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An Assessment of the Opportunities for Re-establishing Sugar Beet Production and Processing in Scotland

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Contents

Executive Summary

Scottish Enterprise and partners have a strategic interest in further developing the industrial biotechnology (IB) industry in Scotland and have identified the sugar industry as a potential sector for development. Scotland is already using bioethanol, either as a transport fuel or an intermediate for biobased chemical production. Historically, 18 sugar beet processing facilities were operational in the UK with one facility in Scotland, located in Cupar, Fife. However, poor yields and the seasonality of supply led the plant to close in the 1970's, whilst more recently other facilities have been in decline, leaving just four operational plants processing 8.9 million tonnes per annum of sugar beet in the UK at present. Since the closure of the Fife facility, yields have significantly improved and markets diversified, thus increasing the profitability of sugar beet production and processing somewhat.

Scotland offers favourable conditions for sugar beet production in terms of day length and soil moisture availability. Eight percent of the Scottish land area is suitable for arable production, equating to 625,800 hectares. This land lies primarily in East Lothian, East Fife, East Perthshire, Angus and Morayshire. As a bulky crop with high moisture content, transport can be costly and therefore any processing facility would need to be located within or adjacent to key growing regions. Whilst the potential looks very good for sugar beet production in Scotland, it is not possible to be more conclusive about potential crop yields and quality, without conducting specific variety trials in the region to determine performance and input requirements.

A sugar beet refinery can involve a vast range of processing steps, and produce a vast array of outputs, from food, feed, fuel and chemicals, for example. In Scotland, due to pre-existing markets and competition from other producers, a sugar beet refinery would ideally focus on bioethanol and sugar syrups, for biofuel and biobased chemical production, but there would inevitably be additional co-product streams that could prove valuable as animal feed or for renewable energy generation. In order to overcome seasonality issues, it may be possible to import molasses into a sugar beet refinery, which can then be stored and processed to allow year-round production.

The agronomic and technoeconomic feasibility of re-establishing a sugar beet industry in Scotland was evaluated, taking into consideration yields, land availability, and the new and emerging markets for ethanol and the various co-product streams. A number of scenarios have been developed, based on fuel blend targets both now and in the future, and considering likely restrictions on land availability. A domestic sugar beet refinery could produce sufficient bioethanol to meet the current 4% and future 10% blend requirement in the petrol fleet, which amounts to 57 million litres in total. Using up to 20,000ha of land could be utilised, delivering over 170 million litres of bioethanol per annum from over 1.6 million tonnes of beet. Significant quantities of pulp could also be generated, and biogas could be produced from additional outputs in the absence of higher value market outlets.

There are clear benefits, in terms of Scottish and UK food and energy security and potentially also in terms of the resilience and security of Scottish farming businesses if sugar beet were to be produced and processed in Scotland. Sugar beet ethanol shows high land efficiency and also compares well to other crops in terms of water usage and broader sustainability, as well as offering high levels of employment, both in sugar beet production and processing activities. A Scottish sugar beet refinery will help both Scotland and the UK to meet sustainability and decarbonisation targets, as well as contributing to the wider bioeconomy, which is expected to double in size by 2030.

In order to pursue this opportunity, a number of recommendations for further work should be considered, as follows:

- Work with SRUC, SSCR at The James Hutton Institute or Scottish Agronomy, to establish variety trials in Scotland, to identify the best suited modern variety and to verify yield potential.
- Liaise with the Scottish Farmers Union, to engage with farmers in the early stages, to allow any concerns to be addressed from the outset.
- Identify any pre-existing grower groups or collectives who may have a particular interest in the sugar beet industry or be looking for solutions to address production challenges currently faced.
- Undertake further work on markets for co-product streams from bioethanol production, to ensure processing efforts are demand-driven; this will enable plant configuration and the range of outputs to be optimised from the outset, to deliver the most economically robust and stable development. A number of potential partners have been identified in this work, but others undertaking research or early stage development work may exist and should be engaged, should the project be pursued.
- Undertake further analysis on technical and commercial opportunities for importing molasses as a feedstock for the processing facility, to make use of the redundant capacity when sugar beet is no longer available, prior to the following years harvest; knowledge gaps remain on the technical requirements, specifically the compatibility and ability to switch between feedstocks, the environmental impact and lifecycle GHG emissions, and the economics of importing molasses to produce ethanol for local supply.
- Engage with operators at Grangemouth refinery, to explore options for supply of bioethanol, for local blending into the Scottish transport fleet.
- Engage with Scottish Government to communicate the contribution a local processing facility would make to decarbonisation targets, energy and food security objectives, and the wider Scottish economy.
- Seek public-sector support, in the form of supply chain facilitation, direct investment or specific legislative mandates for producing or using the biobased fuel, chemical and energy outputs from such a facility domestically.

SWOT Analysis

Strengths	Weaknesses
- Regions with long day length are best suited for optimal beet production - Lower soil moisture deficits in Scotland, put Scottish growers at an advantage in dry years - Beet fits well in a rotation, as a non-cereal break crop, alongside cereals, oilseeds, potatoes & veg - Gross margin compares favourably to spring-sown cereals - Vastly improved yields, could be as high as 70-90t/ha in Scotland - Net energy balance is higher than for wheat and other cereals (but lower than cane) - Up to 79% lifecycle GHG emissions saving when using natural gas and co-generating biogas - Low water footprint compared to other crops, including cereals, potatoes and maize - Blend limits are increasing, along with demand to deliver against RED renewable fuel targets - Up to 2,000 jobs created in sugar beet production and processing in Scotland	- Gross margin lower than winter cereals, oilseeds and potatoes - Potentially lower yields due to lower average day- and night-time temperatures - Late autumn harvest has potential to cause soil damage if poorly managed - Specialist harvesting equipment required; no current surplus capacity; costly machines - Concern from potato growers and processors who may see divergence of interests to beet - Significant energy demands and costs in dewatering beet, processing and extracting sugar - Transport costs can be significant and can hinder economic performance - Volatile ethanol price, closely correlated with oil price; import duties and trade protection measures also impact - Short harvesting period, concentrating processing and leaving 6-9 months of redundant capacity in sugar beet processing plant
Opportunities	**Threats**
- Increased fuel and energy security; secure internal market to mitigate against Brexit impact - Establish variety trials in Scotland, to select best suited varieties and verify yield potential - Lower farm carbon footprints and improve sustainability of the agricultural industry - Produce bioethanol from 'thin juice', as biofuel or biobased chemical feedstock, plus beet pulp as animal feed and renewable energy, or higher value outputs from other co-products - Production from 'thin juice' will reduce energy consumption and cost of processing - Up to 20kha of land could be utilised; equating to 3.2% of arable area in Scotland - UK consumed 744 million litres of bioethanol in 2017; 17% derived from beet, mostly from France - UK is a net importer of sugar; sugar demand is growing for fuel and chemicals - Closure of Vivergo Fuels leaves an ethanol capacity gap in the UK - Importing molasses to use as a raw material, to extend the processing period; global production is expected to increase by 19% in coming years	- Unknown yield potential as modern varieties have never been grown in Scotland - Sensitive to low soil pH, which is common of soils in Scotland - Abolition of quotas in 2017 caused a 30% increase in cropped area and 58% increase in production - Beet price has fallen by 20% since 2013 - Global ethanol production is expected to increase by 9.2% in the next 10 years - Low sugar prices are putting constraints on the production area; processors are cutting back - RTFO Crop Cap will limit biofuel production from crops to 2% under RED II - Tightening of GHG limits, to 65% for plants starting production after 1st January 2021

1 Current landscape analysis

Scottish Enterprise and partners have a strategic interest in further developing the already well-established industrial biotechnology (IB) industry in Scotland and have identified the sugar industry as a potential sector for exploitation. Scotland is already home to an oil refinery that imports bioethanol for blending, as well as a number of innovative SMEs developing IB technologies to produce biofuels and high-value products from sugar beet and its co-products. This report is intended to provide advice and analysis on the economic and environmental benefits that the development of a beet supply chain could potentially bring to the Scottish economy.

This section presents an overview of the current landscape for sugar beet production in Scotland and the UK, including current production and the history of sugar beet production in Fife, as well as an introduction to typical beet yields, crop varieties and the agronomy of sugar beet production. The aim of this section is the determine the likely competitiveness of Scotland as a beet-growing region and to quantify the potential scale of production, should the industry be reintroduced in future years.

1.1 100 Years of Sugar Production in the UK and Today's Market

Sugar beet production originated in Germany and France but was not grown on a large scale in the UK until the 1920's. By 1928 there were a total of 18 beet factories operating across the country, including one in Cupar, Fife. The Cupar plant was commissioned by the AngloScottish Sugar Beet Corporation and feedstock was amassed from across Scotland, from Morayshire to the Borders, with 1,100 hectares contracted in the first year [1]. Farmers were initially sceptical of the crop due to intensive labour requirements in the autumn period, the low tonnage achieved and high transport distances (and cost). The Cupar plant struggled financially in the 1930's [2][3] but the tonnage processed increased during the WWII years as farmers were mandated to grow beet; however, the factory eventually closed in 1972.

Today, following further rationalisation of the industry just four sugar beet processing facilities remain in the UK; all located in Eastern England and operated by British Sugar. Raw cane sugar is also refined in the UK by Tate and Lyle Sugars subsidiary ASR Group, which processes 1.2 million tonnes of sugar annually at its Thames Refinery in London.

UK production of sugar beet totalled 8.9 million tonnes in 2017, with a value of £229 million. The abolition of EU sugar quotas (which formerly acted to control the area of production and support prices) at the end of 2017 led to a 30% increase in cropped area and a 58% rise in production in 2017 compared to the previous year, as shown in table 1.

Table 1. UK sugar beet crop production statistics 2013-2017. Source: [4]

Parameter	Unit	2013	2014	2015	2016	2017
Crop area	kHa	121	117	84	80	107
Yield	t/Ha	70	80	74	71	83
Harvested production	kt	8,432	9,310	6,218	5,687	8,918
Value of production	£ million	270	315	173	150	229
Sugar content	%	17.5	17.2	17.3	17.3	17.8
Price	£ per tonne	32.0	33.9	27.8	26.3	25.7

Further information on the abolition of EU sugar quotas is given in section 3. According to provisional data from Defra [5], the cropped area of sugar beet further increased to 116 kHa in 2018 and production is nearing 1 billion tonnes. However, since 2013, the average price of sugar beet has reduced by 20%.

Data shows that the UK has dramatically improved the yield of sugar beet since the 1930's when yields were typically only 24 t/Ha [2]. A record yield of 112 t/Ha was achieved in Norfolk in 2017/18 whilst average yields increased 15% on the previous year due to favourable weather conditions, giving farmers attractive margins for the beet crop. It has been argued that further significant increases in yield are unlikely, but increased resistance to disease and degradation may reduce sugar losses and thus further increase returns [6]. Technologies and consultancy services for improving sugar beet crop varieties are available thorough companies such as Germains (Kings Lynn, Norfolk).

The two dominant sugar producers in the UK are British Sugar (mostly beet) and T&L Sugars (mostly imported cane), with a total estimated market worth £900 million. British Sugar has processing facilities at Bury St Edmunds, Newark, Wissington and Cantley. British Sugar is supplied by over 3,000 growers, supporting 9,500 jobs.

In Europe, sugar beet is used to produce a number of products in addition to crystallised sugar, including bioethanol, animal feed, biogas and bio-based plastics. As shown in Figure 1, the vast majority of beet is processed for sugar consumption in the food and beverage industry in the EU, with just 9% going to ethanol production and 4% going to the chemicals industry.

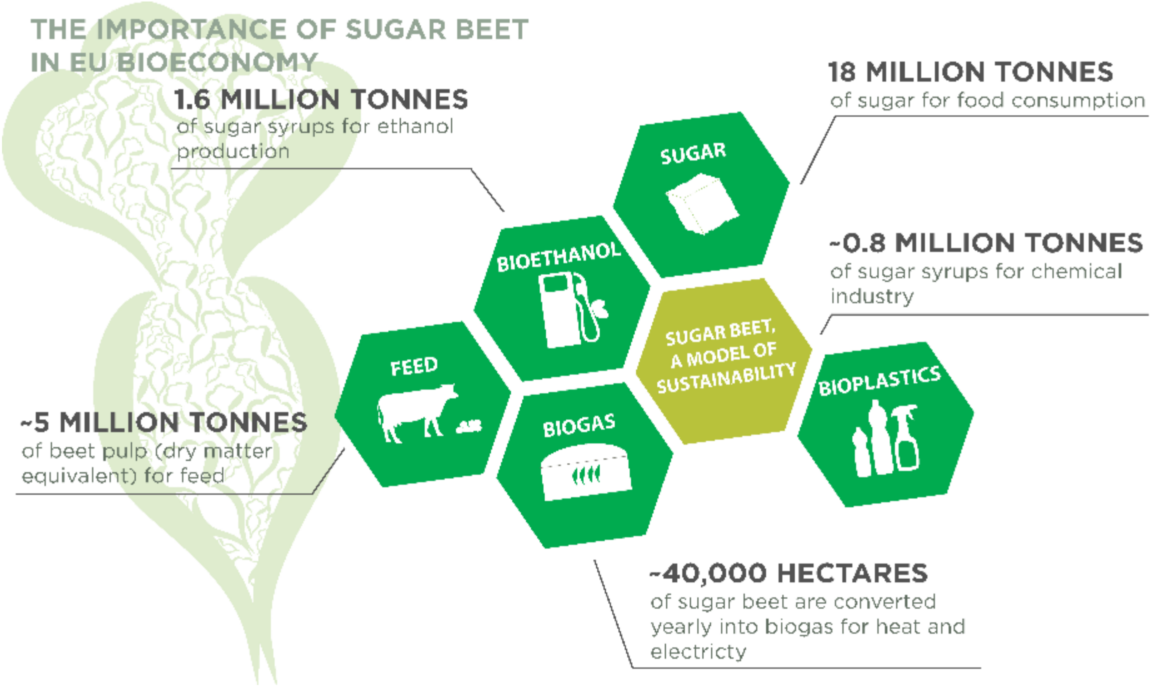

Figure 1. Use of sugar beet in different sectors of the EU bioeconomy (2017). Source: CIBE

As shown in Figure 2, UK production of refined sugar has remained fairly constant over the last 10 years, but exports have reduced by nearly two-thirds. However, this may have changed significantly since the abolition of EU sugar quotas during 2017; the 2018 data will provide the definitive position when it becomes available. Any new processing plant producing outputs such as bioethanol would have to be cost-competitive with plants which produce crystallised sugar, that could itself be used as a feedstock.

The retail price of granulated sugar in the UK was 76p/kg in February 2019[1], compared to a high of 104p/kg in April 2014 and a low of 60p/kg in May 2016. Depending on the sugar content, around 6kg of beet are required to produce 1kg of sugar (giving the equivalent of 167kg sugar per tonne of fresh beet).

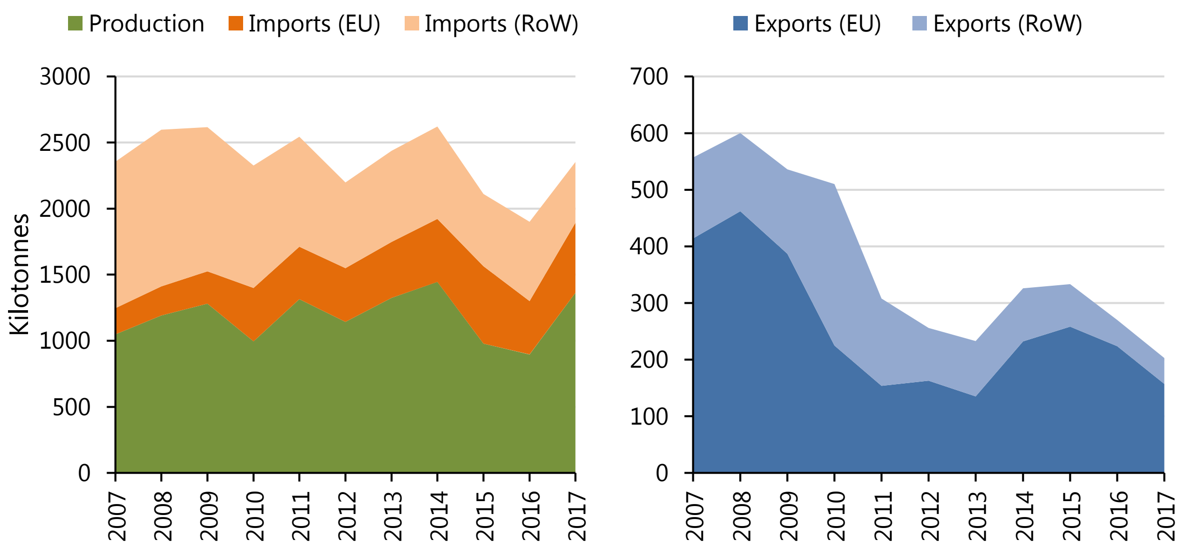

Figure 2. Domestic production, imports and exports of refined sugar in the UK 2007-2017. Data source: Agriculture in the United Kingdom

1.2 Potential for sugar beet production in Scotland

1.2.1 Sugar beet – history, physiology and basic requirements

Sugar beet is adapted to a wide range of climatic conditions, although it is primarily a temperate zone crop produced in the Northern Hemisphere at latitudes of 30 to 60°N, (the UK ranges from 51 to 56°N from London to Edinburgh which puts it towards the Northerly limit).

Sugar beet is sown in the spring in the UK and is harvested in the autumn and winter. The crop is not frost hardy. From sowing to complete leaf canopy cover usually takes 70 to 90 days from planting. Once the crop canopy is well established, the plant's resources are diverted into producing a robust taproot, the main sugar storage organ.

Optimal daytime temperatures are 15 to 27°C for the first 90 days of plant growth. Regions with long day length are most suitable for optimising sugar beet growth, thus the UK, including Scotland is ideal in this respect. The most favourable environment for producing a high quality, high yielding sugar beet crop from 90 days after emergence to harvest is bright, sunny days with 18 to 27°C temperatures

[1] Average monthly retail price from the ONS
https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/cznn

followed by night-time temperatures of 4 to 10°C, though the crop will grow and yield well in cooler daytime temperatures.

Decades of plant breeding and agricultural research to develop effective agronomic strategies have resulted in a crop with the potential to yield high tonnages of sugar-rich crops. The British Beet Research Organisation (BBRO) has established a highly effective research and development and knowledge exchange programme which aims to develop and implement best practice in sugar beet production [7]. Their collaborative approach continues to drive increased sugar beet yields and over the past 10 years average UK yields have increased by 25%. Today, yields of over 70 t/ha are not uncommon, where modern varieties are grown with best agronomic practice in appropriate weather and soil conditions [8].

1.2.2 Suitable land areas for sugar beet production in Scotland

Agricultural land in Scotland is classified in terms of its potential productivity and cropping flexibility by the Land Classification for Agriculture (or LCA) system developed by the Macaulay Institute (now the James Hutton Institute) [9]. This is determined by the extent to which the physical characteristics of the land (soil, climate and relief) impose long term restrictions on its use. The LCA is a seven-class system: Class 1 represents land that has the highest potential flexibility of use whereas Class 7 land is of very limited agricultural value. Four of the classes (Classes 3, 4, 5 and 6) are further subdivided into divisions. The seven classes have been simplified into four categories including:

- Arable agriculture (LCA classes 1 to 3.1)
- Mixed agriculture (LCA classes 3.2 to 4.2)
- Improved grassland (LCA classes 5.1 to 5.3)
- Rough grazing (LCA classes 6.1 to 7).

The LCA classification is applied through a series of guidelines that allows a high degree of consistency of classification between users. The classification is based upon a number of assumptions. These specifically include the potential flexibility of cropping and agricultural options, assuming a high level of management. However, they exclude other factors, such as distance to market and individual landowner choices, all of which can influence actual land use decisions. The LCA system is the official agricultural classification system widely used in Scotland by agriculturalists, planners, estate agents and others as a basis of land valuation.

Economic production of sugar beet crops would be possible on land classified as being suitable for arable agriculture under the LCA system (that is land in LCA classes 1, 2 or 3.1).

Land in these classes, is capable of being used to produce a wide range of crops. The climate is favourable, slopes are no greater than 7 degrees, the soils are at least 45 cm deep and are imperfectly drained at worst. The great majority of this land, which is often referred to as prime agricultural land, lies in a near continuous coastal strip in the East of Scotland (Figure 3), from the English border to Inverness. It includes parts of East Lothian, mid and West Lothian, parts of Fife, East Stirlingshire, East Perthshire, Angus, Aberdeenshire and Morayshire and areas around Inverness. Eight percent of the Scottish land area (i.e. 625,800 Ha) is classed as being suitable for arable agriculture. Most of this is Class 2 and 3.1 land, with only a very small amount of land in Class 1 (around 0.2% or 4,100 Ha [9]).

The Class 1 agricultural land is located along the Northwest coast of East Lothian and in one continuous block to the North of Carnoustie in Tayside (Angus). In the Tweed valley (Borders and East Lothian) and Tayside, continuous areas of Class 2 land make up around half of the arable area, although these are mixed in with areas of Class 3 land. Land in Fife and East Morayshire forms mosaics of Class 2, 3 and 4 land, which reflects their more complex geologies and topographies. Arable land in Aberdeenshire and Stirlingshire is mainly Class 3. In summary, most of the land suitable for sugar beet production lies in parts of East Lothian, East Perthshire, Fife, Angus and Morayshire.

