising including their fate.

Address the issue of 'Hidden' bioresources. The research identified a number of bioresources that do not appear on any available data set. The reason for their lack of visibility is due to the fact the waste data system is designed to capture 'waste' and not resources. As such, by-products and any material treated or disposed of under an

exemption are not captured in a way that is accessible. In addition, agricultural residues are not captured within the waste framework and so they are not visible. To be clear, this is not a suggestion to include agricultural residues within the waste regulations as this would not be appropriate.

Opportunity: There are many bioresource streams that would be attractive to the biorefining and wider bioeconomy and it would be helpful to have an increased understanding of the quantity and quality and fate of these arisings.

10.2 Bioresources

The bioresource data model outputs suggest a number of interesting volumes of biochemical components (proteins etc.) which will help inform future research opportunities. There is a huge potential for biorefining given the 27 million tonnes of materials arising across Scotland.

Key opportunities identified as part of this study include utilisation of by-products from the distillery sector with used cereal grains having an abundance of carbohydrate with potential for fermentation into chemical compounds of sorbitol glucosamine and levulinic acid. Also, food waste provides a very attractive volume of valuable components such as: fibre, functional proteins and carbohydrates although the mixed nature of this stream will create a challenge in accessing the components but biorefining technology advances, such as countercurrent purification linked to molecular membranes, could see this problem significantly minimised. Agricultural residues also provide a large tonnage of bioresource which at present is underutilised with over fruit and vegetables being disposed of or not fully valorised, each year, across Scotland.

The outputs of the bioresource data model should be viewed through the lens of what is usable in terms of accessibility – geographically accessible (transportation costs and ability to store the bioresources) and technical availability (can the biochemical components be captured (i.e. protein removal from pot ale)).

The data covering animal and mixed food waste suggests that there are significant losses of materials from estimated arisings to those which are actually managed. Circa 1 million tonnes is lost or unaccounted for resulting in an economic loss to Scotland. There is also over 365,000t of animal and mixed food waste being sent to landfill which indicates that the Waste (Scotland) Regulations 2012 are not yet being adopted well as intended. Looking ahead, this also means that this 365,000 tonnes of biodegradable material will no longer be able to be disposed of to landfill given the biodegradable landfill ban for Municipal Solid Waste coming into force in 2021.

Opportunity: A wider and more thorough insight into the location and quantity of C&I food waste arisings that are generated and collected would inform future bioeconomy opportunities.

The model suggests there are meaningful concentrations of bioresources across Scotland which result from population density and also specific industrial or agricultural practices (i.e. agricultural enterprise types – dairy in Dumfries and Galloway, and cereals in the east).

Opportunity: Establish biorefining potential in geographic ‘hotspots’.

The significant amount of organic bio-waste and by-products arising in Scotland have the potential to be utilised ideally via biorefining, then as an organic soil enhancer/fertiliser.

Opportunity: To work with the agricultural sector to assess the potential to source material and utilise significantly more organic fertiliser for domestic use.

A barrier to the valorisation of mixed animal and food waste is the lack of quality composition analysis, particularly mixed food and animal waste.

Opportunity: Improve understanding of mixed food and animal waste stream through targeted composition analysis of specific bioresource streams.

The report shows that there are meaningful amounts of waste materials arising in similar geographic areas - sewage sludge, macro algae and agricultural residues for example. There is an opportunity to explore the suitability of certain bioresources with the aim of creating biorefining opportunities but also valuable agricultural fertiliser/soil improver perhaps utilising, macro-algae, sludge, farm yard manure. With regard to sewage sludge, co-digestion is not allowed under the existing certification scheme and so any further application/use would need to be done under a waste management licence and exemption which would need to be renewed each year.

Opportunity: Explore the possible regulatory barriers and opportunities, to support biorefining, co-location of services and greater application of organic fertilisers to land.