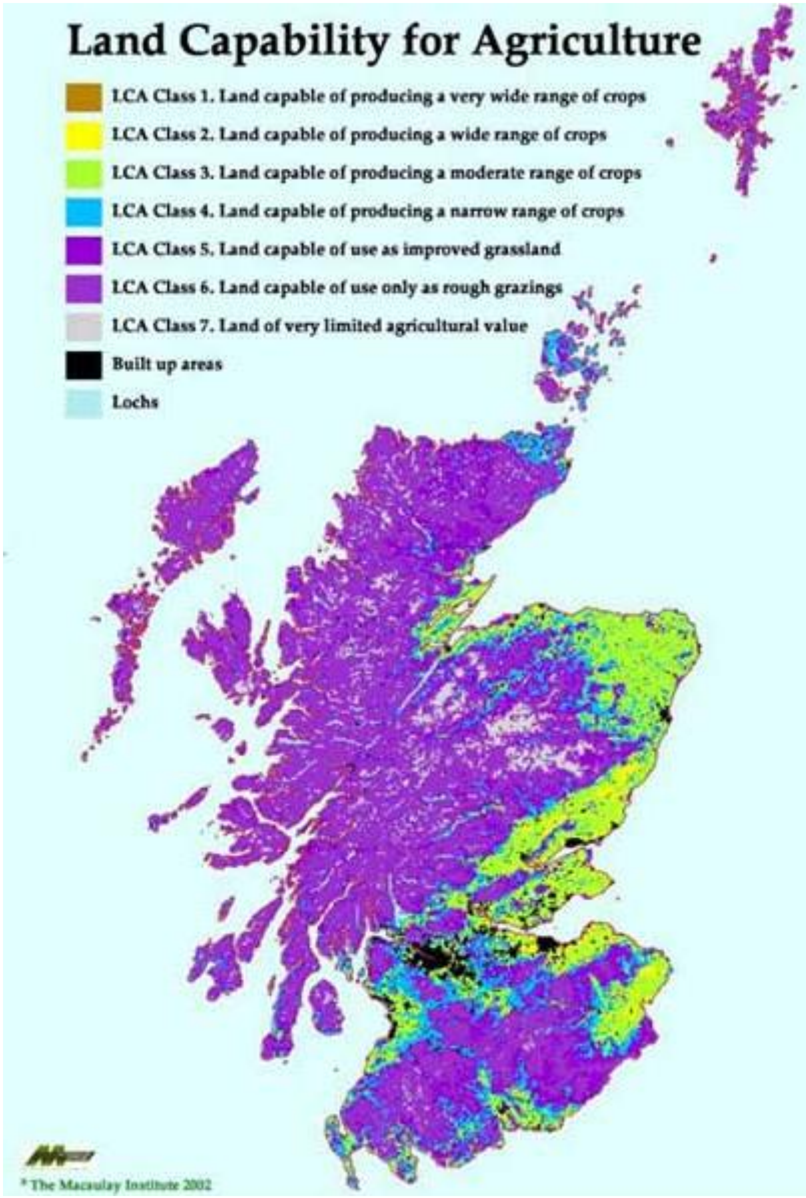

Figure 3. Distribution of land capability classes in Scotland

Sugar beet would fit well into cereal rotations, which might also include oilseeds, potatoes and high value vegetable crops such as carrots or brassicas. The requirements of the sugar beet crop are broadly similar to those of cereals and oilseeds. Further details on appropriate rotations, soils, fertiliser requirements, crop protection and general agronomy are provided in the following pages.

1.2.3 Agronomic requirements

The agronomic requirements of the sugar beet crop are well-defined in the Fertiliser Manual [10] and the Sugar Beet Reference Book [11]. Advice (based on standard best practice and recent research/development) on crop protection and crop nutrition is available through the BBRO, a non-profit making company set up jointly by British Sugar plc (BS) and the National Farmers' Union (NFU) [7]. Its objective is to commission and implement research and technology transfer designed to increase the competitiveness and profitability of the UK sugar beet industry in a sustainable and environmentally acceptable manner. Advice is also available from numerous agrochemical and agronomy companies (such as Agrii, Syngenta, Frontier and Bayer CropScience, as well as independent crop consultants).

1.2.3.1 Rotations

Sugar beet is generally grown in rotation with other crops including cereals, oilseeds and potatoes. It would typically be grown one year in four, five or six. Crops are grown in rotation to reduce susceptibility to pests, diseases (in particular beet cyst nematode and rhizomania) and weed problems and because more diverse rotations are known to be better in terms of nutrient use, soil quality and for the wider environment.

1.2.3.2 Suitable soil types

Sugar beet will generally grow in soils which are suitable for the production of key arable crops including cereals, oilseeds and potatoes, and other vegetables. However, the beet is very sensitive to poor soil structure and grows best in deep, fertile soils with good structure[2] [11].

Economic yields of sugar beet are most consistent on fairly light to medium textured soils (i.e. sandy loams, silt loams, sandy silt loams and the lighter types of clay loams, sandy clay loams and silty clay loams). It would be less consistent on clays, sandy clays, silty clays and the heavier, more poorly drained clay loams, sandy clay loams, silty clay loams). Yields on very light soils (such as loamy sands) are likely to be affected by drought, particularly in lower rainfall areas.

Sugar beet is extremely sensitive to low soil pH and this was one of the major contributory reasons for poor beet yields in Scotland in the early 20th Century [3]. Scottish soils typically have lower pH values than those in England. Sugar beet growers are recommended to ensure that no parts of the field have pH values below 6.5 [11] in order to maximise yield. Peaty and organic soils can be maintained at slightly lower pH values [10][12]. It is risky to rely on a composite soil sample taken from entire fields for pH testing. Precision sampling, which will give a much more accurate idea of the variability of soil pH across the field is a better option for sugar beet, since this will allow variable rate application of lime in order to correct soil acidity more accurately across the field.

Soils for sugar beet production should be maintained at target nutrient indices of 2 (the Scottish equivalent of “moderate” status) for phosphorus (P), potassium (K) and magnesium (Mg). Once soils have reached these target indices (or statuses) then fertilisers are required simply to replace the

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[2] Soil texture is the relative proportion of sand, silt and clay in a soil, whereas soil structure is the way in which these particles have combined to form stable aggregates and pore spaces/channels for air/water movement.

amount of nutrients removed by the crop at harvest (see 1.2.3.3).

Assessment of soil texture combined with an understanding of likely climate and weather patterns will help the farmer to determine appropriate cultivation and crop production strategies [11]. Assessment of soil structure will help the farmer to decide whether measures are necessary to alleviate compaction or structural problems prior to sowing sugar beet [11].

Farmers' experiences over the past 5 years in growing energy beet (a relatively new crop for Scotland) for anaerobic digestion (AD) have shown that it has been possible to iron out early challenges in growing the crop. They are able to achieve fairly consistent, economically acceptable yields of around 60-70 t/Ha from a range of soil types (avoiding heavy land and steep slopes) and have adapted production methods to suit their farm, its soils and its topography. They are appreciating the benefits to other crops and to their soils of having a non-cereal break crop in the rotation. Scottish farmers growing energy beet are also managing to avoid soil damage during harvest using modern harvesting techniques, including dedicated machinery with flotation tyres. All farmers felt that soil damage caused by energy beet production was minimal and certainly less than where root crops such as carrots or potatoes were being grown.

1.2.3.3 Fertiliser requirements

To ensure a high sugar yield, the beet crop requires sufficient amounts of major nutrients, secondary nutrients and trace elements. No fertiliser recommendations specific to sugar beet in Scotland have been published because sugar beet is not currently produced in Scotland. It is likely that fertiliser requirements for Scottish beet crops will be very similar to those of English crops, therefore the following summary of nutrient needs is based on information published in the Fertiliser Manual, published by AHDB and widely used in England and Wales [10].

Nitrogen is a major component of the proteins and enzymes that drive plant growth: it is essential for the rapid development of the leaf canopy and the capture of solar radiation during the early stages of sugar beet growth. Nitrogen (N) requirements are based on assessments of past cropping, soil type and annual or excess winter rainfall. Sugar beet crops would normally receive between 40 and 120 kg N/Ha in the year of production. Trials on N requirements and seeding rates were conducted by SRUC on energy beet in Angus, Scotland in 2013/14 [13]. The results showed that dry matter yield was not affected by N rate where rates of 119 or 149 kg N/Ha were applied to a mineral soil.

Phosphate is essential in plants for the development of plant cell membranes, as part of genetic material, for energy transfer, for protein synthesis and the formation and transport of sugars. Potassium is recognised as being particularly important for sugar beet. It allows plant tissues to regulate their water content and osmotic balance. This maintains the cellular rigidity (turgor) needed to drive the growth and control the photosynthetic activity of the leaf canopy. It also acts as an activator of the enzymes involved in the production and transport of sugars. Under some circumstances, Na may replace K as an osmotic solute. Sodium is not normally applied to arable crops, but it is important for members of the beet family, including sugar beet. A sufficient supply of sodium improves water use efficiency and can partly offset potassium deficiency during dry periods. Magnesium helps to maintain the healthy green canopy enabling more sugar to be produced for a longer period of time. Secondly magnesium is crucial in the citric acid cycle (important for cell respiration) where the synthesis of proteins, fats and carbohydrates can be optimised.

Fertiliser requirements for phosphorus (P), potassium (K) and sodium (Na) are generally determined following routine soil analysis and are usually around 50, 100 and 100 kg/Ha for P, K and Na respectively in soils which are at the target index of 2 for these nutrients. Magnesium (Mg) will also be required where the soil is below the target index of 2. Fertiliser recommendations should be adjusted downwards where yields of less than 60 t/ha are expected, or upwards, where higher yields are expected or soil nutrient indices are below target [10].

Fertiliser requirement for sulphur (S) is usually based on an assessment of soil type, on past manure applications (if any) and on whether past crops in the rotation have shown sulphur deficiency symptoms. Higher yielding crops, those grown on light and shallow soils, and those on soils where no organic manures have been used are more prone to deficiency. Where deficiency is likely, an application of 25 - 50 kg/Ha is effective [10]. An adequate supply of sulphur improves sugar quality by decreasing α-amino-N-content.

The trace element Boron (B) is of particular importance for sugar beet. It is vital for cell development and for production of components such as sugar. Boron deficiency results in the physiological disorders "heart rot" and "dry rot" and therefore in substantial yield losses. An application of boron should generally be made where soil analysis indicates levels are below 0.8 mg B/l (ppm B). Deficiency can be corrected by applying just 3 kg/Ha [10].

1.2.3.4 Pests and diseases

Crop protection (from pests, diseases and weeds) is vital for the sugar beet crop if high yields of quality roots are to be produced. The crop is susceptible to attack from the following pests, for which a programme of insecticides and nematicides are routinely applied as seed and foliar treatments:

- Aphids, which transmit virus yellows and beet
- Beet cyst nematode
- Soil pests including millipedes, symphylids and springtails
- Slugs and leatherjackets
- Foliar pests including flea beetles, thrips, capsid bugs and beet leaf miners

The crop is susceptible to attack from a range of diseases including the following principle ones:

- Rust
- Cercospora leaf spot
- Powdery mildew
- Ramularia
- Downy mildew
- A range of seed-borne diseases and black leg
- Rhizomania (which is spread by a soil-borne fungus-type organism).

Growers typically monitor their crops regularly and apply a programme of fungicides, dependent on the level of disease incidence and risk of future disease problems.

1.2.3.5 Weed control

Sugar beet is very sensitive to weed competition, especially in the early stages of growth, and effective weed control is vital if high yields of quality beets are to be produced. Weeds compete with beet for nutrients, water and light, but in most UK crops it is their competition for light that is most important. Yield losses from weed competition depend on their competitive ability, density and how long they are present. Weeds that emerge early and grow taller than the crop are the most competitive and, if present in large numbers, can cause complete yield loss.

Ahead of drilling, growers would typically apply a non-selective herbicide for:

- perennial weeds or volunteer potatoes just before or after cereal harvest;
- weeds of the two-leaf stage or older which are present prior to seedbed cultivations;
- volunteer cereals and grasses.

Straight after drilling, growers might apply a pre-emergence herbicide when soil is moist, to:

- help give flexibility with the timings of post-emergence sprays;
- to help where large populations of troublesome weeds (such as blackgrass) are expected.

After crop emergence, growers are likely to apply one or more selective herbicides to control problem weeds as the crop is growing.

Weed beet and bolters (plants which produce seed rather than a high-quality root) can be a serious problem in some sugar beet crops, and a range of methods are used to prevent these plants from causing reductions in yield and economic crop failure. These methods include delayed drilling into a stale seedbed, tractor hoeing, pulling, weed wiping and cutting.

1.2.3.6 Cultivation and harvest

Good soil structure is very important for sugar beet, therefore assessment of soils and alleviation of any compaction and soil structural problems before seedbed establishment is important in order to give the crop the best chance. The seedbed should be prepared to a depth of 5 -7 cm, aiming for a minimum of 30% of particles of <3 mm around the seed to improve availability of moisture to seed. Below the seedbed, larger aggregates and a more open soil structure is desirable. Inappropriate soil cultivations, incorrect timing of cultivations or carrying out cultivations under sub-optimal conditions can result in yield losses of 30% or more [7].

Spring cultivations to create a seedbed should be done as early as possible, but as late as necessary. In England, this means ideally by the end of March, though in Scotland, experimentation will be required to determine the ideal sowing time for modern sugar beet varieties. Soil conditions should be sufficiently dry to allow creation of a fine seedbed without causing soil damage. Establishing a uniform population of 100,000 plants per hectare is arguably the single most important factor that drives high yields in sugar beet crops.

Seed should be placed into moist soil, ideally 2 - 3 cm below the surface, using a dedicated beet drill. Drilling depth should be increased in dry conditions to ensure seed is placed into moist soil, but growers should avoid drilling deeper than 5 cm. Plant establishment is frequently lower on headlands and parts of fields where seedbeds are poor. For this reason, higher seed rates should be considered in these areas.

Irrigation has not been shown to be cost-effective in England, even though soil moisture deficits in dry years can reduce crop yield. Soil moisture deficits are likely to be lower in Scotland and this could put Scottish sugar beet growers at an advantage in some years.

Harvest planning is very important for sugar beet growers, who are advised to harvest following discussions with their harvesting contractor and buyer. When choosing harvest dates, the aim is always to optimise the yield and root quality whilst aiming to minimise the need for storage prior to sale and to protect soils during harvest. Crops with the poorest yield potential should be harvested first, leaving the better crops for later lifting. Roots should be handled with care to prevent bruising and sugar loss. Harvest is undertaken by 1- or 2-row trailed harvesters, or 4- or 6-row self-propelled harvesters in the late autumn or early winter. During harvest the beet is collected but the leaves are left in the field, to return organic matter to the soil.

Storage should be minimised, but where it is essential, it is important to minimise the danger of frost and mechanical damage. Guidance is available on the design and use of storage clamps [11].

1.2.4 Modern crop varieties

Recommended List (RL) trials are conducted annually in England to test the genetic potential of new candidate sugar beet varieties. The best performers (based on three years of trials work conducted in the current sugar beet growing areas) are recommended annually. The varieties in 2019 RL are selected based on their potential yield and quality, and their resistance to bolting and to named pests and diseases [14]. Given that the soils in Scottish arable areas can be somewhat different to those in the English sugar beet production areas and that the climate tends to be cooler and slightly wetter, it stands to reason that variety trials should be conducted to determine the best varieties for Scotland.

Some varieties of *Beta vulgaris* which are being grown successfully for fodder beet (animal feed) and energy beet (feedstock for anaerobic digestion) in England are also doing well in terms of yield and quality in Scotland. There is therefore a strong possibility that the range of recommended sugar beet varieties suitable for use in England will contain at least some varieties suitable for use in Scotland.

It is worth noting that varieties of *Beta vulgaris* used for energy beet and fodder beet are bred with a focus on maximising dry matter content and digestibility, whereas sugar beet varieties are bred with the aim of maximising sugar content and minimising impurities. Sugar beet varieties are therefore not the same as those used for energy production or fodder. The varieties currently on the RL are produced by six companies and include Aurora, BTS1140, BTS 3325, Cantona, Daphna, Degas, Firefly, Flixter, Haydn, Jura, Kortessa, Sabatina and Salamanca, amongst others. Listed varieties show a 10% difference in root yield potential, with sugar content ranging from 17.5 – 18.3%.

1.2.5 Yield potential

Average UK sugar beet yields have increased by 25% over the past decade and are currently around 80 t/ha, with some UK growers achieving yields of over 100 t/Ha [8]. Although sugar beet is not currently grown in Scotland, yields of energy beet grown in Scotland compare well with English yields; recent trials on Keithick Estates in Angus have achieved yields of between 64 and 102 t/Ha fresh weight (18 – 24 t/Ha dry matter) [13]. Scottish yields of some cereal types, in particular oats and barley can also easily equal, or in some cases, exceed those in England (RESAS [15] and personal communications with several Scottish agronomists).

There is no reason why the yield of Scottish sugar beet crops should not equal those of English crops, providing sufficient attention is paid to choosing appropriate varieties, suitable fields (soil types) and providing soils and the agronomy of the crop are managed to a sufficiently high standard.

However, for growers to consider including sugar beet in their rotations, soil conditions for seedbed preparation and harvest must be suitable at the appropriate time of year. In terms of soil type and climate, growers with land in LCA classes 1, 2 and 3.1 could grow sugar beet, but production is likely to be cost-effective only on light and medium textured soils.

1.2.6 Why grow sugar beet

Farmers will only grow sugar beet if there are advantages in doing so in relation to other options open to them for the land in question. If gross margins (output less variable costs, but excluding fixed costs) are similar to other crops and there is certainty of market, then sugar beet is likely to be an attractive option, given that it will offer a break from more commonly grown plant families (particularly cereals, but also potatoes, brassicas and carrots).

The main economic drivers to sugar beet production will be:

1. *Gross margin compared to other crops being considered* - there are no published typical gross margins for sugar or energy beet in Scotland. However, those for typical yields of sugar beet in England (published in Nix [16]) compare favourably with those for typical yields of Scottish spring cereal crops (Table 2, based on figures from SAC Consulting 2018 [17]). The gross margins for winter cereals and winter oilseed rape crops are likely to be higher than for sugar beet unless yields of over 80 t/Ha are achieved.

2. *Certainty of market* - in the absence of a current market in Scotland for sugar beet, farmers will only grow it if they have a buyer with a favourable agreed price. If they believe the price to be favourable and stable, then many farmers will choose to try sugar beet, especially if gross margins for alternative crops are significantly less favourable.

3. *Usefulness of this break crop* - many farmers are increasingly aware of the problems associated with growing monoculture cereals. They find increasing levels of pests, diseases and problem weeds and they often experience declining yields. The benefits of break crops in reversing these problems are well known. Farmers are increasingly keen to grow break crops from different plant families and many will be keen to try sugar beet if the price is right, since it is in a different family to all other commonly grown arable crops.

4. *Degree of certainty that the crop can be produced with minimal or no soil damage* - this will be a significant concern for farmers in areas with higher rainfall or heavier soil textures. Soil damage is much more likely where intensive cultivations are required and where the crop is

harvested in autumn and winter (as sugar beet is). Farmers with light to medium textured soils that tend to remain in suitable condition (i.e. sufficiently dry) for cultivation for a long growing season will be more willing to try sugar beet.

Table 2. Typical gross margins for key arable and vegetable crops commonly grown in Scotland*

Crop	Typical Yield (t/ha)	Variable Costs (£/ha)	Gross Margin ** (£/ha)
Winter Wheat	8.0	£466	£1,062
Winter Barley	7.5	£416	£899
Spring Barley	5.5	£303	£652
Winter Oats	7.5	£352	£1,048
Spring Oats	5.0	£299	£626
Winter Oilseed Rape	4.0	£366	£934
Spring Oilseed Rape	2.5	£194	£619
Potatoes - New	20	£1,552	£4,448
Potatoes - Ware	45	£3,291	£3,609
Energy Beet (SAC Consulting, Scotland)	75	£809	Not available
Sugar Beet (England)	66.5 *(Low)* 78 *(Med)* 89.5 *(High)*	£1,294 £1,359 £1,423	£512 £760 £1,008

* Data obtained from SAC Consulting [17], other than for sugar beet and energy beet in England and Wales [16].

** Gross margins are useful for comparison purposes; they represent output less variable costs (seed, fertiliser, chemicals, casual work and contracting costs specific to the crop) but exclude fixed costs (rent, labour, machinery, overheads). The gross margin is not a profit figure.

1.2.7 Environmental impacts

Sugar beet, like any crop that is harvested in the late autumn and early winter months carries a risk of causing structural damage to soils. Soils are more likely to be wet at that time of year, and therefore much more susceptible to damage from movements of heavy machinery. Light soils tend to drain more quickly and are therefore likely to be workable over a wider range of weather conditions, thus more suitable for sugar beet production. Farmers considering sugar beet production are advised to consult published guidance on soil assessment, soil management and soil health in order to help decide whether their soils are suitable for sugar beet production, to help optimise soil management practices and to minimise the risk of damage. Appropriate publications include '*Valuing your soils – Practical guidance for Scottish farmers*' [18], for example.

Farmers wishing to consider sugar beet production would also be well advised to gain a good understanding of likely availability of beet harvesting machinery in their area. Unless there is good availability of harvesting machinery for those growing the crop, many farmers may end up having to wait for their chance to harvest, which may mean harvesting when ground conditions are unsuitable.

1.2.8 Social impacts

It is not anticipated that extra labour will be required on farms where the decision is made to grow sugar beet. Scottish farmers, particularly those in the best arable areas, are innovative and competent growers of high value produce. They will readily adapt to growing a new crop if the economics look favourable for them. However, jobs would inevitably be created elsewhere in the supply chain. Food security

There is clear value in developing secure markets for Scottish farmers, firstly to mitigate against the impact which Brexit might have on trade with other countries inside and outside the European Union (EU). However, there is also growing concern amongst both farmers and consumers over "food miles" and the broader environmental impact of the food that we produce and eat, as well as the energy that we use. Farmers are keen to diversify in order to spread the risk of their enterprises and also increasingly aim to minimise the carbon footprint of their operations.

1.3 Conclusions

Scotland offers favourable conditions for sugar beet production in terms of day length, although average day- and night-time temperatures may compromise yield potential. It is therefore essential to select more hardy varieties, through discussions with plant breeders and by undertaking local variety trials.

Economic production of sugar beet crops would be possible on land classified as being suitable for arable agriculture. Eight percent of the Scottish land area falls within this classification, equating to 625,800 hectares. This land lies primarily in East Lothian, East Fife, East Perthshire, Angus and Morayshire. There are no published figures on the percentage of land specifically suited to sugar beet production in Scotland; however, consultation with Scottish farmers and soils experts suggests that around 70-90 % of Scotland's arable land area would potentially be suitable.

Farmers contacted were interested in the potential for sugar beet production but stated that, given the high cost of production (fertilisers and pesticides and contract harvesting), the price offered by any local processor would have to be appropriate. Economic production of sugar beet would also only be possible where transport distance to a processing facility is short.

The greatest challenge associated with sugar beet production in Scotland is likely to be in selecting fields which allow for effective timings of cultivations and harvest, with minimal or no soil damage. In soils appropriate for sugar beet production, yields could potentially be higher in Scotland than in England in years where soil moisture deficits are severe during the growing season in England. Work will be required to fine-tune production variety choice and agronomic protocols for sugar beet in order to maximise crop quality and yield of Scottish crops. SRUC have undertaken similar work on energy beet so it would be advantageous to engage with them early, to benefit from any pre-existing knowledge and expertise.

Whilst the potential looks very good for sugar beet production in Scotland, it is not possible to be more conclusive about potential crop yields and quality, given that modern varieties of the crop have never been grown here using modern methods and equipment. Specific variety trials should be established early in collaboration with plant breeders and a local institute, such as SRUC or the James Hutton Institute, to determine performance and input requirements, to validate crop production potential at the outset.

There are clear additional benefits, in terms of Scottish and UK food and energy security and potentially also in terms of the resilience and security of Scottish farming businesses if sugar beet were to be produced and processed in Scotland. However, there are also likely to be concerns from other sectors which need to be considered. These may include concerns from environmentalists around the impact on soils due to the late harvest, as well as potato growers and processors who may see a divergence of interest to sugar beet, as an alternative break crop, albeit offering lower returns. It is expected such concerns can be addressed through effective and proactive communication from the outset, to minimise the impact and any resultant negativity.

2 Industrial biotechnology and biorefinery opportunities

This section describes the wide range of sugar and sugar co-products that can be produced from a sugar beet refinery. The extent of processing undertaken within the refinery depends on the desired outputs. In Scotland, should a sugar beet refinery be established, the expected focus would be on bioethanol and sugar syrups, primarily as feedstocks for the fuels and chemicals industry; although inevitably other outputs may be best suited to other sectors, such as energy, feed and food.

2.1 Beet biorefinery process overview

Figure 4 provides a comprehensive illustration of the key stages of sugar production, and the range of outputs that can be produced from beet processing.

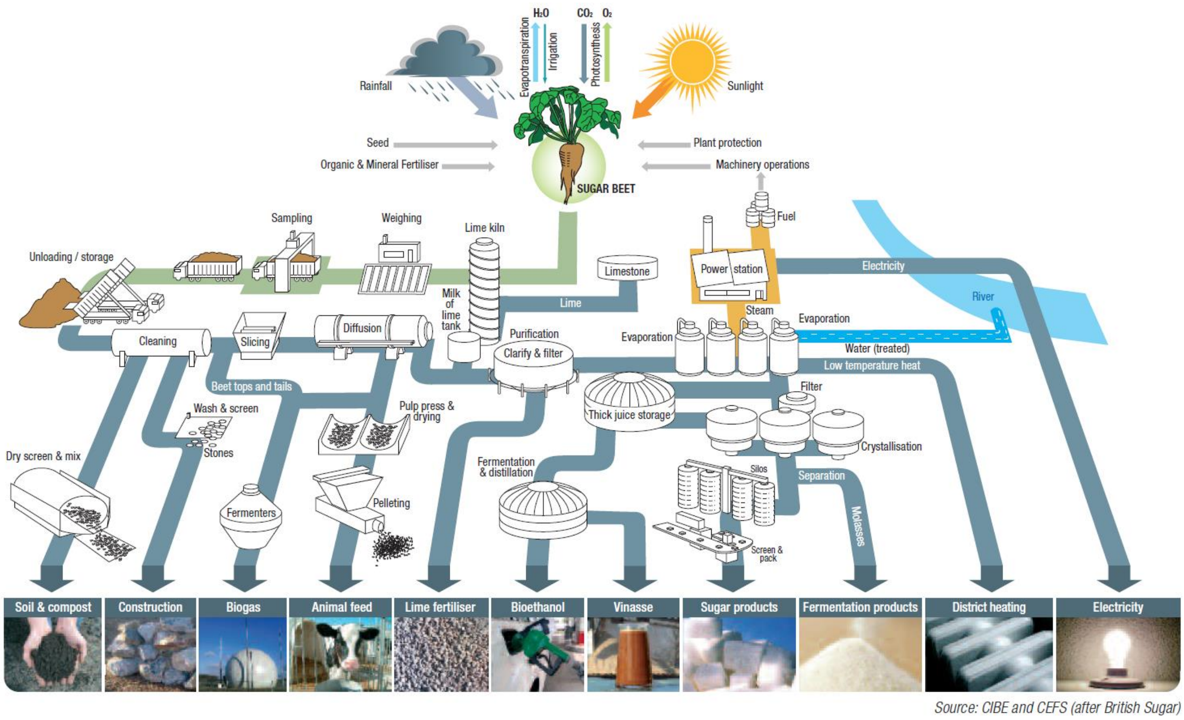

Figure 4. Flow diagram of the sugar production process. Source: [20]

It is possible to simplify the production process by reducing the range of outputs being produced; removal of the purification and crystallisation steps required to produce crystallised sugar for the food industry, for example, could significantly reduce technology demands. A description of the key steps and the relevant outputs are provided below:

1) Cleaning
   To remove soil and stones which can be sold on as co-products or returned to the producers. Wissington sells approximately 150,000 tonnes of topsoil and 5,000 tonnes of stones each year to land-owners and aggregate producers.

2) Shredding
   This is a simple mechanical process where cleaned beets are shredded into cossettes, increasing the surface area to facilitate sugar extraction in the diffuser.

3) Diffusion
   The cossettes are mixed with high temperature water in a counter-current continuously agitated tank, with a residence time of approximately one hour, drawing the sugar into solution known as juice.

4) Pressing & drying
   Cossettes are mechanically pressed in order to release the remaining juice and the residual pressed beet, known as pulp, is then sent to a drying plant for use as an animal feed either in shredded or pelleted form. The drying stage carries a significant energy input.

5) Purification
   The crude juice enters a series of carbonation steps in order to remove the soluble non-sugar materials which have been leached from the beet alongside sucrose. Milk of lime (calcium hydroxide) is added and carbon dioxide bubbled through before the spent material is filtered out. Any juice remaining in the lime mud is removed by slurrying with water which creates 'sweet water' that is used elsewhere in the process. The lime mud is then disposed of or applied to agricultural land as a liming agent (to raise soil pH). After carbonation, sulphur dioxide is pumped through the juice in order to neutralise the alkalinity and lower the pH.

6) Concentration
   The 'thin juice' or 'clear juice' is passed into an evaporator which increases the viscosity to form liquor or 'thick juice' which can be boiled to crystallise the sugar. The crystals are separated from the residual liquor in centrifuges and the process is repeated up to three times before the residual liquor (beet molasses) is separated. This step is not necessary when crystallised sugar or sugar products are not the desired output.

7) Molasses processing
   Molasses can be further processed to extract further value, producing:
   a. Salts, high MW colourants and saccharides
   b. Sucrose, residual sugar not extracted during the diffusion stage
   c. Betaine (Trimethylglycine), an amino acid used as a surfactant or feed additive
   d. Raffinate, left over after the de-sugaring of molasses which is used in animal feed.

8) Fermentation/Distillation
   Either the thin juice, thick juice, or molasses can be fermented or distilled to produce bioethanol. The stillage released following distillation is a by-product known as vinasse.

If the focus is on bioethanol production, which is likely to be the case in Scotland, steps 4, 5, 6 and 7 described above may not be necessary and the 'thin juice' produced during diffusion (step 3) would be fermented or distilled to produce bioethanol.

2.2 Opportunities for major by-products and side streams

The full range of processes outlined above would result in a number of by-products and side-streams which can be used in various ways within the biorefinery. This full range of outputs may not be produced in every case, depending on the extent of processing undertaken, demand for certain outputs and the techno-economic evaluation.

2.2.1 Molasses

Molasses may be used to produce bioethanol as a residue of the sugar extraction process. It is a highly viscous liquid containing up to 70% sugar which is produced in large volumes globally, from both cane and beet. Over 60 million tonnes are produced each year, mostly in Brazil, India, Thailand and China, which may be suitable for import to a Scottish beet refinery in order to extend the processing season. Typical uses of molasses include livestock feed, yeast production, food flavouring, de-icing agents, and a substrate for bio-based chemicals and materials [21].

2.2.2 Sugar beet pulp

Beet pulp contains around 67% carbohydrates, such as cellulose (19%), hemicelluloses (28%), and pectin (18%) and 8% protein (by weight) [22]. The majority of this is dried and used for animal feed. Sugar beet pulp is one of the highest volume vegetable wastes produced in Europe and consequently there have been a number of studies and commercial projects looking at valorising this waste stream.

The European public-private partnership known as the Bio-Based Industries Joint Undertaking (BBI JU) launched a multimillion-pound project in July 2015 aiming to demonstrate new value chains for sugar beet pulp. The project, Pulp2Value, concludes in June 2019 and aims to increase revenues of sugar beet processing residues through three key routes:

1) Microfibres based on cellulose, producing stable liquids for use in detergents or paints
2) Arabinose, with demonstrable health benefits
3) Galacturonic acid, a major constituent of pectin, used for polymers

Dutch firm Royal Cosun has developed a microcellulosic fiber known as Betafib® through point 1 above, and Pulp2Value aims to build long lasting value chains for this beet product. The only UK-based project partner is Refresco Gerber UK Ltd.; a successful fruit juice drink manufacturer based in Somerset, producing 650 million litres of juice per year. More detail on the three target products above is given in section (2.3).

A separate EU-funded project, CARBAFIN, aims to develop new value chains for surplus sugar beet in the food, feed, cosmetics, detergents and polymers sector. The project concludes in 2021 and has several industrial partners including beet sugar producers; its focus is on two key platforms:

1) Conversion of excess sucrose into glucose and then into innovative function glucosides via industrial glycosylation biocatalysts.
2) Production of hydroxymethylfurfural (HMF) from a fructose substrate

2.2.3 Betaine

Betaines are naturally occurring compounds which play a key role in metabolic pathways [23]. The betaine content of raw sugar beet is typically 0.2-0.3% and up to 6% in molasses [24]. Trimethylglycine was the first betaine to be discovered in the juice of sugar beets and has a variety of uses. It fits within a major class of cationic surfactants and is available in several forms including, for example, Lauryl betaine which is a natural surfactant used in cosmetics [25]. The manufacturer Lush uses lauryl betaine in 96 of its products including shampoos, conditioners, shower gels and cleansers. Cocamidopropyl betaine is also a surfactant used in cosmetics but is not entirely bio-based [24].

Glycine betaine is available to buy as a health supplement, costing approximately £0.04 per gram. The specific health benefits of anhydrous betaine are not well proven for the most part, but it has been used under the trade name Cystadane® for treatment of homocystinuria; a condition where the body is unable to process the amino acid methionine, leading to a build-up of methionine and homocysteine. It also shows potential in the treatment of liver disease and as an anti-inflammatory [26][27]. Choral betaine has been used for the treatment of insomnia under the name Somnwell.

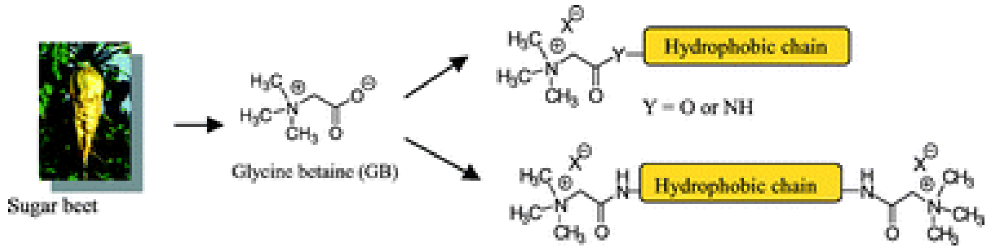

Figure 5. Production of surfactants from sugar beet betaine. Reproduced from [25].

2.2.4 Carbon dioxide

There are fossil CO_2 side-streams from power generation and distillation which can be diverted for storage or utilisation. Fermentation to bioethanol also produces biogenic CO_2, which can be used in fizzy drinks carbonation, for example. The British Sugar biorefinery in Wissington produces a fossil CO_2 side-stream which is pumped to local greenhouses to enhance the production of hemp for the production of cannabidiol (CBD) for medical purposes such as epilepsy medicine. CO_2 levels in the atmosphere of the greenhouse may be increased to up to 1000 ppm which in the past has increased production of salad crops by up to 30-40% [28].

Industrial grade carbon dioxide is a relatively low value product but is estimated to have a total market value of approximate £25 million in the UK, with highest demand coming from the food and beverage industry.

2.2.5 Animal feed

Pressed sugar beet pulp can be used as a feed for dairy cows, beef, sheep, goats and horses. It has an energy content of 13.0 MJ/kg (dry), with a dry matter content of 27% and a sugar content of 6%. There are also a range of dried and pelletised feeds available with a much higher dry matter content (89%) and a higher sugar content (20%)[3].

In total 297,400 tonnes of dried sugar beet pulp and 297,400 tonnes of molasses were used as animal feed in Great Britain in 2017 [32]. Each represented just 2.6% of the total amount of feed used in the UK, with whole wheat grain being the dominant feedstock. Materials like sugar beet pulp are fed as high protein supplements to livestock to boost live weigh gain. Beet pulp pellets currently retail for around £219/tonne (88% DM). The Wissington plant sells over 140,000 tonnes of dried animal feed each year. Pressed sugar beet pulp animal feed is sold by Nordic Sugar in Denmark and Sweden under the names HP-Pulp® or HP-Massa®.

[3] See for example https://www.tridentfeeds.co.uk/products/bettaflow/ https://www.kwalternativefeeds.co.uk/products/view-products/

2.3 Opportunities for bulk and specialty chemicals

In addition to the above, the processing of sugar beet can produce hundreds of bulk and speciality chemicals, both as a co-product of crystallised sucrose and directly from refining and reforming building on a sugar platform[4]. An overview of the key routes to biochemicals from the sugar platform is presented below, whilst detailed lists of all the products and processes are available in [35][36] [37] [38] [22].

2.3.1 Bioplastics & polycarbonates

Beet residues can be converted into fatty acids and then biodegradable bioplastics, demand for which has been growing rapidly in recent years. However, bioplastics production capacity is increasing relatively slowly in comparison to demand. According to European Bioplastics [39], capacity is forecast to increase by 24% between 2018 and 2023; from 2.11 million tonnes to 2.62 million tonnes; with most growth occurring after 2021[5]. Less than half (43%) of the bioplastics produced are currently biodegradable, but innovative biopolymers such as PLA (polylactic acid) and PHAs (polyhydroxyalkanoates) account for most of the growth in this area. Both PLA and PHAs are produced via the sugar platform utilising fermentation routes. Lactic acid can be used as a base chemical for conversion into several products, as shown in Figure 6.

Beet molasses has also been shown to be a productive feedstock for lactic acid formation, using bacteria such as *Lactobacillus bulgaricus*, *Lactobacillus casei* and *Lactobacillus delbrueckii* [38]. In some cases the mechanical properties of the PLA derived from sugar beet can be improved through the addition of beet fibres [40].

PHA is produced commercially by Italy-based manufacturer Bio-on, using sugar beet as a feedstock[6]. PLA is produced in the UK by companies such as Floreon, based in Sheffield[7]. In Scotland, Fife-based Cellucomp has developed a cellulose nano-fibre from beet feedstocks known as Curran® which has "*exceptional mechanical and rheological properties for numerous applications, such as paints and coatings, inks, personal care, home care, paper, food, concrete, drilling fluids, composites and other potential applications*"[8]. The major feedstock used by Cellucomp is sugar beet pulp residue.

[4] As defined by [35] and IEA Bioenergy Task 42, the term 'sugar platform' refers to the collection of products that can potentially be derived from any combination of C5, C6 and/or C12 sugars that exist as intermediaries within pathways from a biomass feedstock toward a final biochemical product.

[5] https://lb-net.net/wp-content/uploads/2019/05/LBNet-BBNet-Plastics-and-the-Bioeconomy-Report-Final-issue-2-.pdf

[6] See Bio-on website for further information http://www.bio-on.it/what.php?lin=inglese

[7] See Floreon website for further information http://floreon.com/about-floreon/why-choose-floreon

[8] See Cellucomp website for further information https://www.cellucomp.com/products/curran

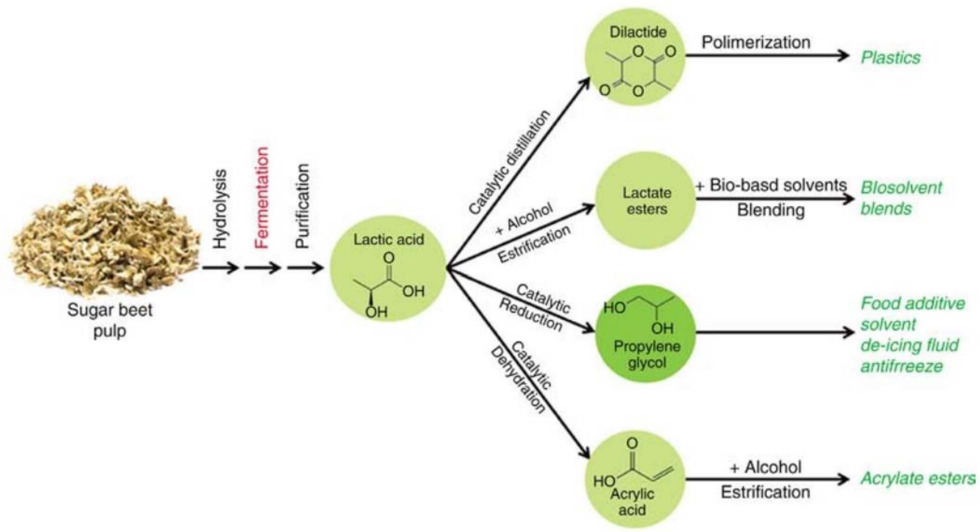

Figure 6. Production route for the bioplastic PLA from sugar beet pulp. Source: [22]

Ethylene and propylene can be produced from sugar feedstocks using bioethanol as an intermediate [41]. Polyethylene (e.g. HDPE) and polypropylene are widely used plastics mostly derived from fossil fuels. Brazilian firm Braskem is a key manufacturer of 'Green Polyethylene', a bio-based plastic derived from sugar cane. Based in Oxfordshire, Polythene UK offer a similar product called Polyair™ which is also derived from sugar cane waste. Other firms operating a commercial ethanol-to-ethylene process include Chematur, BP, Axens, Total and IFPEN. Ethylene glycol is used in the manufacture of polyester fibres, antifreeze and coolants. Propylene glycol is used for the production of polyester resins and polyurethanes. It is also less toxic than ethylene glycol and is used in the food industry, pharmaceuticals and in electronic cigarettes. Biaxially-oriented polypropylene (BOPP) is a widely used packing material and there is a major manufacturer in North Cumbria.

2.3.2 Food applications - Pectin

On a dry basis, sugar beet pulp contains 15-25% pectin, which is a natural gelling agent widely used in the food industry [38]. Most commercial pectins are produced from citrus fruits, but sugar beet pectin is distinct in that it does not have the same gelling properties [42]. It can also be used as an emulsifier. Other key food applications of sugar beet and beet by-products include:

- Monosodium glutamate (MSG), as a flavour enhancer in foods, created by fermenting starch or molasses
- Citric acid
- Low calorie sweeteners
- Yeast cultivation [43]
- Beet-root juice as a sports performance supplement
- Bioactive food ingredient [42]

Glasgow-based biotechnology start-up 3Fbio produce sustainable mycoproteins from grain starch, known as Abunda®. Mycoproteins are typically used as meat substitutes, providing a source of dietary fibre and protein with lower lifecycle environmental impacts than animal products. The company currently uses a distillery mash stream derived from wheat or maize as this has the best ratio of high sugar content to low cost; however, by-products from beet processing could be a suitable alternative.

The mycoprotein typically requires the simplest sugar, glucose, and is produced at a rate of approximately 600 kg per tonne of glucose.

2.3.3 Furfural and furans as platform chemicals

Furfural is a widely used platform chemical for products such as solvents, fuel additives, plastics and resins. Furfural was first produced from sugar dehydration in commercial batch processes in the 1920s by Quaker Oats in the United States. Today, global production is approximately 300kt annually and the global price is approximately £600-1300 per tonne. Yields of up to 5% by weight can be achieved from sugar beet by-products [44].

Derivatives such as furfuryl alcohol are used to produce furan resins used in adhesives, coatings and polymer composites [22]. 5-hydroxymethylfurfural (HMF) is an important building block platform chemical that has been the focus of a wide range of research within green chemistry, as it can be used to produce many valuable compounds with various applications [38]. One example is levulinic acid derivatives which are used in flavourings, pharmaceuticals and polymers. Another example is 2,5-Furandicarboxylic acid (FDCA) which can be used for the production of resins and polymers for use in recyclable bio-based plastics [35].

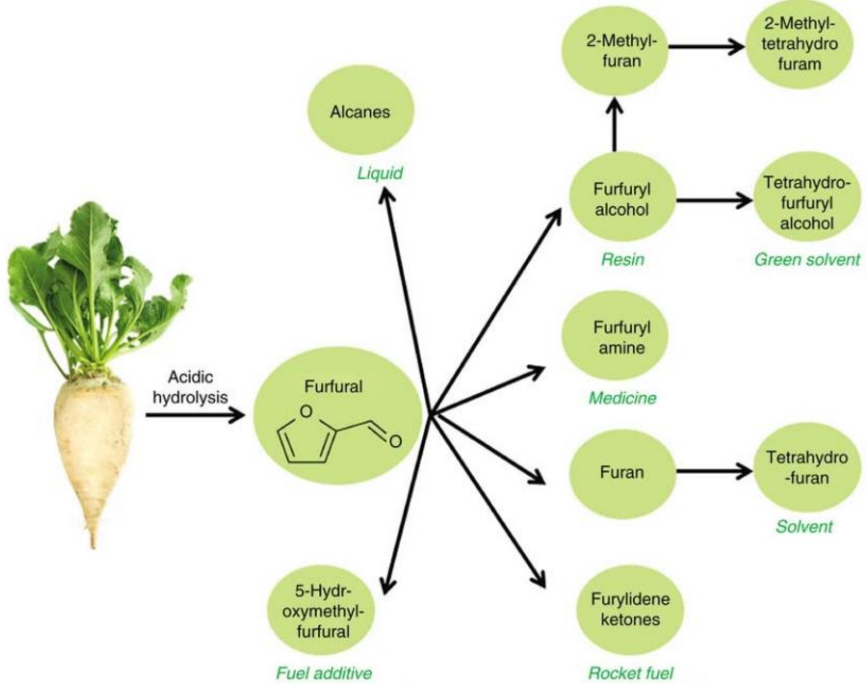

Figure 7. Furfural chemical platform from sugar beet and potential products. Source: [22]

2.3.4 Speciality chemicals

Sugar beet processing residues also have applications in biotechnology, which could benefit some of the more than 100 biotechnology companies in Scotland. One potential area is the development of industrial biocatalysts and enzymes which can be produced from vinasse [45]. Sucrose can be used as a starting material for the production of renewable materials such as resins and alkyds for high solid paints [46]. Sucrose esters – one of the largest classes of sucrose compounds – have applications in cosmetics, pharmaceuticals and food products [47]. Other sucrose derivates include:

- Sucrose acetate isobutyrate
- Sucrose octaacetate
- Sucrose benzoate
- Sucrose cocoate
- Olestra (banned?)
- Sefose

Comprehensive reviews of all the products that can be derived from sugar beet and its residues are available in [22][35][36][37][38]. Examples include:

- Cellulose acetate phthalate (CAP) or Cellacefate, synthesised from sugar beet pulp
- Betalains – antioxidants and/or natural pigments (red or yellow dyes). Betacyanin gives Beta vulgaris rubra its crimson-purple colour and may have anti-cancer properties.
- Uronic acids - glucuronic acid, galacturonic acid (see Pulp2Value project). The uronic acid content of sugar beet pulp is up to 18% of the dry matter [22]. Applications include biomedicine and as precursors of polymers [38]. Galacturonic acid is a major constituent of pectin and its derivatives have potential value in personal care products.
- Pentoses - Arabinose and Xylose. Arabinose can account for as much as 22% of the dry matter in sugar beet pulp, whereas xylose accounts for 2% [22]. Arabinose can be used as a natural sweetener in the food & beverage industry, and in the health sector. Xylose can be used to produce xylitol, dehydrated to furfural, or can be fermented to produce a range of products.
- Glutamine - a naturally abundant amino acid in sugar beet with many uses in nutrition.
- Acrylic acid – predominantly used as a raw material in the manufacture of acrylic esters and also in adhesives, coatings, detergents and cosmetics.
- Sorbitol – can be used as a sweetener and in cosmetics. Isosorbide resins can be used in the linings of food cans [36]
- 1,4-butanediol – platform chemical traditionally derived from petroleum sources for use in the production of solvents, chemicals and polymers [35].