Inclusion of further waste streams – Discussions held around potential additional feedstocks available and also the value of potentially breaking down material streams at a more granular level for example bakery waste or coffee grounds.

Opportunity: Create a complete data set of bioresources in Scotland and to include streams that were outwith the scope of this report, including forestry residues and macroalgae.

Opportunity: Explore arisings of specific sector waste streams if they prove to be of interest for biorefining, examples being coffee grounds, bakery waste and carbon captured from industrial sources.

There is an opportunity for biorefineries to use excess renewable energy or utilise potential wasted heat. As bioresources tend to have a high water content or require energy as part of the pre-treatment or for the biorefining process itself there will be value in exploring further how this energy need could best be provided and support wider low carbon and renewable heat policy objectives.

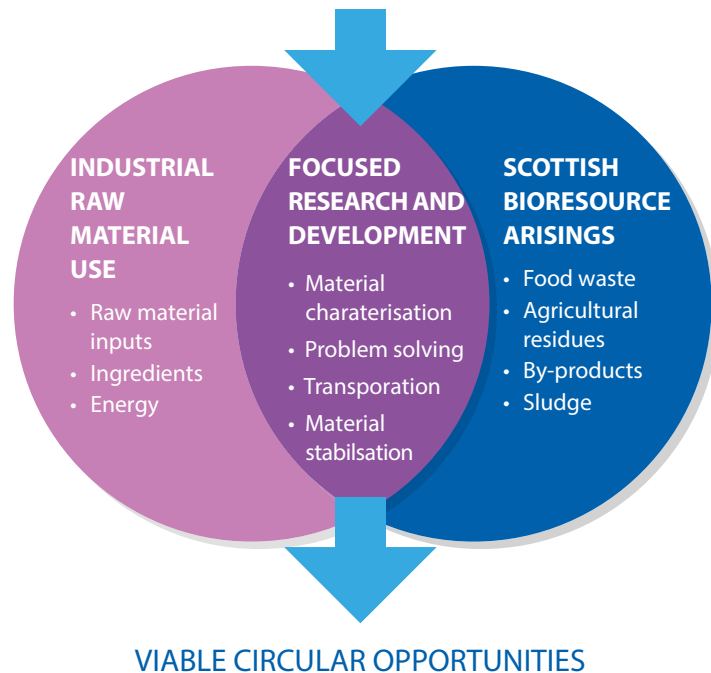
Opportunity: Explore the synergies between biorefinery and energy.

10.3 Strategic opportunities

For the first time this study has highlighted the scale of the biorefining opportunity in Scotland across all waste and resource streams. To realise the opportunities further work will be needed to facilitate and support the transition of the bioeconomy. Our view is that this study has been unique and significant for the Scottish bioeconomy and timely in gaining an understanding of one side of the equation – the supply side – bioresource arisings. Further work will require to be undertaken to understand the demand side – industrial resource inputs. Figure 18 illustrates this.

Figure 18: A schematic of the challenges and opportunities for bioresource utilisation in Scotland

IDENTIFY RAW MATERIALS SUBSTITUTION OPPORTUNITY



It is suggested that a whole system strategic approach which takes account of the demand and the supply and importantly proactively engages both sides of the equation – working with industry to understand the potential to substitute raw material inputs into their processes with available or potentially available bioresources. To facilitate this, focussed research and development will be needed to identify and invest in enabling technologies like de-watering and resource stabilising techniques to aid storage and transportation of bioresources which generally have a high water content.

Opportunities:

- Industrial engagement to understand the 'demand' for bioresources.
- Identify the key bioresources that offer the greatest potential to biorefining and explore the model outputs further with stakeholders to discuss data accuracy and access to further financial information.
- Use tailored outputs of the model to identify specific stakeholders to understand their interest and appetite to develop circular opportunities using bioresources such as proteins and carbohydrates.
- Develop a comprehensive database of all bioresources to support both waste producers and possible end-users/investors.

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