Many of the products described in this section are novel but have existing established markets. A review of the technology readiness level (TRL) and market size of the many sugar platform products was carried out by E4Tech for the Euopean Commission [35], summarised in Figure 8.

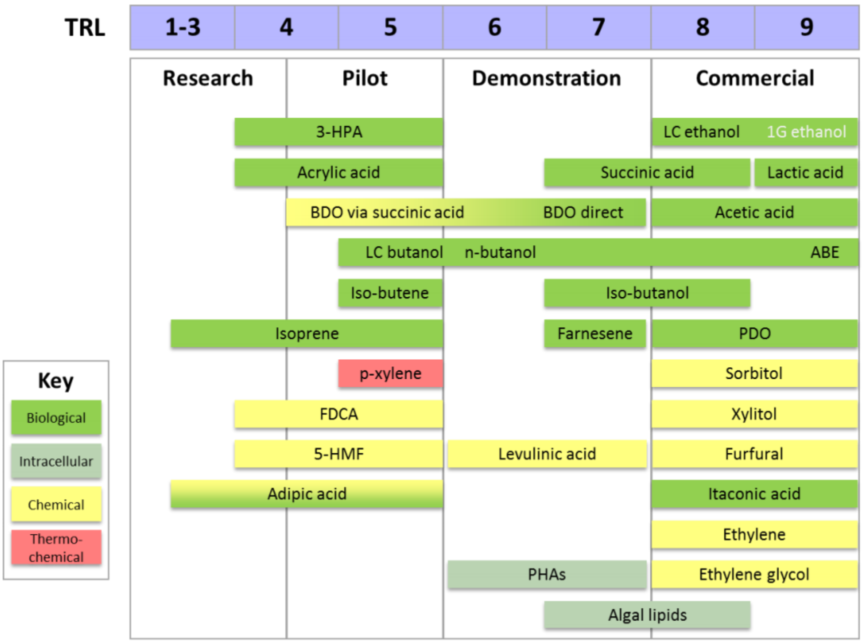

Figure 8. Technology readiness levels for varies bio-based products from the sugar platform. Source: [35].

A comprehensive review document on the European market for bio-based products was recently released by the Joint Research Centre of EU [48]. It found that the largest markets in Europe are for bio-based surfactants, bio-based paints, coatings, inks & dyes, and bio-based fibres. As shown in Table 3, the most rapidly growing markets are for platform chemicals and adhesives.

Table 3. Aggregated prices, turnover and compound annual growth rates (CAGR) for bio-based products in the European Union. Source: [48]

	Aggregated Price (EUR/kg)	Annual Turnover (EUR million)	CAGR (%)
Platform chemicals	1.48	268	10
Solvents	1.01	76	1
Polymers for plastics	2.98	799	4
Paints, coatings, inks and dyes	1.62	1,623	2
Surfactants	1.65	2,475	4
Cosmetics and personal care products	2.07	1,155	3
Adhesives	1.65	391	10
Lubricants	2.33	552	1
Plasticiers	3.6	241	3
Man-made fibres	2.65	1,590	3
Total	1.94	9,167	2

The prices and market size of individual bio-based products is given in table 5 of [35]. Despite the promising figures shown above, the UK did not make the list of top three most important EU member states in any category of bio-based products, with Belgium, France, Germany and Italy being the key producing nations.

2.4 Anaerobic Digestion

Renewable energy sources such as biogas from anaerobic digestion (AD) are vital to decarbonising the energy mix in Scotland. In its 2018 Climate Change Plan, The Scottish Government pledged to '*reduce emissions from the use and storage of manure and slurry by looking into the feasibility of large-scale anaerobic digestion*'. Across the UK, anaerobic digestion is supported through policies and incentives such as the Renewable Heat Incentive (RHI) for heat, and the Renewable Transport Fuel Obligation (RTFO) for transport.

Sugar processing residues and fodder beet are already widely used as a feedstock in AD plants in the UK. Due to the high sugar content of beet, the rate of biogas production is increased using this feedstock as opposed to wastes, residues and other crop feedstocks. Consequently, sugar beet is often mixed with other feedstocks in order to stabilise gas production rates. The potential gas yields from the sugar beet crop, fodder beet crop and various processing residues are given in Table 4.

Table 4. AD properties of sugar beet, fodder beet and associated residues. Source: NNFCC

Parameter	Unit	Sugar beet	Fodder beet	Pressed sugar beet pulp	Sugar beet silage	Sugar processing waste	Sugar beet vinasse*
Dry Matter	%	25	16	24	15	11	61
Volatile solid content	%	90	90	-	89	-	42
Methane yield	Nm^3/tVS	350	350	218	350	183	260

* Data from [50]

Vinasse is produced as a co-product of beet ethanol production at a rate of 7.146 kg per kg ethanol (Ecoinvent [51]). It is commonly used as a feedstock in AD plants, for example wheat vinasse from Ensus and potato vinasse from vodka distilleries. However, vinasse alone is a difficult feedstock to process since it has an unfavourable carbon to nitrogen ratio and requires additional nutrients. These issues can be overcome by co-digesting beet vinasse with cow manure and/or lime mud (another sugar by-product) [50].

Sugar beet pulp may also be used as a feedstock for biogas or biomethane production through AD, achieving reasonable methane yields (Table 4). However, yields may be reduced if beet pulp is not pre-treated before digestion. Pre-treatments are intended to release fermentable sugars through hydrolysis of lignocellulosic biomass and processes include enzymatic depolymerisation, acid hydrolysis, pulsed electric field treatment and microwaving. Berlowska et al [52] found that gas yields from sugar beet pulp can be increased several times through pre-treatments and can be easily integrated into a beet ethanol production facility.

The digestate produced through the AD of sugar beet pulp has been shown to contain useful quantities of N, P and K [53] and can be sold back to the growers to minimise fertiliser use. A study from a Hungarian sugar beet processing facility found that the biogas generated from 50% of the sugar beet pulp output could substitute 40% of the natural gas required to meet the plant's thermal energy demand for processing [54].

Among the largest AD plants to use sugar beet in Europe is the Magyar Cukor Zrt AD plant in Hungary, which operates on approximately 85% sugar beet residues (221 kt). Major plants in the UK include the 5 MW, 20 million Nm^3 Agraferm Technologies plant at Bury St Edmunds, using pressed sugar beet pulp from the British Sugar refinery. Also, the South Petherton plant near Reading uses 43,900 tonnes of mixed feedstocks per year, of which 19.4% is sugar beet.

In Scotland, there are 55 operational AD plants in total with an installed capacity of 49 MW, two thirds of which are farm-fed, with a further 47 projects under development [55]. Of the operational plants, there are 18 in Eastern Scotland (the target sugar beet growing area) with a further 20 under development. Plants currently listed as using sugar beet or energy beet are shown in Figure 9.

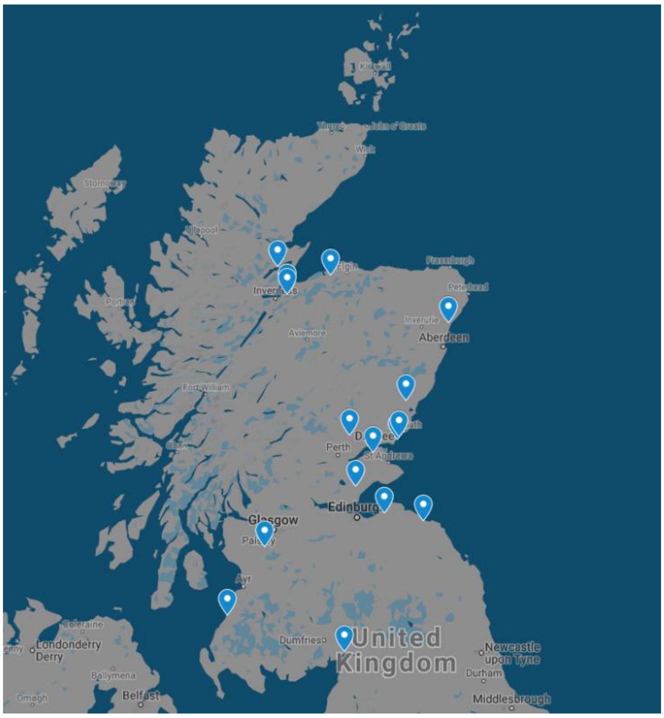

Figure 9. Locations of AD plants in Scotland currently using sugar beet or fodder beet as a feedstock. Data source: NNFCC AD Deployment Report 2019 [55].

2.5 Bioethanol production

Ethanol is produced via the fermentation of sugars by microorganisms such as *Saccharomyces cerevisiae* and can be used as a fuel or as an intermediate in the production of bio-based chemicals. Worldwide, bioethanol is currently produced from a variety of feedstocks, including corn, sugar beet, sugar cane and wheat. Some starchy feedstocks require hydrolysis of the polysaccharides prior to fermentation and cellulosic feedstocks require more significant pre-treatments in order to release fermentable sugars.

Global ethanol production was 120 billion litres in 2017, which is expected to increase by 9.2% over the next ten years [56]. The USA is the largest global producer of ethanol, accounting for 58% of global production, followed by Brazil at 26%. In Europe, production capacity is just over 9 billion litres, with France being the largest producer as shown in Figure 10.

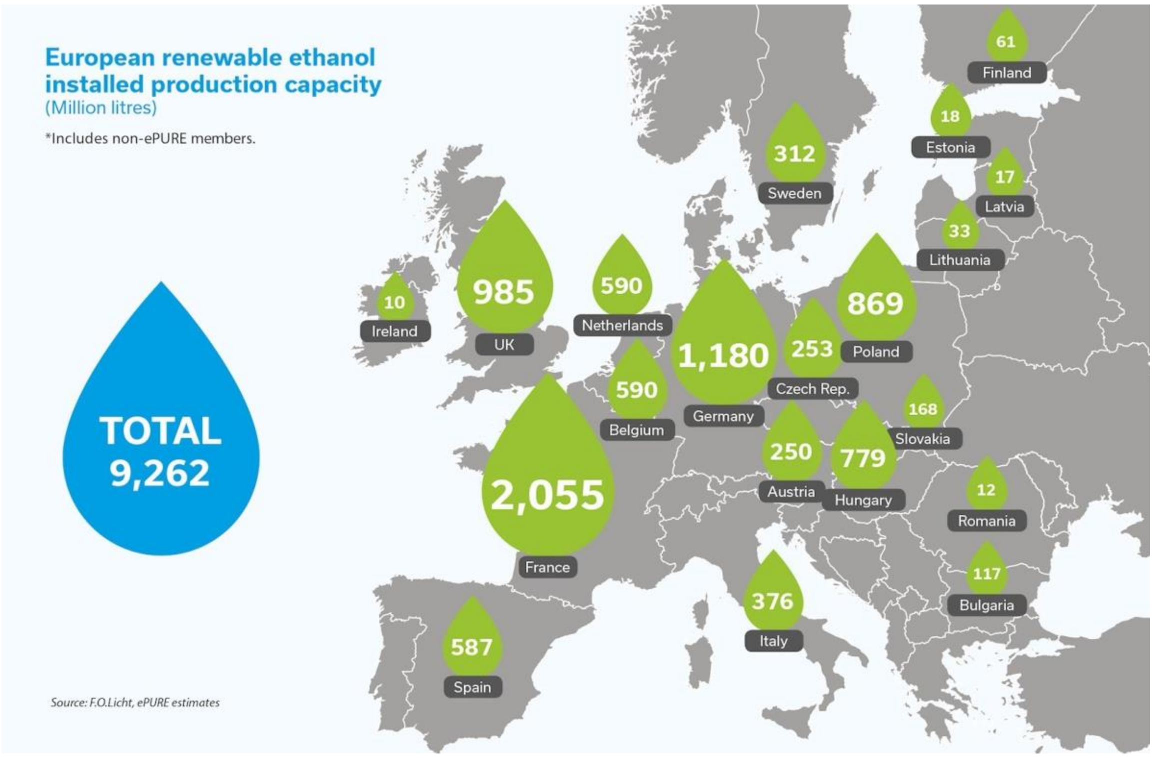

Figure 10. Ethanol production in Europe by country. Source: ePURE [57]

The details of some of the largest ethanol production plants in Europe and the UK that use sugar beet and beet by-products are given in Table 17. In addition to the Wissington plant, the other major bioethanol producer in the UK is Ensus in Teeside which uses wheat as a feedstock. Until recently, Vivergo Fuels also operated a wheat ethanol plant in Hull, but this has now closed due to economic reasons and legislative uncertainty. According to statistics from the Department for Transport (DfT), the UK consumed 744 million litres of bioethanol in the year April 2017 to April 2018 [58]. As shown in Figure 11, 17% of the volume of bioethanol consumed was derived from sugar beet, most of which originated in France.

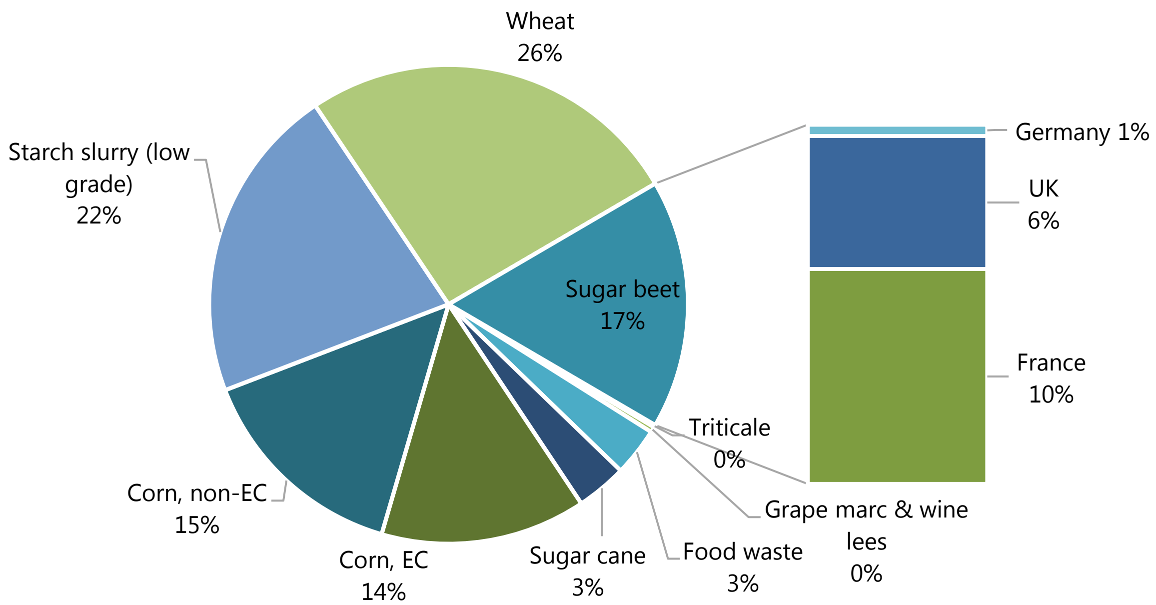

Figure 11. Feedstocks used to produce ethanol consumed in the UK and origin of beet ethanol.

Ethanol can be produced at different stages within the process of refining sugar beet. The Wissington plant was designed to produce ethanol from industrial sugar which was surplus to EU quotas. Thick juice and some molasses are used for bioethanol fermentation.

The potential yields of bioethanol from different streams of the beet refining process are given in Table 5. The values shown are average values, whereas the actual ethanol yield will depend on the sugar content of beet and the level of impurities. Gumienna et al. [59] compared nearly 50 beet varieties and found that ethanol yields are reduced where impurity levels are higher, including impacts from nitrogen, potassium and sodium content.

Table 5. Ethanol yields from different beet processing streams

Beet product	Value	Unit	Reference
Sugar beet (whole crop average)	103.5	litres per tonne of fresh sugar beet	[60]
	117	litres per tonne assuming 40% conversion of pulp	[60]
	75.2	kg per tonne of fresh beet	[61]
Thick juice	376	litres per tonne of thick juice	[62]
Thin juice	96-115	litres per tonne of thin juice	[63]
Molasses	317	litres per tonne of molasses	[62]
Raw pulp	58-104	litres per tonne of pulp	[63]
Pre-treated pulp residue	504	litres per tonne of dry pulp residue	[64]

Ethanol can be produced from thin juice, without the need for drying or crystallisation, which could potentially reduce energy consumption and costs. For example, Gumienna et al. [63] found that the highest ethanol yields could be achieved from sterilised thin juice compared with thick juice or sugar beet pulp. However, thin juice degrades more readily during storage than thick juice [65] which may prove to be problematic for beet ethanol plants given the seasonal nature of the crop. In order to produce ethanol year-round, plants must have significant storage facilities on site.

Sugar beet ethanol shows high land efficiency, with bioethanol yields of 6,355 litres per hectare compared to 2,686 litres per hectare for wheat [66]. However, despite the higher yields, there are significant energy requirements and associated costs in dewatering the beet, processing it and extracting the sugar for fermentation. Hattori et al. [67] found that the net energy balance of ethanol produced from beet was higher than for wheat and about the same as for maize, but the balance was significantly higher for sugarcane and cellulosic energy crops.

Yields of ethanol may be increased further if sugar beet pulp, which contains cellulose, hemicellulose and pectin, is utilised. The beet pulp must be pre-treated before hydrolysis in order to release fermentable sugars by processes such as acid pre-treatment, steam explosion, ultrasound or microwave pre-treatments [68]. This can, however, be integrated with the extraction of bio-based chemicals [64].

2.5.1 Environmental credentials of beet ethanol

Sugar beet ethanol consumed in the UK transport sector in 2017/18 had a carbon intensity of 34-40 grams of CO_2-equivalent per megajoule of ethanol (gCO_2e/MJ), achieving greenhouse gas savings of 52-60% [69] (against the fossil-fuel comparator, of $84gCO_2/MJ$). The total lifecycle emissions of molasses ethanol (both corn and beet) was estimated to be 41 gCO_2e/MJ (with a range of 35 to 53 gCO_2e/MJ) [21]. However, the lifecycle greenhouse gas emissions are variable depending on growing conditions such as fertilisers rates and process conditions such as fuel used to generate the steam for heat requirements. A study looking at beet ethanol production in California found that a carbon intensity of 28.5 g CO_2e/MJ could be achieved using renewable energy sources [70], not including indirect land use change emissions.

According to REDII, typical conservative greenhouse gas emissions savings for sugar beet ethanol are up to 79% for a plant using natural gas and co-generating biogas from by-products. The distribution of emissions throughout the cultivating and processing stages in presented in Table 6, together with a comparison to other feedstocks used for ethanol production.

Table 6. Typical greenhouse gas emissions from different feedstocks used for bioethanol production according to REDII.

gCO_2/MJ	Sugar beet ethanol	Corn (maize) ethanol	Other cereals (e.g. wheat)	Sugar cane
Cultivation	9.6	25.5	27.0	17.1
Processing	7.6-27.4	1.8-28.6	15.1-30.3	1.3
Transport & Distribution	2.3	2.2	2.2	9.7
Total	19.5-39.3	29.5-56.3	30.7-59.5	28.1

Muñoz et al [71] compared the life cycle environmental impacts of ethanol produced from multiple feedstocks in different countries including Brazilian sugarcane, American maize grain, French wheat and fossil-fuel ethanol. It found that the global warming potential of ethanol produced from French sugar beet was 39% lower than French wheat, 21% lower than Brazilian sugarcane and 20% lower than American maize grain.

Cultivation emissions arise during the preparation of land and the drilling of seeds by farm machinery, which is typically diesel-powered. Seed application emission factors are not insignificant for been, at 3.8 kg of CO_2e per kg of seed (NNFCC Carbon Calculator). The energy requirements for drilling and harvesting of beet can be higher than for cereals due to the weight of the crop and the harvesting equipment needed. However, beet cultivation has lower GHG emissions than wheat due to higher yields and lower specific fertiliser requirements [72]. Beet also compares well to other crops in areas such as water usage, as shown in Figure 12. Best practice advice for sustainability and environmental stewardship is available for growers through the EU Beet Sugar Sustainability Partnership (http://www.sustainablesugar.eu/good-practices).

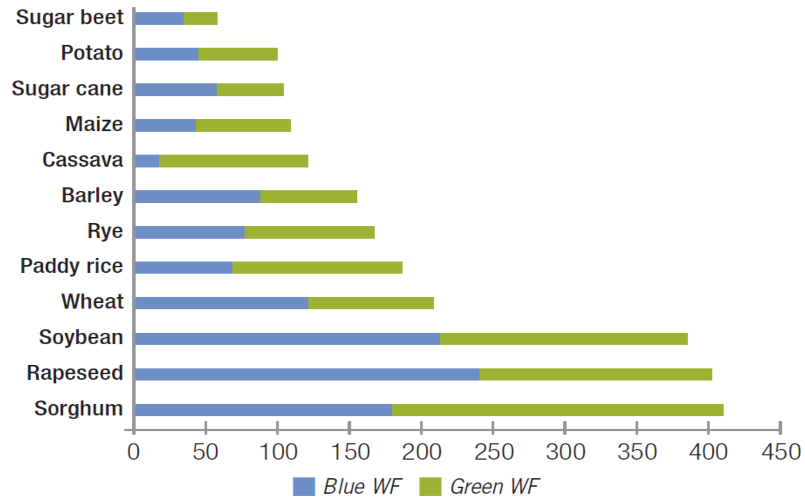

Figure 12. The water footprint of crops used to produce bioethanol or biodiesel. Source: [20]

Life cycle assessment of biorefinery value chains is further complicated by the potential use of products and co-products in other sectors, and an understanding of the target markets is crucial to accurate lifecycle analysis of the environmental impacts. A breakdown of lifecycle CO_2-equivalent emissions for beet ethanol production and co-products is given in Figure 13.

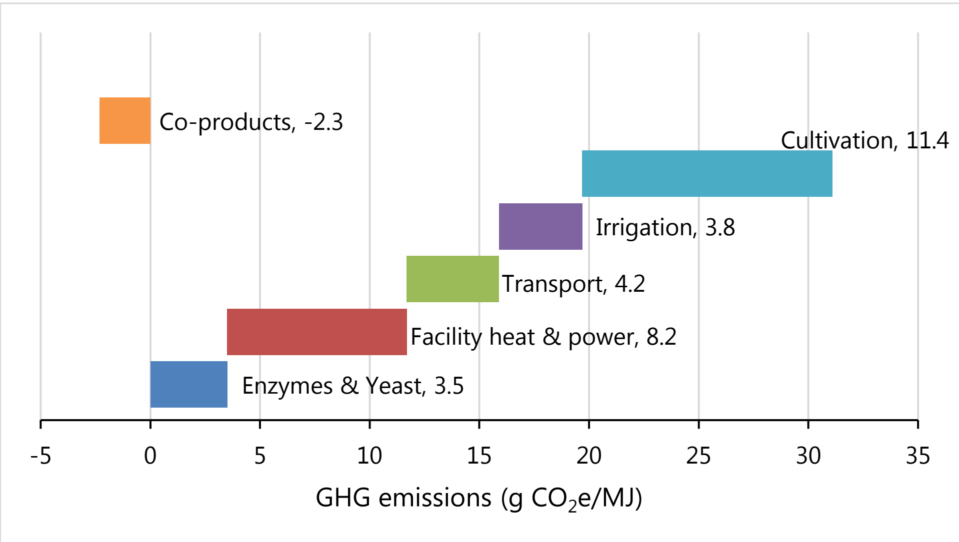

Figure 13. Breakdown of lifecycle greenhouse gas emissions for sugar beet bioethanol production. Data source: Alexiades et al [70].

A study by Foteinis et al [74] looked at the LCA of beet ethanol in Greece and what would be the environmental impact of converting old sugar refineries to beet bioethanol plants. The study found that bioethanol production performed better than crystallised sugar production and conversion of old plants could reduce environmental impacts by almost one third. Other LCA studies for sugar biorefineries are available in [75] and [76].

There is potential to utilise more efficient sugar extraction techniques in sugar beet processing in order to conserve energy and reduce energy demand; for example, microwave extraction is highly efficient [42]. The use of renewables to provide the process heat and electricity requirements also has the potential to reduce life cycle greenhouse gas emissions and environmental impacts which could offer opportunities to increase revenues as renewable fuel demand moves towards offering increased reward based on the degree of carbon saving actually delivered.

2.6 Conclusions

A sugar beet biorefinery can be hugely complex, and the range of processes within and outputs thereof can be vast. A stable feedstock supply is fundamental to the success of a biorefinery, with the extent of processes or products being dependent on the economics, as well as local and global market dynamics.

In simple terms, ethanol can be produced from thin juice, without the need for drying or crystallisation, which can reduce energy consumption and costs. However, thin juice degrades more readily during storage than thick juice which may prove to be problematic for a beet ethanol plant given the seasonal nature of the crop. In order to produce ethanol year-round, plants would need to have significant storage facilities on site or must seek alternative inputs, to enable extended year-round operation.

Yields of ethanol may be increased if sugar beet pulp, which contains cellulose, hemicellulose and pectin, is utilised. The beet pulp must be pre-treated before hydrolysis in order to release fermentable sugars by processes such as acid pre-treatment, steam explosion, ultrasound or microwave pre-treatments. This can, however, be integrated with the extraction of higher-value biobased chemicals.

Sugar beet ethanol shows high land efficiency, and also compares well to other crops in terms of water usage and broader sustainability. The use of renewables to provide input fuel for process heat and electricity requirements also has the potential to reduce life cycle GHG emissions further and reduce environmental impacts. This could offer opportunities to increase revenues in the future as renewable fuel demand moves towards offering increased reward based on the degree of carbon saving actually delivered.

3 Sugar Policy in Europe

The EU sugar sector is regulated by the Common Agricultural Policy (CAP), and its main objectives are:

1. To support farmers and improve agricultural productivity, ensuring a stable supply of affordable food
2. To safeguard European Union (EU) farmers to make a reasonable living
3. To help tackle climate change and the sustainable management of natural resources
4. To maintain rural areas and landscapes across the EU
5. To keep the rural economy alive by promoting jobs in farming, agri-foods industries and associated sectors

As part of the CAP, the sugar sector was originally subject to production quotas and price support. However, as part of the process of making European agriculture more market-orientated, the quota system ended on 30 September 2017. Currently, the EU supports farmers in the form of direct payments, on the condition that they respect strict rules on human and animal health and welfare, plant health and the environment.

EU sugar market policy now focuses on two main areas: market measures and trade measures, which are described in sections 3.2 and 3.3.

3.1 The end of sugar production quotas

In order to support European sugar beet growers and processors, in 1968, a production quota system was originally introduced, along with a support price for producers at a level significantly above the world market price[9]. At this time, the primary objective of the CAP was to encourage agricultural production through remunerative and stable prices for farmers. By setting quotas on how much each sugar processor could produce (restricting sugar supply), the price of sugar could be maintained above a targeted market-clearing price, to incentivise production up to that level[10]. The total EU production quota was 13.5 million tonnes of sugar. Production in excess of the quota was known as "out-of-quota" sugar and strict rules governed its use. It was exported up to the EU's annual World Trade Organisation (WTO) limit of 1.374 million tonnes, sold for biofuel or other industrial non-food uses, or was stored and counted against the following year's sugar quota[11].

However, the CAP is a dynamic policy and over the years it has become more focused on aligning European production with global markets. As part of the process of making European agriculture more market-orientated (Table 7), the production quota system ended on 30 September 2017. There are no longer limits to production or to exports, allowing production to better adjust to market demand, both within and outside the EU.

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[9] EU used a price support system to support production quota and maintain sugar price at a higher level. Price support means that the EU buys up whatever output is missing to maintain sugar price at the target level (EU adds its demand to the demand of sugar consumers, so the price is maintained higher). As shown in table 1, the price support was gradually replaced by payments to support farmers' incomes.

[10] The sugar sector was suffering from low profit margins due to relatively high production costs of sugar beet compared to sugar cane as well as low sugar prices, influenced by low-cost non-EU producers.

[11] There was also a small quota of 0.72 million tonnes for an alternative sweetener called iso-glucose (also known as Glucose Fructose Syrup) and surplus production of iso-glucose is subject to similar restrictions.

3.2 Market measures within the EU that support the sugar sector

Despite the abolition of the sugar production quota, various measures from the CAP still benefit the EU sugar sector, addressing unexpected disturbances on the market.

- Member States have the option of providing voluntary coupled support linked to production, to address sectors in difficulties, including sugar beet production[12].
- A delegated act was adopted that improves the negotiating powers of beet growers towards their sugar producers when concluding agreements regarding the delivery of beet.
- EU Commission launched a Sugar Market Observatory that provides up-to-date information on production and prices to support farmers in making their business decisions.
- Private storage aid can also be granted if necessary, considering market prices, reference thresholds, costs and margins.
- Like other agricultural sectors, the sugar sector is covered by several disturbance clauses available in the Common Market Organisation Regulation that would allow the Commission to act in case of severe market crisis, involving a sharp increase or decrease of market prices.

3.3 Trade with countries outside the EU

While EU countries have a common market organisation for intra-EU trade on sugar, the EU has agreements with other countries worldwide on sugar import and export. Trade policy is an exclusive power of the EU – so only the EU, and not individual member states, can legislate on trade matters and conclude international trade agreements[13]. The EU sugar market is protected by high tariffs[14], but a number of preferential quotas are also used, mainly granted to economically developing countries. More specifically, as a major importer of cane sugar, the EU grants duty-free access to the EU market for developing countries under the "Everything But Arms" (EBA) agreement and Economic Partnership Agreements (EPAs) with the African Caribbean and Pacific (ACP) countries. The EU is also a sugar exporter and since the end of the quotas, these exports are not limited by WTO rules, allowing sugar producers to fully explore new markets and possibilities.

The UK exported 84,000 tonnes of sugar to non-EU countries in 2017/2018 and 245,000 tonnes to other Member States (only 22% of EU-27 imports). Imports into the UK from non-EU countries are mainly raw sugar – on average 482,000 tonnes (26% of overall EU imports of raw sugar) over the last five marketing years and around 475,000 tonnes in 2017/2018. The UK imported close to 560,000 tonnes in 2017/2018, of which around 550,000 tonnes were from the EU-27 (17% of total exports) [84].

[12] This is an option taken up by 11 Member States – Croatia, Czech Republic, Finland, Greece, Hungary, Italy, Lithuania, Poland, Romania, Slovakia and Spain - with overall coupled support for sugar beet amounting in 2017 to roughly €179 million.
[13] International trade is also governed by rules of the World Trade Organisation (WTO).
[14] For the introduction of production quotas to make economic sense, the EU sugar market was protected by high tariffs, limiting external competition. These tariffs remained substantial, after the abolition of production quotas.

Table 7. The evolution of the European sugar support policy

Year	Support price for sugar	Payments to support farmers' incomes	Production Quotas	Management of the EU sugar market
1968	££	✘	✓	The quota system and support prices for sugar were introduced to help the CAP achieve one of its initial goals: to improve food self-sufficiency.
1992	£	££	✓	Reduction in support price for sugar and introduction of direct payments to support farmers' incomes (The CAP shifted from market support to producer support).
2003	£	£	✓	'Decoupling' of direct payments to farmers; payments no longer linked to the quantity of sugar produced.
2006-2010	✘ by 2008/2009	£	✓	Gradual reduction of support prices for beet and sugar, phasing out public intervention and an end to export refunds; EU countries agree in principle to end quotas, and to encourage the restructuring of the EU sector with €5.4 billion.
2013	✘	£	✘ in October 2017	EU countries and the European Parliament agree to end the sugar quota system at the end of the 2016/2017 marketing year
2017	✘	£	✘	The European Commission launches the Sugar Market Observatory to help the sector manage the transition following the end of quotas. The Observatory gives producers and processors access to the latest data on production and prices to help them better develop their business.

3.4 The impact of quota abolition

Following the end of the sugar quota, during the 2017/18 marketing year, sugar beet production reached 142 million tonnes, a level never reached in the past 15 years and 27% above the last five-year average; while EU sugar production reached 21.1 million tonnes, 26% more than in 2016/17.

The additional availability boosted exports significantly, to an estimated 3.3 million tonnes (+149% compared with the five-year average), while at the same time, due to lower domestic prices, imports fell to an estimated 1.3 million tonnes, just over half the average in previous years. The excess supply has put additional pressure on world prices, which have fallen steadily over the last two years from a peak of EUR 540/t in October 2016 to EUR 274/t in August 2018, the lowest level since 2007[15] [78].

Table 8: Market developments in the EU [78]

	2017/2018	2018/2019
Production	↑ +26%	↓ -9.3%
Exports	↑ +149%	↓ -20%
Imports	↓ -46%	⇨ +0.0%
Consumption	↑ +5.6%	⇨ +0.0%

For the period 2018/19, sugar production is forecast at 19.2 million tonnes, which is 9% lower than the previous marketing year, but still 8% above the five-year average. No significant change is expected in imports compared to 2017/18, while the lower availability on the EU market and the low world sugar prices could translate into lower exports [78].

Regarding 2019/20, there is an indication that low EU sugar prices in 2017/18 will probably impact production and sugar beet cultivation area. Royal Cosun (Netherlands) announced its intention to reduce the harvest by 10-15 %, while in the UK, British Sugar announced that it would be offering only annual contracts to sugar beet growers from 2019/20 onwards [78]. These are clear indications of, and response to, what are seen to be more volatile markets for sugar producers in future years as they struggle to predict future demand and competitiveness.

3.5 Short-term effects of the quota abolition

Historically, the EU sugar regime kept EU sugar prices well-above the world price-level[16]. Since the quota abolition, the European sugar sector became more market-orientated, and as a result, EU white sugar prices have moved significantly closer to the world price. Combined with the reduction in world sugar prices, this puts EU sugar sector under significant pressure [79].

[15] In July 2018, the EU sugar price was EUR 346/t, compared with a world price of EUR 284/t.
[16] Measuring the difference between domestic and world prices was commonly used to assess the degree of protection and distortion in a market.

According to European Association of Sugar Manufacturers, current sugar prices are not sustainable for beet and sugar production, as they are falling far below EU average production costs [80]. Despite the savings in production costs there are few sugar processors that have been able to produce sugar at a break-even value. The collapse of EU sugar prices has prompted Europe's biggest sugar refiner Suedzucker to announce the closure of several factories by 2020 [81][17].

According to the European Association of Sugar Manufacturers, due to increased price volatility in the market, the diversification of sugar beet outlets - including bioethanol, biochemical, and bioplastics - has become more important than ever[83].

3.6 Conclusions

The UK remains a net importer of sugar, mostly from within Europe. Sugar demand is growing for fuel and chemicals, but dietary sugar consumption is falling both domestically and within the EU.

There is an indication that low EU sugar prices in 2017/18 will likely impact production and sugar beet cultivation area in the short-term. Key producers are either reducing contracted production areas/volumes or offering shorter-term contracts to reduce their exposure. These are clear indications of, and response to what are seen to be more volatile markets for sugar producers in future years as they struggle to predict future demand and competitiveness.

Since the quota abolition, the European sugar sector became more market-orientated, and as a result, EU white sugar prices have moved significantly closer to the world price. Combined with the reduction in world sugar prices, this puts the EU sugar sector under significant pressure. As the UK is a net importer of sugar, there is a real opportunity for Scotland to mitigate against some of this price volatility, producing bioethanol as a fuel or an intermediate in the production of biobased chemicals.

[17] According to Rabobank, announcements of plant capacity closures are not expected to lead to an equivalent reduction in output, due to partial compensation for closures via boost capacity utilisation in other plants in order to achieve lower costs [95].

4 Policy Landscape

Sugar demand is growing for fuel and chemicals, but dietary sugar consumption is falling both domestically and in the EU, largely due to taxes and labelling requirements on sugary foods and beverages. Despite this, per capita sugar demand is expected to increase in nearly all other regions of the world, with the strongest growth in Asia, Africa and the USA. As a result, both global production and global consumption have increased over the last 10 years. The most signification increases in output have been in Thailand and India, the latter of which recently overtook Brazil and the world's largest producer.

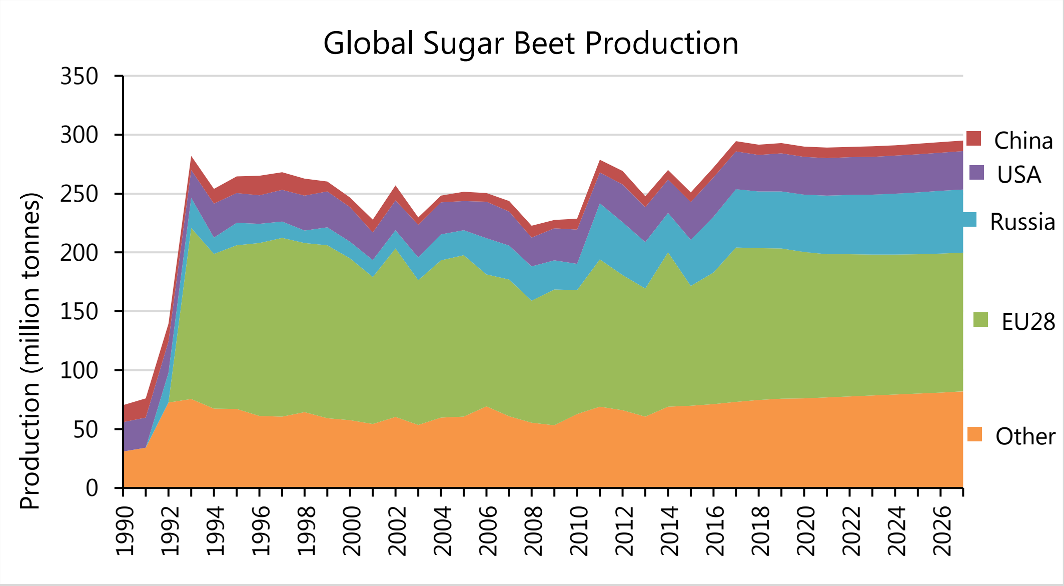


Figure 14. Global sugar beet production 1990 to 2017, and forecasts to 2027. Source: OECD-FAO Agricultural Outlook [56]

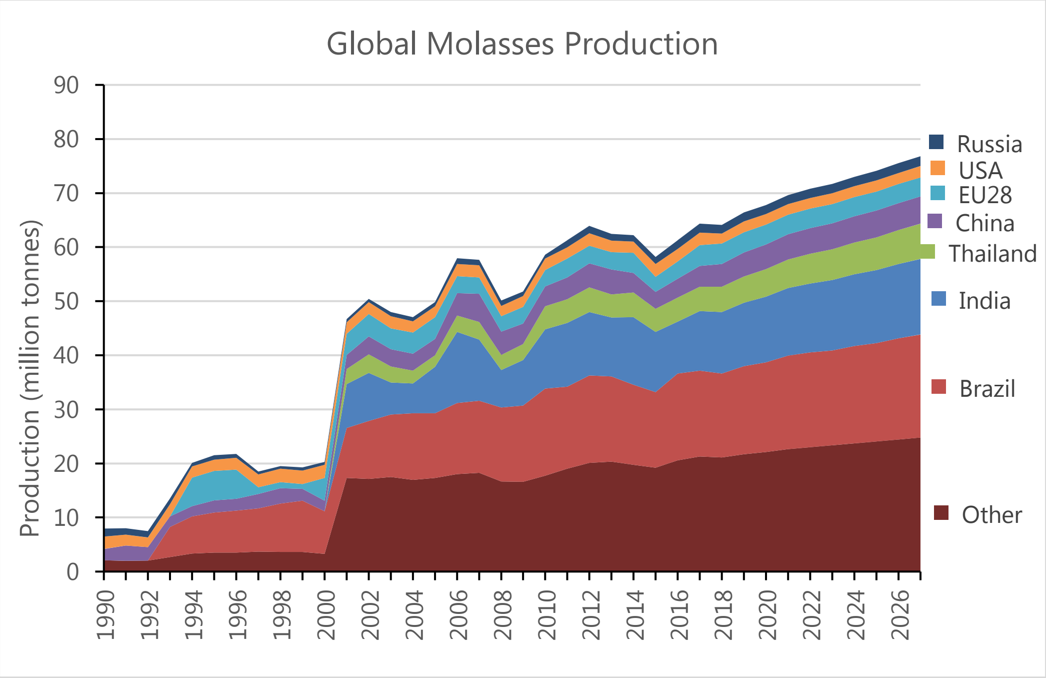


Figure 15. Global molasses production 1990 to 2017, and forecasts to 2027. Source: OECD-FAO Agricultural Outlook [56]

As shown in Figure 14, global sugar beet production is expected to remain stable over the next ten years whereas global molasses production is forecast to increase by 19%, as shown in Figure 15. Molasses is already imported into the UK for animal feed and other purposes, with 120.3 kt imported in 2017/18 (Table 14). The spot price for cane molasses is in the region £210-225 per tonne[18].

National targets set out in the Government's Bioeconomy Strategy [94] were to double the size of the UK bioeconomy from £220bn in 2014 to £440bn by 2030. The value of the bioeconomy in Scotland is estimated at £7.79 billion, supporting 109,260 jobs. Doubling this by 2030 would lead to a Scottish bioeconomy worth £15.6 billion and support 219,000 jobs. Furthermore, a number of other relevant strategies and policies have been published in Scotland, including the Industrial Biotechnology Roadmap and the Climate Change Plan, for example. All such policies include reference to development of the bioeconomy in Scotland, and some more specifically focus on opportunities for producing fuels and chemicals through biorefinery routes.

The following section focusses on biofuels policy as the main driver for a new biorefinery development.

4.1 The current policy landscape for biofuels

UK policy on decarbonisation of transport has to date largely been driven by the EU's Renewable Energy Directive (RED), which built on the earlier Biofuels Directive that established indicative targets for replacement of fossil fuels. The RED established mandatory targets for fossil energy reduction in all sectors of the economy to be achieved by 2020. The RED requires all member states to ensure that 10% of transport energy is derived from renewable sources by 2020. This requirement was transcribed into UK law through introduction of the Renewable Transport Fuel Obligation (RTFO) in 2008.

Under the RTFO, suppliers of transport fuel in the UK must be able to show that a percentage of the fuel they supply comes from renewable and sustainable sources. Suppliers of renewable fuels are awarded Renewable Transport Fuel Certificates (RTFC's) for fuels that meet the required sustainability criteria. These attain a market value through being sold alongside the fuel or via trading platforms used by fuel suppliers looking to purchase certificates to meet their renewable fuel obligation. Over time the RTFO has been complicated by mechanisms adopted by successive governments and revisions to the RED to incentivise specific types of fuels such as those derived from specific waste streams, that are awarded 2 RTFC's per litre. This complicates reporting of progress against the RED target as some fuels now multiple count.

In addition, the EU Fuel Quality Directive (FQD) was transcribed into UK law as the Motor Fuel (Road Vehicle and Mobile Machinery) Greenhouse Gas Emissions Reporting Regulations 2012) which came into force on 1st January 2013 and requires the UK to reduce the average greenhouse gas (GHG) intensity of transport fuels by 6% in 2020 (against 2010 EU average figure). Compliance with achieving a 4% GHG reduction in 2019 and 6% by 2020 has been made a mandatory obligation on UK fuel suppliers.

These two pieces of legislation have a significant impact on the opportunities for different types of

[18] Data from Farmers Weekly market prices for straights http://pages.fwi.co.uk/pdf/market-prices/FWMP_Straights.pdf

biofuels in the marketplace and, from January 2019, the imperative to meet specific GHG reduction targets is focussing specific attention on the GHG credentials of individual biofuels and the cost/kg of carbon saving delivered.

4.1.1 Progress against targets

Progress in meeting the RED target for transport has been slow and there is a significant way to go to achieve the 10% RED target (Figure 16), which demonstrates that there is significant remaining market potential to at least double UK biofuel use if the appropriate drivers are put in place. However, the adoption of double counting for biofuels derived from specified wastes and advanced development fuels which 'virtually' contribute to renewable energy deployment complicates estimation of the actual volume of single counting renewable fuels that would be required to achieve these targets.

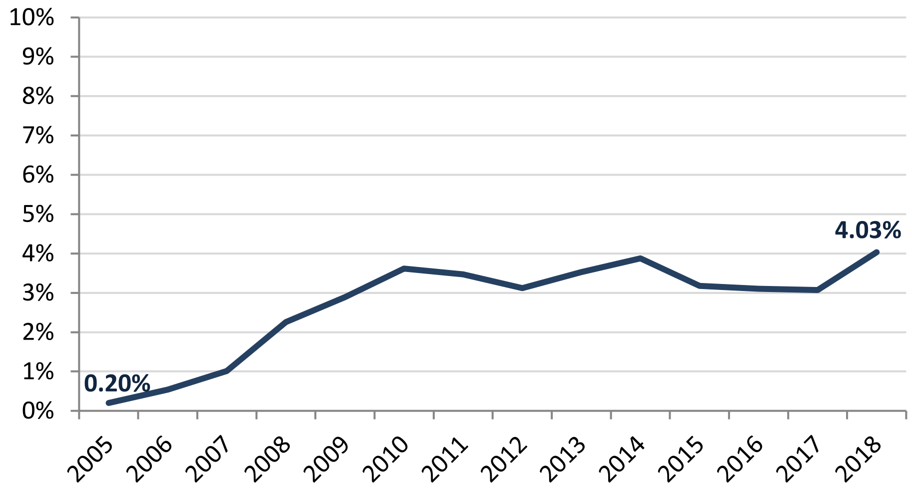


Figure 16. Share of biofuels in transport petrol and diesel consumption, Scotland, 2005 - 2018

Generally, the UK fuel demand has continued to slowly rise, but within this the demand for petrol has declined while diesel demand has increased. Recent concerns over air quality in towns and cities and the role of diesel emissions on this may temper future divergence rates.

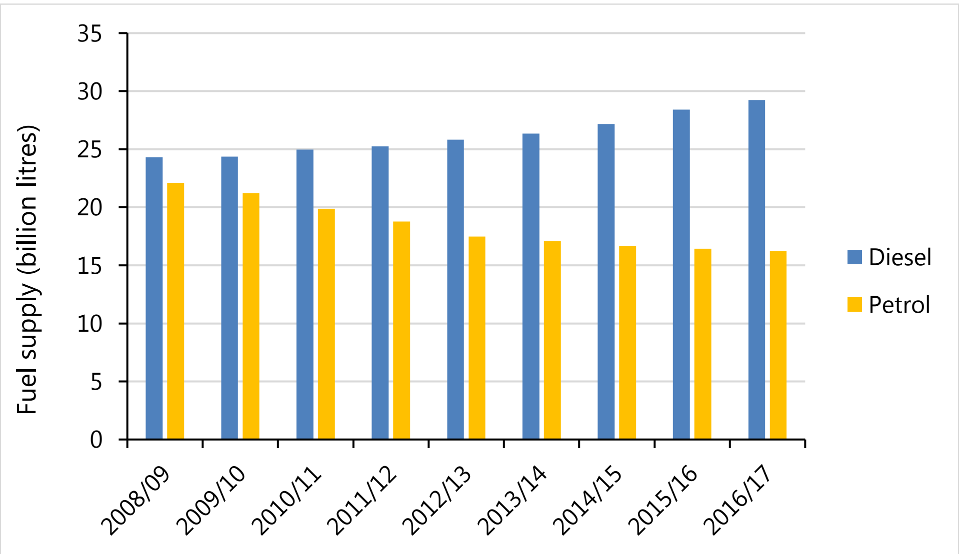


Figure 17. Change in fuel type used in UK road transport since 2008 (Source BEIS: ENV0501)

The UK currently supplies just 23% of its domestic biofuel requirement. Over time, biofuels used in the UK have moved away from biodiesel produced from virgin oils and increasingly towards use of biodiesel derived from used cooking oil (UCO FAME, which accounts for 41% of UK biofuel supply). The FQD is currently pushing up demand for UCO FAME at the expense of other renewable fuels due to its very low GHG credentials compared to other biofuels.

Bioethanol is still predominantly derived from virgin crop sources (Figure 18), though bioethanol derived from starch slurry has made significant inroads into demand in recent years (10%), just behind wheat as the leading source of bioethanol (11%).

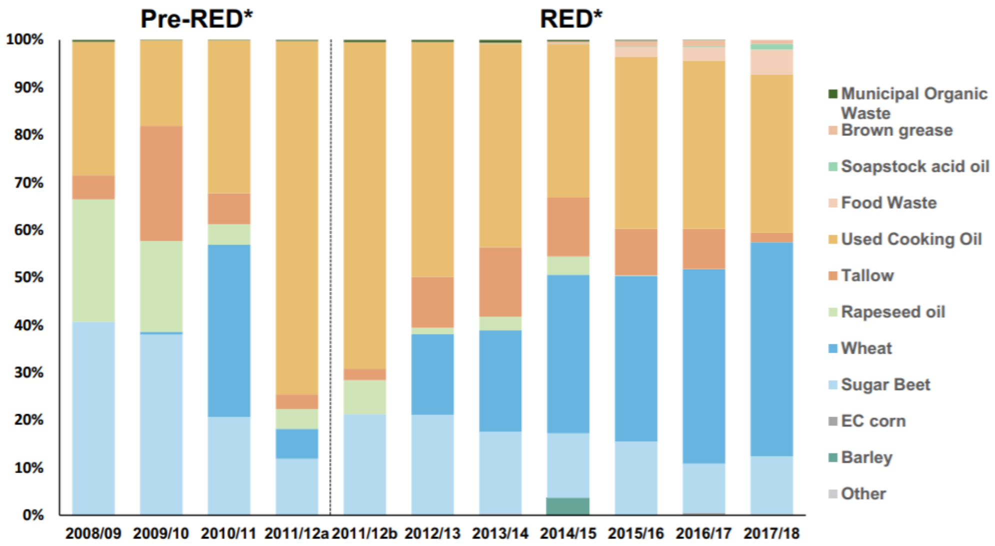


Figure 18. Renewable fuel feedstock mix supplied each year to meet the RTFO (source: RTFO statistics)

Currently, 23% of bioethanol used in the UK is produced from domestic feedstocks; but the UK production of bioethanol is greater than this as UK bioethanol producer Ensus uses a mix of both domestic and imported feedstocks.

4.1.2 Current UK bioethanol supply capacity

The UK has until recently had three key ethanol producers; Vivergo Fuels in Hull with 420 million litre capacity, Ensus (CropEnergies Group) plant in Teesside with 400 million litres capacity and British Sugar's Wissington plant with 81 million litres capacity. Ensus and Vivergo represent some of the largest bioethanol plants in Europe. Vivergo Fuels mothballed production in Autumn 2018, citing market difficulties given the low price of ethanol in Europe. Similarly, Ensus operates intermittently as a balancing plant for Crop Energies European operations, when crop and ethanol price are favourable.

Table 9. Crop derived bioethanol supplied in the UK (2017/18). Source: RTFO Statistics, Year 10

Feedstock	Million litres
Corn	212
Wheat	193
Sugar beet	125
Sugar cane	25
Total	**555**

Recent UK bioethanol demand has ranged from 782 to 861 million litres in the UK which pretty much reflects the production capacity of existing UK bioethanol facilities. After accounting for waste-derived sources, 555 million litres of bioethanol are currently derived from crop feedstocks and supplied in the UK (Table 9). The shutdown of Vivergo Fuels therefore leaves a production capacity gap in the UK.

4.1.3 Calls for increased blend limits for ethanol in conventional petrol

UK bioethanol supply/demand has been well matched in recent years. The supply of bioethanol into the petrol market currently equates to 4.5% on a volumetric basis, closer to 4% on an energy basis. Car manufacturers currently warrant unmodified petrol engines to utilise up to 5% bioethanol inclusion, but technically it is possible to increase this to 10% for most modern cars with low risk. The biofuel industry in the UK has been lobbying for the introduction of so called "E10" biofuel blends to support the DfT in delivering on its decarbonisation targets while also increasing the market headroom for domestic supply in the face of fierce competition from imports.

4.2 Future policy drivers

Following substantial amendments made to the RED over time it has recently been 'recast' to increase clarity. The recast "Renewable Energy Directive II" (RED II) also establishes new renewable energy targets for the 2021 – 2030 period. While the current Brexit debate leaves uncertainty over whether in the longer term this has any relevance to the UK, currently it is still the basis for UK policy making.

RED II requires fuel suppliers in all member states to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 from renewable sources, with each member state defining its own detailed trajectory to reach these targets. However, due to ongoing concerns about impact on land use change associated with crop-derived biofuels, the contribution of these will be capped at 2020 consumption levels within the community, and with a maximum allowable contribution of 7% towards road and rail transport in each member state, but member states are free to set lower caps than this. The UK has opted to set a crop cap of 4% on the contribution that can be made from crop-derived biofuels which after 2020 will fall linearly to 2% by 2032.

In addition, GHG saving requirements of biofuels are also tightening, a saving of at least 65% should be achieved in GHG emissions for biofuels derived from installations starting operation after 1 January 2021 compared to 60% for those that started after 5 October 2015.

4.2.1 Consequences for crop-derived fuel ethanol

Assuming petrol demand remains at current levels in the UK (given uncertainty around how diesel demand will respond to air quality concerns and how quickly electric cars will enter the fleet) a 4% cap on crop-derived biofuels would currently provide headroom of around 2,031 million litres of biofuel production from crops like sugar beet, which would reduce over time to 1,015 million litres by 2032 (Figure 19).

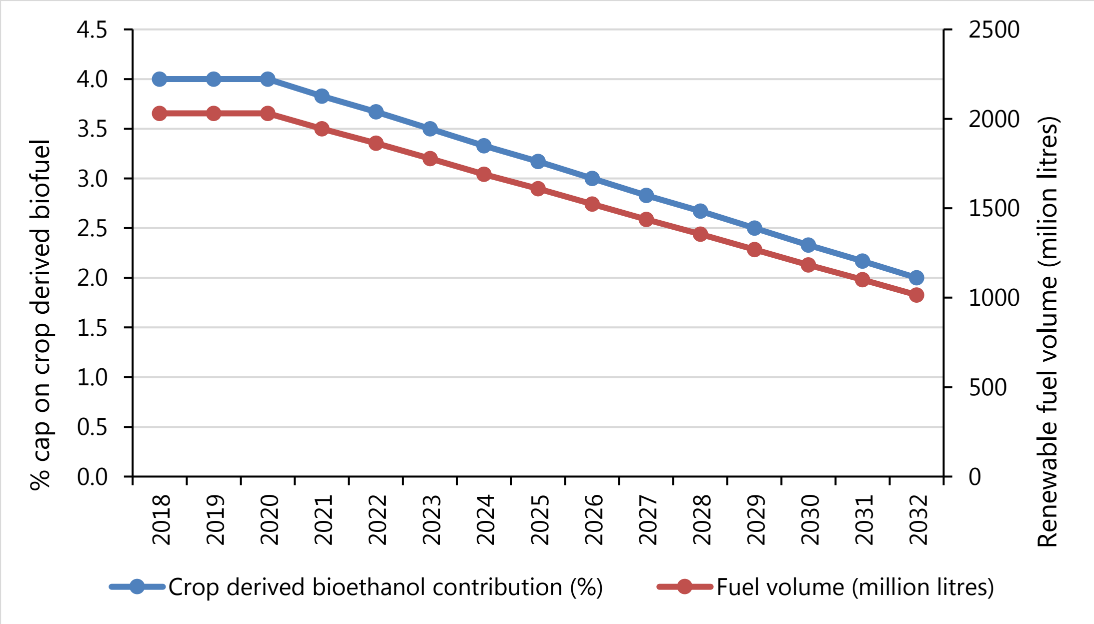


Figure 19. Limit on % contribution to biofuel obligation from crop-derived biofuels and equivalent estimated volume of fuel (million litres). The latter assumes conventional fuel demand remains at current levels

As most biodiesel would most likely continue to be derived from waste oil resources (via imported feedstocks) much of this potential market would be available for bioethanol fuels. With a current UK ethanol demand of around 760 million litres, this provides some headroom for UK growth to replace lost UK capacity and compete with imports, but there would also be limits on how much of an E10 market (of potentially 1,900 million litres) could be addressed by food crop-derived bioethanol which would be open equally to both domestic production and imports. There would need to be development of cellulosic ethanol capabilities and exploitation of more waste-derived resources to fully exploit the UK markets opened by introducing E10 fuels.

4.3 Demand for biofuels in Scotland

It is difficult to obtain detailed data on transport fuel use in Scotland, but based on petroleum product sales and assuming a similar split in fuels to that for the rest of the UK, estimates of petrol demand and associated renewable fuel demand were calculated on a volumetric basis and in this case taking account of the different energy values of petrol and biodiesel (to identify biofuel volumetric demand based on an equivalent energy forgone basis for petrol).

The implications on bioethanol demand for current blend volumes (4%) and a potential E10 blend across the petrol fleet in Scotland (i.e. all flex fuelled vehicles) are shown in Table 10.

Table 10. Maximum ethanol demand in Scotland created by different inclusion rates in the road transport fleet

Fuel ethanol blend	Ethanol demand (million litres)
Current (4%)	57
E10	145

The current Scottish fuel-ethanol demand equates to the output of a relatively small ethanol plant by European standards. For example, Wissington which produces ethanol as a subsidiary by-product produces 81 million litres per year. The potential Scottish fuel demand created by an E10 mandate would equate to a typical medium-scale bioethanol plant in mainland Europe.

4.4 Refining capacity

The UK has the fourth largest oil refining capacity in Europe, primarily used for the production of transport fuels. The UK has seven active refineries, which includes Grangemouth in the Firth of Forth owned by PetroIneos. It supplies most of Scotland's forecourts as well as sites in northern England, producing 13% of the UK's refined fuel output (with the capacity to refine 210,000 barrels per day of crude oil). Annually, Grangemouth produces over 9 million tonnes of fuel per year (LPG, gasoline, jet fuel, diesel, home heating oil) plus 1 million tonnes of chemical products (ethylene, propylene, polyethylene, polypropylene, ethanol). The site directly employs over 1,300 people and contributes 4% of Scottish GDP. Scotland therefore has significant regional capability for blending transport fuels.

4.5 Conclusions

The capability of plants to produce ethanol from molasses has been well established, with yields of up to 317 litres of ethanol per tonne of molasses. Molasses is already imported into the UK for animal feed and other purposes. Although global sugar beet production is expected to remain stable over the next decade, global molasses production is forecast to increase by 19%. Therefore, imported molasses may be a potential alternative source of sugar for a bioethanol production facility in Scotland; this could be particularly useful to allow continuous operation, even outside the beet harvesting season.

A Scottish sugar beet biorefinery will help both Scotland and the UK to meet sustainability and decarbonisation targets. This includes building on national targets set out in the Government's Bioeconomy Strategy [94] to double the size of the UK bioeconomy from £220bn in 2014 to £440bn by 2030. The value of the bioeconomy in Scotland was estimated at £7.79 billion, supporting 109,260 jobs. Doubling this by 2030 would lead to a Scottish bioeconomy worth £15.6 billion and support 219,000 jobs.

Table 11. Potential contributions of a Scottish beet ethanol facility to local and national policies

Policy	Publisher	Contribution of Scotland beet biorefinery
UK Bioeconomy Strategy	HM Government	Helping double the size of the bioeconomy by 2030 and creating jobs.
Scotland Biorefinery Roadmap	Scottish Enterprise	Innovation, industry engagement, stimulation of market demand through a flagship project.
Biorefining Potential for Scotland	Zero Waste Scotland / Ricardo	Fits well within the strategic opportunities outlined for bio-based raw materials and products.
Bioeconomy Accelerator	Zero Waste Scotland / IBioIC	Potential funding source for SMEs to develop new processes and products from plant by-products such as beet pulp.
National Plan for Industrial Biotechnology	IBioIC	Fits in with vision to achieve a mature bioeconomy by 2025, increasing the number of industrial biotechnology active companies to over 200 with turnover over £900m.

Climate Change Plan	Scottish Government	Help to deliver sustainable economic growth and create a greener, fairer and healthier Scotland by 2032. Achieved by decarbonisation of transport with bioethanol and of heat with biogas/biomethane.

Progress for meeting the RED target for transport has been slow and there is a significant way to go to meet the current 10% target. As RED II comes into force, this target rises to 14% from renewable sources by 2030, with each member state defining its own detailed trajectory to reach these targets. As a result of ongoing concerns about the impact on land use change associated with crop-derived biofuels and new incoming legislation, the UK has opted to set a crop cap of 4% which after 2020 will fall linearly to 2% by 2032. However, as biodiesel would most likely continue to be derived from waste oil resources much of this potential market would be available for bioethanol fuels.

The biofuel industry in the UK has been lobbying for the introduction of “E10” biofuel blends to support the DfT in delivering on its decarbonisation targets while also increasing the market headroom for domestic supply in the face of fierce competition from imports. There is clear headroom for UK growth to replace lost UK capacity and compete with imports, but there will also be limits on how much of an E10 market could be addressed by food crop-derived bioethanol which would be open equally to both domestic production and imports. Other waste-derived or developmental fuels need to be pursued in parallel, to ensure the 2% limit remains feasible, without compromising production potential.

Vivergo Fuels mothballed production in Autumn 2018, citing market difficulties given the low price of ethanol in Europe. Similarly, Ensus only operates intermittently as a balancing plant for Crop Energies European operations, when crop and ethanol price are favourable. This provides clear evidence that such facilities are highly sensitive to market conditions, so in the case of Scotland, diversity of outputs would be key, to mitigate risks of collapse when ethanol prices fall.

Recent UK bioethanol demand has ranged from 782 to 861 million litres in the UK which pretty much reflects the production capacity of existing UK bioethanol facilities. The shutdown of Vivergo Fuels therefore leaves a production capacity gap in the UK.

5 Technoeconomic analysis

5.1 Supply chain costs

This section outlines the typical costs that would be associated with the establishment of a sugar beet supply chain in Scotland and the value of the products, skills and labour to the Scottish economy.

5.1.1 Cultivation and harvesting

Growing costs for sugar beet are encountered through cultivation and drilling, as well as the purchase of seeds, chemicals and fertiliser and the application thereof.

Advanced agricultural machinery has allowed the automation of beet harvesting, using multiple-row self-propelled harvesters, which has reduced the labour requirement and the time taken for harvesting. However, the purchase of harvesting machinery can be a significant capital investment for farmers. A six-row trailed harvester is estimated to cost between £102,400 and £153,600, and a six-row precision pneumatic drill is estimated to cost up to £19,200 with twelve row drills costing up to twice that amount [16]. Different ownership models for the machinery have been evaluated below (see 5.1.2). The seasonal labour demands from sugar beet growing can be significant between the end of September and early January, as shown in Figure 20.

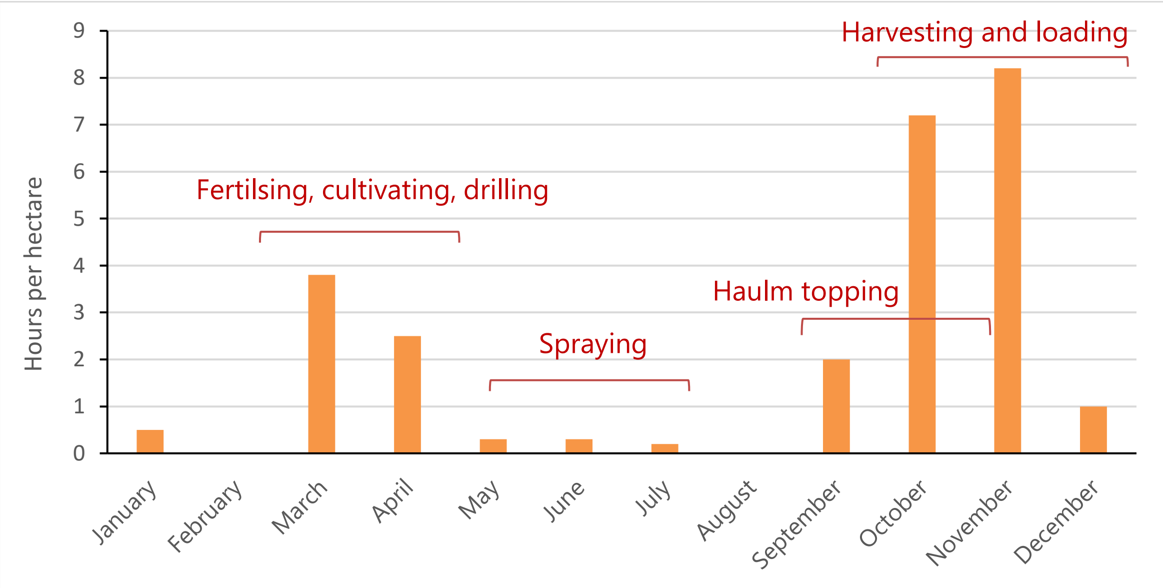


Figure 20. Seasonal labour requirements for sugar beet growing and harvesting

The haulm (leaves, stalks and tops) of the crop may be removed by a separate harvester or flail prior to harvest. Most farmers contract out the harvesting at a cost of approximately £281 per hectare, with 10 hectares typically harvested in a standard 8-hour day.

Loading is another labour-intensive aspect of sugar beet production, often requiring manual loading of several HGVs per day using a front-loader, and the requirement to clean the beet prior to delivery is becoming increasingly common. This slows the loading process as all beet must be loaded via a cleaner, to remove soil and stones, thus reducing overall transport volumes, minimising waste derived on the processing site, and lowering the overall environmental impact. This activity intensifies labour demands in the autumn months, as often beet is delivered to processors at or shortly after harvest, due to the inability to store beet for long periods. A breakdown of the growing costs for a sugar beet crop is presented in Figure 21.

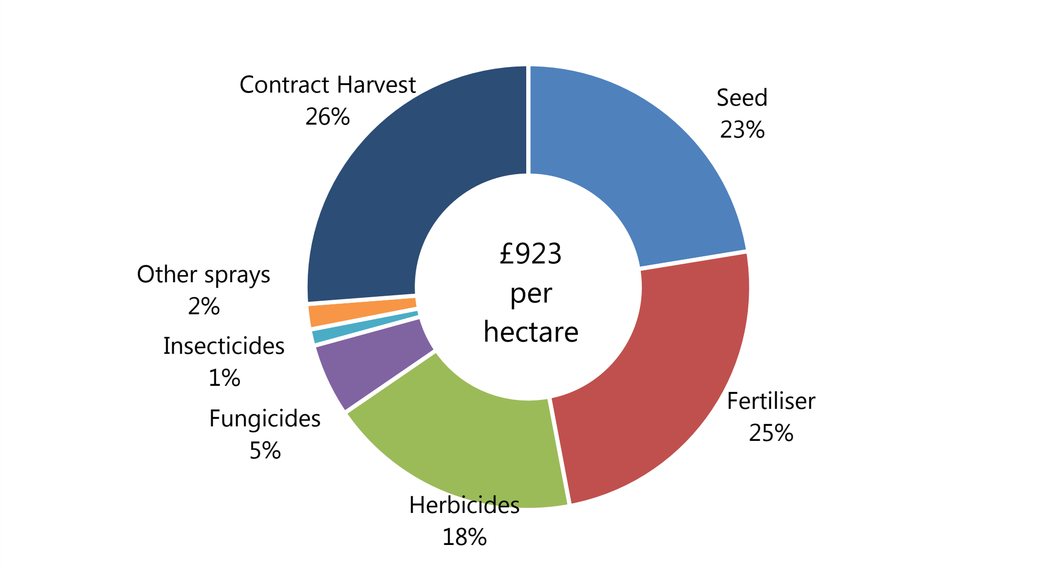


Figure 21. Growing and harvesting costs for sugar beet crops (2019). Data source: [16]

5.1.2 Ownership models for sugar beet sowing and harvesting equipment

Sugar beet production requires specialist precision sowing equipment, flails and harvesters. There are several machinery ownership models that can help to reduce the cost burden on individual farmers. A contracting service can be set up by the sugar beet processing plant or intermediaries to spread the machinery cost over a larger production area. Under this model, farmers do not have to invest in their own machinery and can avoid certain financial risks. Currently, there are no contractors in Scotland offering sugar beet harvesters with capacity beyond fodder- and energy-beet areas, and some initial investment would be required to build up this capability. There would be little prospect of waiting for equipment to move from further south in what could be an increasing risk of deteriorating weather conditions in the autumn harvesting period and increasing risk of soil damage.

Machinery Rings can deliver substantial savings on machinery, labour and commodities (machines can be made available with skilled operators). A shortage of machinery and labour capacity on one farm is matched with a surplus on another and they can also benefit from the collective buying power of their members to source both machinery and other farm inputs at better prices than individuals. In this model, the farmers act as shareholders of the machinery, while an administration/management team would remain responsible for the distribution, financing and maintenance of the equipment.

A machinery ring can also take the form of a co-operative of farmers and agricultural businesses who have the mutual aim of reducing machinery and labour costs. The supplier benefits by spreading machinery costs over a larger area and the member is able to reduce his capital investment in labour and machinery while at the same time having access to up to date equipment. In this model, the investment will be made by individual contractors or farmers, who will rent the equipment to members of the ring. Again, there is a need for an administration team who remain responsible for the machinery rental payments and the organisation of the ring. Machinery Rings already play a key role in Scotland, optimising efficiency and generating economic activity for agriculture and associated rural businesses. There are examples of successful machinery rings in the UK at http://www.machineryrings.org.uk/.

5.1.3 Transport costs

Transport costs for sugar beet can be significant and can hinder the economic performance of processing facilities. Beet is a heavy, bulky crop with a high moisture content which can lead to high haulage costs.

The average distance for transport between the beet grower and processing facility is 28 miles for the British Sugar plants, although a maximum of 60 miles was agreed between British Sugar and the NFU. It is estimated, based on discussions with NFU, that transport distances in excess of 60 miles (approx. 100 km) will incur haulage costs of almost half the price of the crop.

The average cost of haulage is £5.60 per tonne, but prices vary according to the distance between farm and factory [16]. Some indicative transportation costs for growers within a 28-mile and 60-mile radius of a theoretical plant location of Cupar, Fife, is shown in Figure 23. Not surprisingly, as the location of the previous sugar processing plant in Scotland, Cupar has good road connections and a rail connection to Dundee, which presents a potential alternative transportation route for beet grown outside the 60-mile economic area.

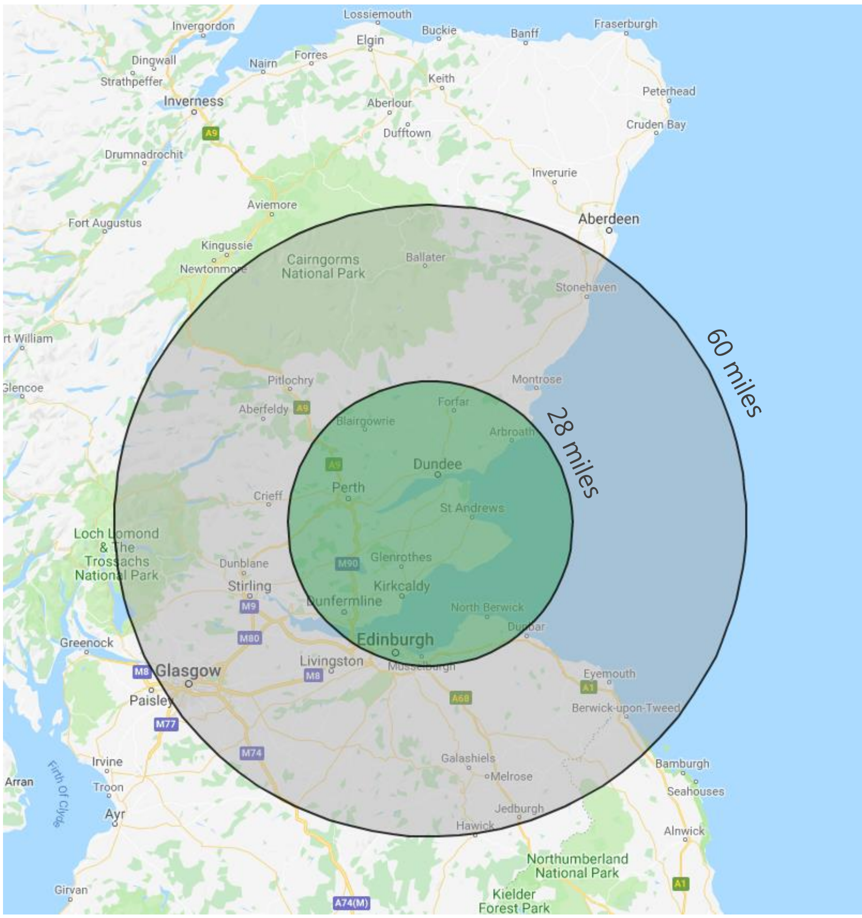
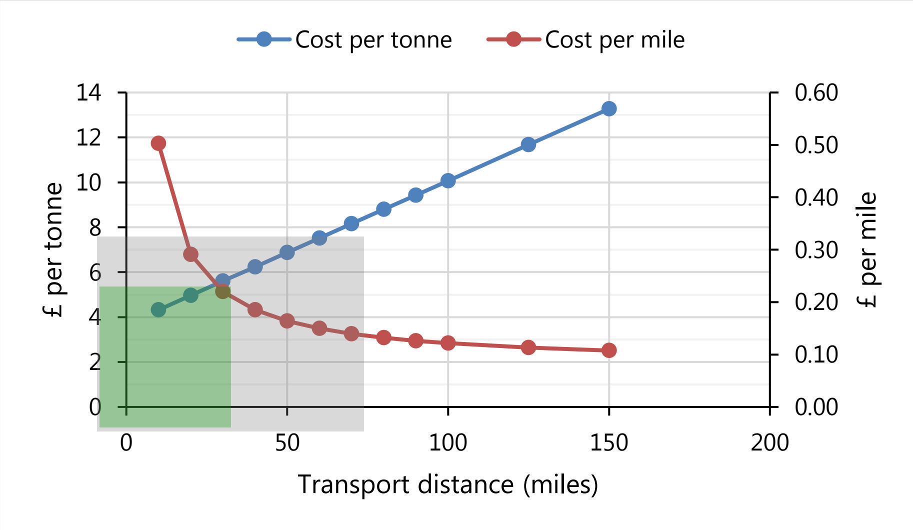


Figure 22: Illustrative 28-mile and 60-mile raidus round theoretical Cupar processing facility location.

The Industry Harvest and Haulage Scheme was set up by British Sugar in 2010 to provide harvesting and haulage services to beet growers. The scheme was amended in 2018 following a review by WSP[19] in order to identify where greater transparency would benefit growers and hauliers alike. An estimate for the haulage costs can be derived from Figure 23.



*Costs are derived from the AHDB/HGCA Grain Haulage Survey 2014, adjusted for inflation. As such, these costs should only be used as an indicator rather than definitive costs.

Figure 23. Haulage costs for harvested crops by weight and distance for a plant located in Cupar.

5.1.4 Plant capital costs

The capital expenditure (CAPEX) costs of establishing and constructing a sugar beet to bioethanol facility in Scotland are dependent on the location and the specific circumstances and requirements of the plant.

CAPEX costs for a 38, 76 and 152 million litre plant located in Oklahoma, USA, were estimated at £851/m^3, £712/m^3 and £592/m^3 respectively [85]. However, CAPEX costs as low as £253/m3 have been reported (figures from USDA [86], adjusted for currency and inflation). A study by Vučurović et al [87] reported an average investment cost of £55.5 million for a 44 million litre/year capacity beet ethanol plant located in Europe, averaging over £1,200/m^3.

A breakdown of the CAPEX costs for this scale of plant is provided in Table 12, for illustrative purposes. These figures are also used in the scenario analysis (see section 5.5), scaled according to the ethanol demand.

Table 12. CAPEX costs for a sugar beet bioethanol plant

	£ GBP (2018)
Total capital investment cost	**55,560,114**
Direct fixed capital (DFC = TPC + CFC)	51,764,985
Total plant cost (TPC = TPDC + TPIC)	45,013,241
Total plant direct cost (TPDC)	28,133,074

[19] Copy of the report available at https://www.britishsugar.co.uk/perch/resources/nfu-british-sugar-industry-haulage-scheme-independent-observer-final-rep....pdf

Equipment purchase cost:	8,801,986
Fermenters	2,423,454
Disc-stack centrifuge	1,191,532
Batch distillation vessel	386,137
Scrubber	46,046
Rectification column	203,570
Molecular sieves	2,181,109
Evaporators	442,684
Rotary drum dryers	780,352
Condenser	46,046
Unlisted equipment	880,522
Installation	3,751,507
Process piping	2,640,757
Instrumentation	3,345,175
Insulation	264,157
Electrical	880,522
Buildings	3,784,628
Yard improvement	1,319,975
Auxiliary facilities	3,345,175
Total plant indirect cost (TPIC):	16,880,167
Engineering	7,033,672
Construction	9,846,495
Contractors fee and contingency (CFC):	6,751,744
Contractors fee	2,250,581
Contingency	4,501,163
Working capital	1,206,880
Start-up and validation cost	2,588,249

*Assumes a plant capacity of 44 million litres of ethanol per year produced from 564 kt of raw juice. Data sourced from Vučurović et al [87] and adjusted for inflation and currency.

5.1.5 Plant operational costs

The plant operational expenditure (OPEX) costs consist of routine maintenance and servicing of equipment, as well as costs of utilities for process energy requirements. In addition, there are costs associated with feedstocks, raw materials and labour. An outline of these costs for a beet ethanol plant with a capacity of 44 million litres is given in Table 13. These figures are also used in the scenario analysis (see section 5.5), scaled according to the ethanol demand.

Table 13. OPEX costs for a sugar beet bioethanol plant

	£ GBP per year
Total OPEX	**16,949,640**
Raw materials	1,645,525
Yeast	342,515
Raw juice	1,302,203
Fixed costs (e.g. service, maintenance, insurance, taxes, etc.)	5,709,820
Labour	5,628,957
Laboratory QC/QA	224,977

Utilities	5,999,827
Electricity	3,327,080
Steam	804,264
Chilled water	1,868,483
Co-production	-2,259,467

* Assumes a plant capacity of 44 million litres of ethanol per year produced from 564 kilotonnes of raw juice. Data has been sourced from Vučurović et al [87] and adjusted for inflation and currency.

The average cost of producing bioethanol from sugar beet in Europe was reported at £403-520 per m^3 ethanol capacity, significantly more expensive than the cost to produce bioethanol from Brazilian sugar cane, estimated to be £112 per m^3 (figures from [85], adjusted for currency and inflation). The cost difference is primarily down to the feedstock being used. The focus in Europe and the US is on producing ethanol from corn (maize) which involves a more complex enzymatic extraction process, to convert starch to sugar, than sugar cane or beet which can simply be pressed and distilled.

A techno-economic analysis of a 75 million litre beet ethanol plant in the USA was conducted by De Laporte and Ripplinger [88]. It found that net benefits could be achieved for both growers and ethanol producers and that the plant could be profitable at higher beet prices ($33/tonne) and lower ethanol prices ($0.40/litre) than typically seen in the UK. The yields used in the economic modelling (60-76 t/Ha) were also lower than UK averages (83 t/Ha).

5.2 Value of products and co-products

5.2.1 Sugar beet

British Sugar and NFU Sugar announced their agreement on sugar beet contract terms for 2019/20 in September 2018, offering a one-year 2019 contract price of £19.07 per tonne (ex-farm), with no crown tare deduction. Other changes to the agreement terms were also announced, as follows:

- The crown tare deduction will be removed permanently for all new contracts agreed from the 2019 crop onwards.
- No new three-year deal on offer in 2019.
- For the 2019 one-year contract - a 15% (increasing from 10% in 2018) revenue share for growers above an EU average white sugar price of €375/tonne.
- Late Delivery Allowance payments in each campaign to be calculated based on the highest guaranteed minimum beet contract price paid during a campaign.
- Performance rules to be based on fulfilling at least one of two criteria, either delivering sufficient tonnage or planting a sufficient area of sugar beet.

Building on this increased focus on revenue share, British Sugar and NFU Sugar have also agreed to work together to develop a greater risk/reward contract model with the intention of a one-year pilot in 2020/21. This is an important step forward in growers having the option to share more of the reward and risk that exists in the sugar market today.

5.2.2 Ethanol

The Argus spot asking price for ethanol (T2 fob Rotterdam incl. duty) was $606 per tonne in January 2019 (approx. 54.5 pence per litre). Since May 2016, the price has reached a low of 39.1 ppl and a high of 58.9 ppl. The price volatility shows a close correlation with oil prices; as oil price increases ethanol becomes a comparatively cheaper alternative and an increase in demand drives prices up. Furthermore, price is highly sensitive to changes to import duties and trade protection measures in force, in particular in the US.

5.2.3 Sugar beet pulp

The value of sugar beet pulp to the Scottish economy is determined by the animal feed spot price. Dried sugar beet pulp pellets are already imported into Scotland from overseas for animal feed via the ports at Glasgow and Grangemouth.

Cellucomp, a potential key market for pulp from the proposed plant, currently use less than 1,000 tonnes of dried beet pulp pellets per year. The Cellucomp facility is currently at the demonstration scale, and pulp demand could be up to 10,000 tonnes per year following scale-up. A local source of beet pulp may be attractive if there are lower transport costs and lower lifecycle GHG emissions; however, raw materials must be price-competitive with imports.

As shown in Table 14, 153 kt of beet pulp was imported to the UK in the year July 2017 to July 2018, of which 48% came from outside the EU. The value of this import is £25 million assuming a beet pulp price of £166 per tonne.

A key requirement of sugar beet pulp as a raw material for Cellucomp is that it is dry and pelletised. Wet sugar beet pulp is not suitable for the process and in order to be used alternatively as an animal feed, it must be either consumed within 10 days or ensiled to prevent degradation. A Scottish plant may therefore require additional drying and pelleting steps to process of beet pulp in order to remain an attractive source of raw materials, even for local processors.

Table 14. Imports of sugar beet pulp and molasses in 2016/17 and 2017/18. Source: AHDB [89]

Feed type	Import region	2016/17 (tonnes)	2017/18 (tonnes)
Beet pulp	EU	73,077	79,889
	Non-EU	155,305	73,040
	Total	**228,382**	**152,929**
Beet molasses	EU	75,375	67,690
	Non-EU	52,586	52,600
	Total	**127,962**	**120,291**

5.3 Job creation

According to a recent report by British Sugar [90], the sugar beet value chain currently supports 9,500 jobs in the UK economy; 3,388 in beet production and 6,067 in processing.

Table 15: Number of jobs created in sugar beet value chain. Source: British Sugar [90]

	Sugar beet production	Sugar beet processing	Total
Direct employment	1,438	1,701	3,139
Indirect employment	1,625	3,937	5,562

Direct and indirect employment	3,063	5,638	8,701
Induced employment	325	429	754
Total employment	3,388	6,067	9,455

5.4 Case studies of similar plants in Europe

A typical UK sugar factory, such as the British Sugar factory in Wissington, processes 3 million tonnes of sugar beet annually which generates 400,000 tonnes of refined sugar, 64,000 tonnes of bioethanol and over 100,000 tonnes of dried sugar beet pulp. The target end product for Wissington is refined sugar, with bioethanol mostly being produced from surplus and by-products. Across Europe, there are numerous other beet refineries and several beet ethanol plants. The locations of these plants are given in Figure 24, together with the beet growing areas shown in green.

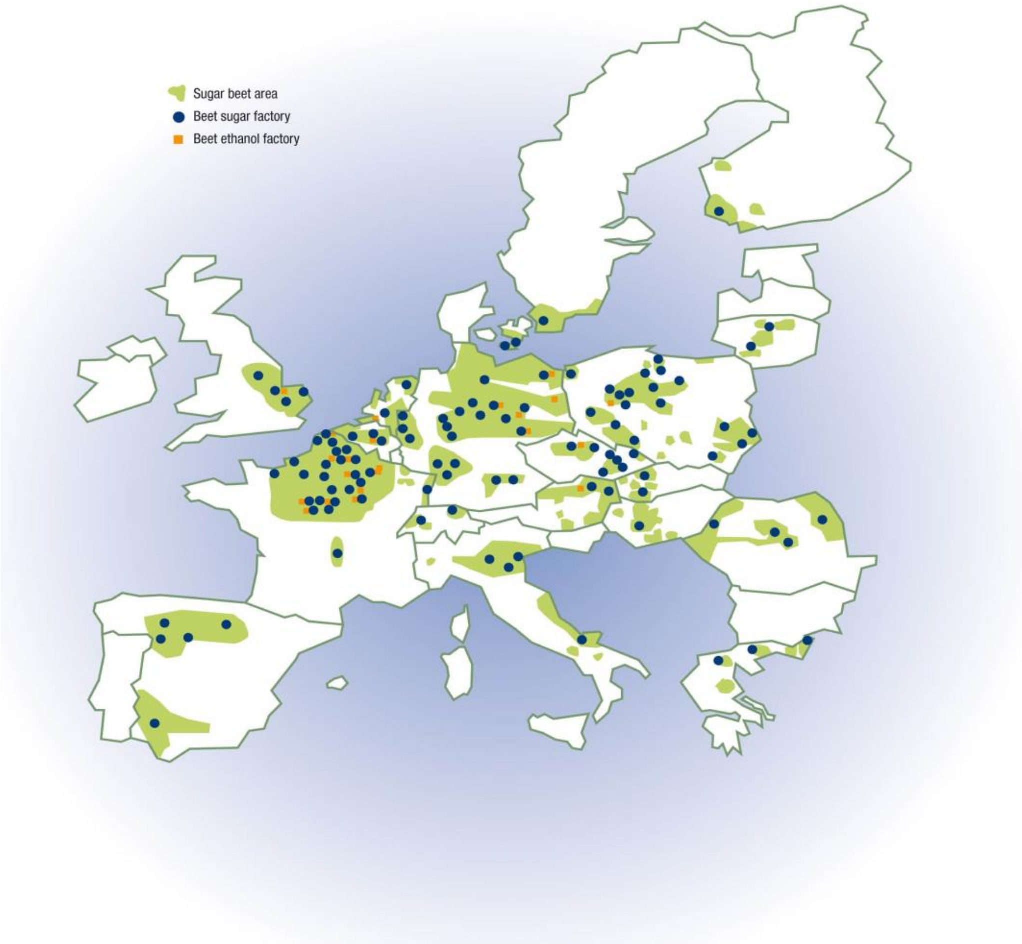


Figure 24. Locations of beet growing areas, beet sugar factories and beet ethanol plants in Europe. Source: ePURE [57].

In total there are 106 sugar beet factories in Europe, supplying and processing beet from 140,000 growers in 19 different member states, plus Turkey and Switzerland.

Figures for the sugar beet growing area, production and yield in each member state are given in Table 16Figure 11, together with the number of sugar beet refineries operating in that country and the key companies who own and operate them.

Table 16. Production of sugar beet in Europe and number of beet factories in 2018. Data sourced from [91] and Eurostat.

	Harvested production in 2018 ('000 tonnes)	Crop area ('000 ha)	Yield (t/ha)	Operating sugar beet factories	Key companies
Hungary	942	15.9	59.3	1	Agrana
Sweden	1,698	30.7	55.3	1	Nordzucker
Finland	355	9.8	36.3	1	Nordzucker
Switzerland	1,231	18.7	66.0	2	Swiss Sugar AG
Slovakia	1,312	21.9	59.9	2	Nordzucker, Agrana
Lithuania	889	15.5	57.2	2	Nordzucker, Danisco
Netherlands	6,508	85.2	76.4	2	Raffinerie Tirlemontoise, Iscal, Suiker Unie
Italy	1,941	34.4		2	Eridania, Italia Zuccheri
Greece	397	6.9	57.5	2	Hellenic Sugar Industry (EBZ)
Denmark	2,108	34.3	61.5	2	Nordzucker
Austria	2,150	31.3	68.8	2	Agrana
Croatia	771	14.1	54.8	3	Viro, Sladonija
Belgium	5,192	62.7	82.8	3	Finasucre, Raffinerie Tirlemontoise, Iscal
Serbia	2,583	51.3		3	Sunoko
Romania	937	24.3	38.5	4	Agrana
United Kingdom	7,620	110.0	69.3	4	British Sugar
Spain	3,064	35.4	86.7	5	Azucarera
Czech Republic	3,724	64.8	57.5	7	Agrana
Poland	14,300	235.0	50.7	18	Krajowa Spółka Cukrowa, Nordzucker, Südzucker, Diamant
Germany	26,191	413.9	63.3	20	Nordzucker, Südzucker, Pfeifer & Langen
France	39,580	485.3	81.6	25	Saint Louis Sucre, Erstein, Tereos, Cristal Union
EU	**119,687**	**1,731.4**	**62.3**	**106**	**Südzucker, Tereos, Agrana, AB Sugar**

The market leader and largest processor of sugar beet in Europe is Südzucker, producing almost 5 million tonnes of sugar per year. Headquartered in Mannheim, Germany, the group has 29 sugar factories and two refineries spanning 11 countries. Südzucker is also the largest producer of bioethanol in Europe through its subsidiary CropEnergies. Through its facilities in Germany, Belgium, France and the UK, CropEnergies has an ethanol production capacity of 1.3 million m^3 per year. The UK site is Ensus Ltd in Teeside, which has a production capacity of 400,000 m^3.

French company Tereos is the second largest processor of sugar beet in Europe, producing 2 million tonnes of sugar and 675,000 m^3 of bioethanol from 19.8 million tonnes of raw beet across 4 countries. Details of the major beet bioethanol plants in Europe are given in Table 17, together with the estimated mass of beet required (assuming ethanol yields of 117 litres per tonne of fresh sugar beet).

Table 17. Major bioethanol producers in Europe. Data source: EurObserv'ER [92]

Country	Location	Company	Feedstock	Ethanol capacity (million litres)	Theoretical beet requirement * ('000 tonnes)
UK	Wissington	British Sugar	Beet	81	689
Germany	Klein Wanzleben	Nordzucker	Beet	130	1,111
Austria	Pischelsdorf	Agrana	Beet plus grain sugar	250	2,137
Hungary	Szabadegyhaza	Hungrana	Multiple feedstocks, mainly corn	189	1,614
Germany	Misburg	KWST	Beet molasses	24	205
France	Bazancourt	Cristanol	Beet	150	1,282
France	Origny + others	Tereos	Beet plus grain sugar	1,260	10,769

* This assumes the maximum potential ethanol yield from beet roots, whereas in reality most plants will use a waste stream such as molasses

5.5 Demand scenarios

An overview of the assumed plant structure is shown in Figure 25. This simplified structure assumes that ethanol is produced from the thick juice and the vinasse is used in an on-site anaerobic digestion plant. Here the pulp is assumed to be sold as animal feed, since this is the base cost scenario (any other use for the pulp, as described earlier, must be cost competitive with the use as animal feed). The key potential uses of the sugar beet are shown in green in Figure 25. The pulp may be digested to produce biogas or may be pre-treated and fermented to produce additional ethanol.

Three scenarios have been devised to estimate the potential demand for bioethanol in Scotland and what this translates to in terms of sugar beet demand and land area. The scenarios are based on projected demand to meet potential bioethanol fuel blending targets, descried below:

1) **Current ethanol demand scenario**: A plant able to produce enough ethanol to achieve a 4% blend of ethanol in current petrol supply across Scotland.
2) **E10 Fuel Mix**: A plant able to produce enough ethanol to achieve a 10% blend in petrol, in the Scottish transport fleet
3) **Most likely outcome**: The amount of ethanol a plant is likely to produce given available land and agronomy constraints.

The underlying assumptions for each of the scenarios are presented in Table 18. This includes fixed constants such as total available land area and assumed values such as sugar beet yields per hectare. The process heat is assumed to be from steam derived from natural gas at 60% thermal efficiency, with utilities paid for at standard rates for industrial consumers.

Scenarios present the main revenue and expenditure likely to be incurred, based on expected scale of operation. The Net Turnover figure is revenue less expenditure, as illustrated in the tables. Additional expenditure, such as cost of finance, has not been excluded so would need to be considered in order to determine the likely profitability of such a facility.

Table 18. Underlying assumptions in each of the three scenarios

Total croppable area:			Beet growing area:		
England	4,995	kHa	England	116.3	kHa
Scotland	625.8	kHa	Yield	83	t/Ha
INPUTS					
Utilities:			**Fiscal values:**		
Electricity	18.5	kWh per tonne beet	Sugar beet value	19.07	£ per fresh tonne
Process heat	91.4	kWh per tonne beet	Bioethanol	0.55	£ per litre
Products and co-products:			Animal feed	219	£ per tonne
Ethanol yield	103.5	litres per fresh tonne	Topsoil	50	£ per tonne
Pulp	70	kg per tonne	Stones	5	£ per tonne
Topsoil	50	kg per tonne	Spent lime	30	£ per tonne
Stones	1.7	kg per tonne	CO_2	10	£ per tonne
Spent lime	40	kg per tonne	Vinasse	-	-
CO_2	0.001	tonnes per litre of ethanol	Biogas	0.4	£ per m3
Vinasse	5.56	kg per l ethanol	Digestate	5	£ per tonne
Biogas	109.2	m^3 per tonne vinasse	Electricity	0.100	£ per kWh
Digestate	0.9	tonnes per tonne vinasse	Natural gas	0.0222	£ per kWh

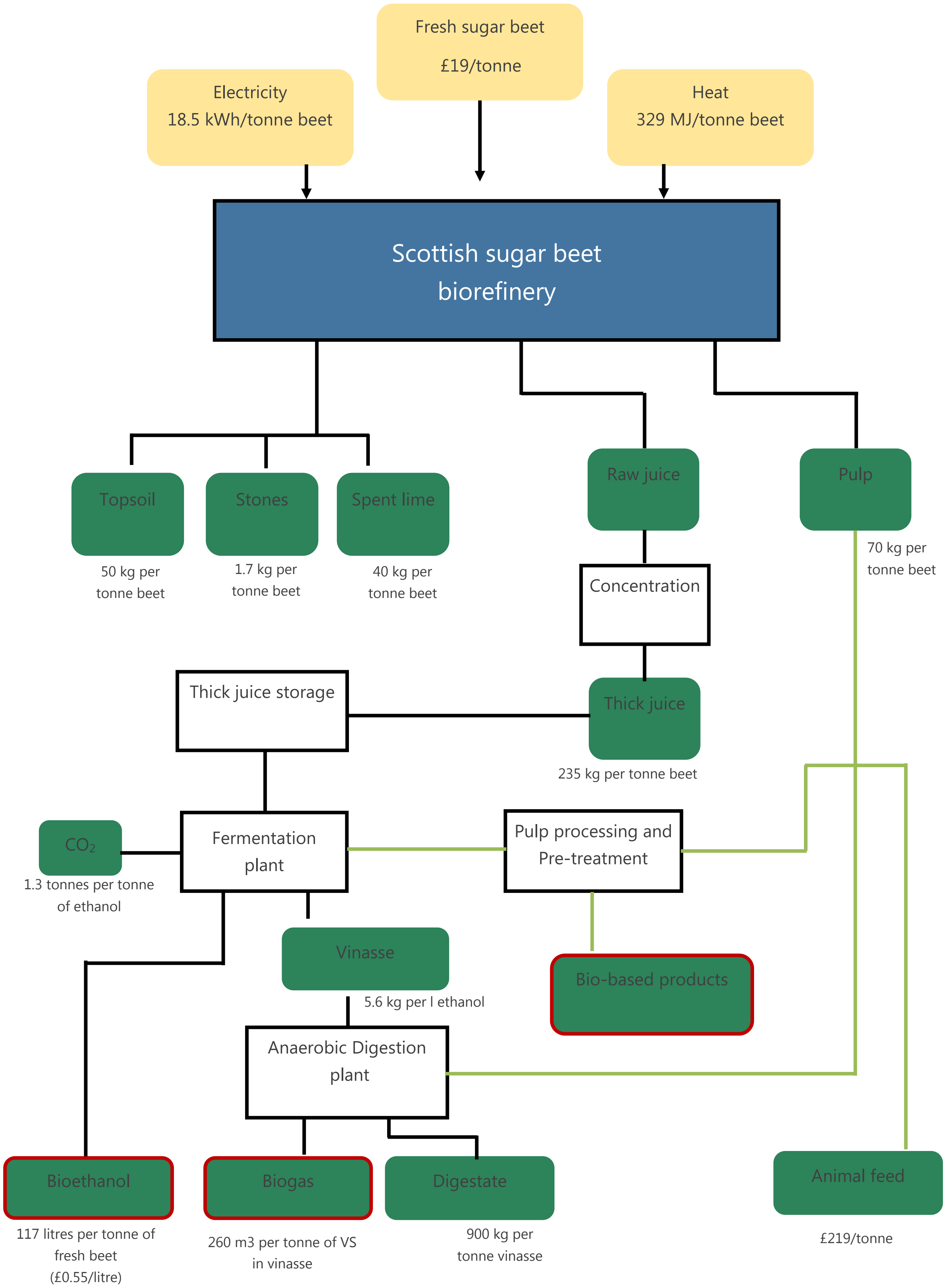


Figure 25. Flow diagram for the proposed plant

5.5.1 Scenario 1: Current ethanol demand

This scenario looks at the possibility of establishing a sugar beet biorefinery to produce enough bioethanol to meet the current demand in the Scottish transport sector. Currently, petrol sold at the pump contains 4-5% bioethanol and 95-96% fossil gasoline.

Table 19. E4 scenario plant outputs and costs

Scenario 1: Current ethanol demand E4					
Key metrics			**Capex**	**£**	**71,975,602**
Ethanol required	57,000,000	litres	Lifetime (years)		20
Beet required	550,725	Fresh tonnes	**Revenue**	**£**	**57,692,739**
Land cultivated	6,635	Hectares	Bioethanol	£	31,350,000
% of growing area	1.1	%	Beet pulp as animal feed	£	8,442,609
Co-Products			Topsoil	£	1,376,812
Pulp	38,551	Tonnes	Stones	£	4,681
Topsoil	27,536	Tonnes	Spent lime	£	660,870
Stones	936	Tonnes	CO_2	£	588,562
Spent lime	22,029	Tonnes	Biogas	£	13,843,066
CO2	58,856	Tonnes	Digestate as fertiliser	£	1,426,140
Vinasse	316,920	Tonnes	**Expenditure**	**£**	**34,535,835**
Biogas	34,607,664	m3	Raw materials	£	10,946,031
Digestate	285,228	Tonnes	Utilities	£	5,302,153
Utilities			Labour	£	7,292,058
Electricity	10,188,406	kWh	Fixed costs	£	7,396,812
Process heat	50,330,113	kWh	Depreciation *(straightline)*	£	3,598,780
Natural gas (assuming 60% effic	83,883,521	kWh	**Net turnover**	**£**	**23,156,904**

In order to produce 57 million litres of ethanol, 551 kt of beet will be required from a land area of 6.6 kha (just over 1% of available croppable land area in Scotland).

Given land availability and agronomy constraints, this scenario does seem feasible. The estimated net turnover of this plant is £23.2 million; this figure takes into account the most significant OPEX but doesn’t include project-specific expenditure such as cost of finance and other administrative expenses. Such additional costs would need to be considered in order to more accurately determine the net profit of such a facility.

5.5.2 Scenario 2: E10 fuel mix

This scenario looks at the possibility of a potential plant to produce enough bioethanol to increase the bioethanol blend percentage to 10% ethanol and 90% fossil gasoline, with a correction for the lower energy content of ethanol.

Table 20. E10 scenario plant outputs and costs

Scenario 2: E10 fuel mix					
Key metrics			**Capex**	**£**	**183,357,819**
Ethanol required	145,207,478	litres	Lifetime (years)		20
Beet required	1,402,971	Fresh tonnes	**Plant revenue**	**£**	**146,972,231**
Land cultivated	16,903	Hectares	Bioethanol	£	79,864,113
% of growing area	2.7	%	Beet pulp as animal feed	£	21,507,542
Co-Products			Topsoil	£	3,507,427
Pulp	98,208	Tonnes	Stones	£	11,925
Topsoil	70,149	Tonnes	Spent lime	£	1,683,565
Stones	2,385	Tonnes	CO_2	£	1,499,362
Spent lime	56,119	Tonnes	Biogas	£	35,265,204
CO2	149,936	Tonnes	Digestate as fertiliser	£	3,633,091
Vinasse	807,354	Tonnes	**Expenditure**	**£**	**59,968,759**
Biogas	88,163,011	m3	Raw materials	£	27,885,011
Digestate	726,618	Tonnes	Utilities	£	13,507,234
Utilities			Labour	£	18,576,515
Electricity	25,954,960	kWh	Fixed costs	£	18,843,376
Process heat	128,215,943	kWh	Depreciation *(straightline)*	£	9,167,891
Natural gas (assuming 60% effic	213,693,238	kWh	**Net turnover**	**£**	**87,003,471**

In order to produce 145 million litres of ethanol, 1.4 million tonnes of beet will be required from a land area of 17 kHa (almost 3% of available croppable land area in Scotland).

Given land availability and agronomy constraints, this scenario does seem feasible. The estimated net turnover of this plant is £87 million; this figure takes into account the most significant OPEX but doesn't include project-specific expenditure such as cost of finance and other administrative expenses. Such additional costs would need to be considered in order to more accurately determine the net profit of such a facility.

5.5.3 Scenario 3: Most likely outcome

This scenario takes into account the findings of the previous two scenarios, together with the agronomy constraints and socioeconomic issues for growers to re-establish a beet crop in Scotland (section 1.2). Taken together, these variables are constrained to a most likely outcome based on available evidence and professional judgement of NNFCC.

Though this is the most likely outcome, there may be several limiting factors which are currently unknown, such as achievable beet yields in Scotland compared to the rest of the UK. The authors therefore recommend that these figures be used as indicative estimates rather than absolute values.

Table 21. Most likely outcome scenario plant outputs and costs.

Scenario 3: Most likely outcome					
Key metrics			**Capex**	**£**	**216,949,618**
Ethanol required	171,810,000	litres	Lifetime (years)		20
Beet required	1,660,000	Fresh tonnes	**Plant revenue**	**£**	**173,898,061**
Land cultivated	20,000	Hectares	Bioethanol	£	94,495,500
% of growing area	3.2	%	Beet pulp as animal feed	£	25,447,800
Co-Products			Topsoil	£	4,150,000
Pulp	116,200	Tonnes	Stones	£	14,110
Topsoil	83,000	Tonnes	Spent lime	£	1,992,000
Stones	2,822	Tonnes	CO_2	£	1,774,051
Spent lime	66,400	Tonnes	Biogas	£	41,725,914
CO2	177,405	Tonnes	Digestate as fertiliser	£	4,298,686
Vinasse	955,264	Tonnes	**Expenditure**	**£**	**70,955,247**
Biogas	104,314,785	m3	Raw materials	£	32,993,643
Digestate	859,737	Tonnes	Utilities	£	15,981,806
Utilities			Labour	£	21,979,798
Electricity	30,710,000	kWh	Fixed costs	£	22,295,549
Process heat	151,705,556	kWh	Depreciation *(straightline)*	£	10,847,481
Natural gas (assuming 60% effic	252,842,593	kWh	**Net turnover**	**£**	**102,942,814**

Here we assume that the growing area is initially limited to 20 kha due to agronomy constraints, transport distances and farmer attitudes towards growing the sugar beet crop. For context, each of the four sugar refineries in England is served by 29 kha of beet growing area on average. This equates to 2.3% of croppable land area in England being used for beet.

In this scenario, 172 million litres of ethanol are produced from almost 1.7 kt of fresh beet, requiring 3.2% of croppable land area in Scotland. The estimated net turnover of this plant is £102.9 million; this figure takes into account the most significant OPEX but doesn't include project-specific expenditure such as cost of finance and other administrative expenses. Such additional costs would need to be considered in order to more accurately determine the net profit of such a facility.

5.6 Sensitivity analysis

The success of a sugar beet to ethanol facility in Scotland would be highly sensitive to beet and ethanol price; both of which have experienced volatility in recent years. The analysis below provides an indication of the degree of sensitivity to such values, and the impact low, medium and high price scenarios could have on the net turnover of a processing facility in line with the scale proposed under Scenario 3 (see 5.5.3).

Table 22: Sensitivity analysis on beet and ethanol price, for the most likely outcome (Scenario 3)

Sensitivity analysis: Revenue		Ethanol price (£ per litre)		
		Low	Med	High
Beet price (£/tonne)		0.40	0.55	0.70
Low	14.30	£ 148,126,561	£ 173,898,061	£ 199,669,561
Med	19.07	£ 148,126,561	£ 173,898,061	£ 199,669,561
High	23.84	£ 148,126,561	£ 173,898,061	£ 199,669,561

Sensitivity analysis: Expenditure		Ethanol price (£ per litre)		
		Low	Med	High
Beet price (£/tonne)		0.40	0.55	0.70
Low	14.30	£ 63,037,047	£ 63,037,047	£ 36,037,047
Med	19.07	£ 70,955,247	£ 70,955,247	£ 70,955,247
High	23.84	£ 78,873,447	£ 78,873,447	£ 78,873,447

Sensitivity analysis: Net turnover		Ethanol price (£ per litre)		
		Low	Med	High
Beet price (£/tonne)		0.40	0.55	0.70
Low	14.30	£ 85,089,514	£ 110,861,014	£ 136,632,514
Med	19.07	£ 77,171,314	£ 102,942,814	£ 128,714,314
High	23.84	£ 69,253,114	£ 95,024,614	£ 120,796,114

In each of these scenarios, the largest revenue stream is the bioethanol, typically making up more than 50%, with biogas making the second largest contribution (ca.25%) followed by beet pulp used as animal feed (ca.15%). There are many other potential process configurations that would affect the revenue potential, for example, the biogas potential could be significantly reduced should some of the other side streams be diverted to other uses. However, if this is the case, the alternative uses are likely to be higher value, and this the biogas revenue would likely be substituted on an equivalent basis.

Another element that could impact on the overall plant economics would be the ability to extend the processing period beyond the typically short beet supply season. Importing molasses into the facility, for bioethanol production would potentially allow year-round production; however, the economics and technical feasibility of this option need to be explored further, to determine whether it would be feasible to switch between feedstocks without significantly increasing CAPEX.

5.6.1 Job creation potential

Assuming a linear relationship between the amount of beet harvested and the jobs created, the job creation potential all three scenarios is given below, for illustrative purposes. These job numbers are based on current employment figures for the UK beet supply chain, recently published by British Sugar. These jobs would likely be split 35% in sugar beet production and 65% in processing under each scenario.

Table 23. Job creation potential of establishing a sugar beet industry in Scotland

	Scenario 1	Scenario 2	Scenario 3
Direct employment	216	550	651
Indirect employment	383	975	1,154
Direct and indirect employment	**599**	**1,526**	**1,805**
Induced employment	52	132	156
Total employment	**651**	**1,658**	**1,962**

6 Conclusions & Recommendations

Scotland was home to a large sugar beet processing facility in Fife for around 50 years until it closed in 1972 for economic reasons. Since then, average beet yields per hectare have increased more than three-fold and a range of markets have emerged or matured for beet products and co-products other than crystallised sugar.

The agronomic and technoeconomic feasibility of re-establishing a sugar beet industry in Scotland has been evaluated, taking into account crop yields, land availability and the new and emerging markets for co-products identified. The key target product is assumed to be bioethanol for the transport fuel sector, with significant value generated from side-streams such as pulp for bio-based products and chemicals, and vinasse which can be used to produce biogas from anaerobic digestion.

The findings of the work are:

Agronomy

- Average yields in the UK are at record levels of 83 t/Ha, some of the best in the world.
- There is limited evidence for the performance of high-yielding varieties in Scotland, but trial data and data from energy and fodder beet grown in Scotland suggests that yields are likely to be the same as or exceed those in England. Nevertheless, large scale trials are recommended to verify potential and select best suited varieties.
- There is a lack of evidence of what the suitable land area for beet would be in Scotland, but the total available area of arable land is 626 kHa; our analysis suggests an optimum cultivation area of 20-30 kHa, equating to 3-4% of total arable area.
- Sugar beet would fit well into cereal rotations as a non-cereal break, but Scottish farmers may be unwilling to adopt an unfamiliar crop that requires specialist drilling and harvesting equipment, unless the market is significantly more attractive, and stable.
- Due to the high capital costs of farm equipment and machinery, different ownership models have been considered. A co-operative system such as the East of Scotland Growers Association may benefit farmers, though increasing numbers of growers in England are using contract drilling and harvesting services to eliminate upfront costs.
- The gross margin for growers is estimated at between £500 and £1000 depending on yield and beet price; modest yields and current beet price would deliver a gross margin of around £900 per hectare.
- Transport could be prohibitively expensive for farms more than 60 miles from the plant.

Opportunities for bioethanol and co-products

- There is well established market for ethanol in Scotland and a refinery currently blending, using imported bioethanol to deliver current blend levels.
- Demand from the transport sector is currently 57 million litres which is a blend of approximately 4% (E4) at the pump, rising to 10% (E10) in the future.
- Several potential markets exist for sugar beet pulp which is produced in large volumes, including anaerobic digestion, pre-treatment for further ethanol production or for bio-based products (local companies include Cellucomp, 3FBio and Vegware). However, these

must be cost competitive with the animal feed market which is currently £219 per tonne of dry pulp.
- Large volumes of molasses are produced globally and importing this high-sugar feedstock could supplement seasonal beet production and provide economic flexibility.

<u>Technoeconomic analysis</u>

- Three scenarios were evaluated for a plant sized to produce enough ethanol to meet current and possible future road transport demands. The findings were:
  - Current demand (E4) — 6.6 kHa land required. Feasible.
  - Medium-term demand (E10) — 17 kHa land required. Feasible.
  - Most likely scenario — 20 kHa land required. Optimum plant size.
- 20kha equates to 3.2% of total arable land area in Scotland; this compares favourably with the 2.3% of arable land currently used for sugar beet production in England.
- Economics are highly sensitive to beet price and ethanol price; however, even with high beet prices and low ethanol prices a plant can be economically attractive.

In order to pursue this opportunity, a number of recommendations for further work should be considered, as follows:

- Work with SRUC, SSCR at The James Hutton Institute or Scottish Agronomy, to establish variety trials in Scotland, to identify the best suited modern variety and to verify yield potential.
- Liaise with the Scottish Farmers Union, to engage with farmers in the early stages, to allow any concerns to be addressed from the outset.
- Identify any pre-existing grower groups or collectives who may have a particular interest in the sugar beet industry or be looking for solutions to address production challenges currently faced.
- Undertake further work on markets for co-product streams from bioethanol production, to ensure processing efforts are demand-driven; this will enable plant configuration and the range of outputs to be optimised from the outset, to deliver the most economically robust and stable development. A number of potential partners have been identified in this work, but others undertaking research or early stage development work may exist and should be engaged, should the project be pursued.
- Undertake further analysis on technical and commercial opportunities for importing molasses as a feedstock for the processing facility, to make use of the redundant capacity when sugar beet is no longer available, prior to the following years harvest; knowledge gaps remain on the technical requirements, specifically the compatibility and ability to switch between feedstocks, the environmental impact and lifecycle GHG emissions, and the economics of importing molasses to produce ethanol for local supply.
- Engage with operators at Grangemouth refinery, to explore options for supply of bioethanol, for local blending into the Scottish transport fleet.
- Engage with Scottish Government to communicate the contribution a local processing facility would make to decarbonisation targets, energy and food security objectives, and the wider Scottish economy.
- Seek public-sector support, in the form of supply chain facilitation, direct investment or specific legislative mandates for producing or using the biobased fuel, chemical and energy outputs from such a facility domestically.

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