GROWING
KENT & MEDWAY

Plant Crop Waste and Valorisation in South East England

Report: The potential of horticultural by-products for a biobased circular economy

March 2025

UK Research and Innovation

Contents

Contents (cont.)

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Executive Summary

This report examines the potential of agricultural waste and horticultural crop by-products in South East England to contribute to a biobased circular economy.

With a significant portion of the UK's horticulture sector located in this region, substantial volumes of agricultural residues are generated, offering an opportunity for sustainable and economically valuable reuse. These by-products range from high-value compounds, suitable for applications in the food, cosmetics, and pharmaceutical industries, to high-volume, lower-value materials that can be repurposed for bioenergy, biofertilizers, and compostable packaging.

Key findings include the identification of valuable compounds in crop residues, such as polyphenols from grape waste and essential oils from hops, which have applications across various industries. Lower-value but abundant waste materials, like straw from cereal crops, can also serve as renewable sources for biofuels, animal feed, and biodegradable packaging, aligning with the region's efforts to reduce plastic waste and greenhouse gas emissions.

The analysis highlights gaps in regional infrastructure, specifically in the collection, processing, and upcycling of agriwaste materials. Addressing these gaps through targeted investment and innovation can enable South East England to become a leader in sustainable bioproduct development. Additionally, collaboration among local stakeholders, support from government policies, and increased consumer awareness are crucial to fostering a thriving circular economy that minimises waste and maximises resource efficiency.

Introduction to report

Biorefining and biomass utilisation in the UK

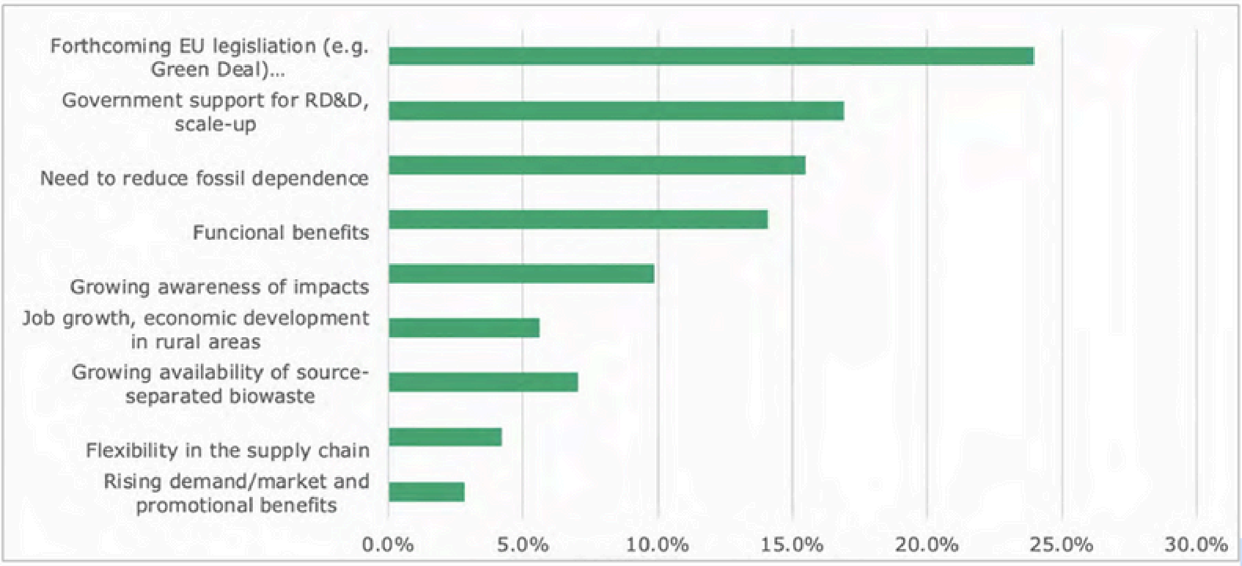
Biorefining plays a crucial role in advancing a biobased circular economy, which is essential for reducing reliance on fossil fuels, achieving net-zero emissions, and enhancing resource efficiency while fostering economic growth. According to the International Energy Agency Bioenergy Task 42, biorefining involves "the sustainable processing of biomass into a spectrum of marketable products and energy" (International Energy Agency, 2021). The concept encompasses three core transposable elements: Materials, Chemicals, and Energy, which can be utilised across diverse industries such as food and beverage, pharmaceuticals, textiles, construction, and fuel.

Significant technological progress in recent decades has made biomass processing in biorefineries more efficient and cost-effective. Advances in biological, biochemical, mechanical, and thermo-chemical methods have enabled the fractionation of biomass to produce high-value compounds (NNFCC). For instance, techniques like steam explosion and enzymatic processing have been investigated for breaking down resilient lignocellulosic materials to yield sugars.

Across Europe much work has been done to enable industries to switch from fossil fuels to renewable feedstocks. This work is summarised in the EU Biorefineries Outlook 2039 report, which includes.

- A biorefining classification system
- A database of operation or announced biorefineries (for EU and 10 non-EU countries)
- A detailed opportunities and barriers analysis
- And a Market Outlook to 2030, with a focus on 11 biorefinery pathways.

The biorefining classification system can be easily adapted to suit the UK, and many of the opportunities and barriers are likely shared (see figure 1).



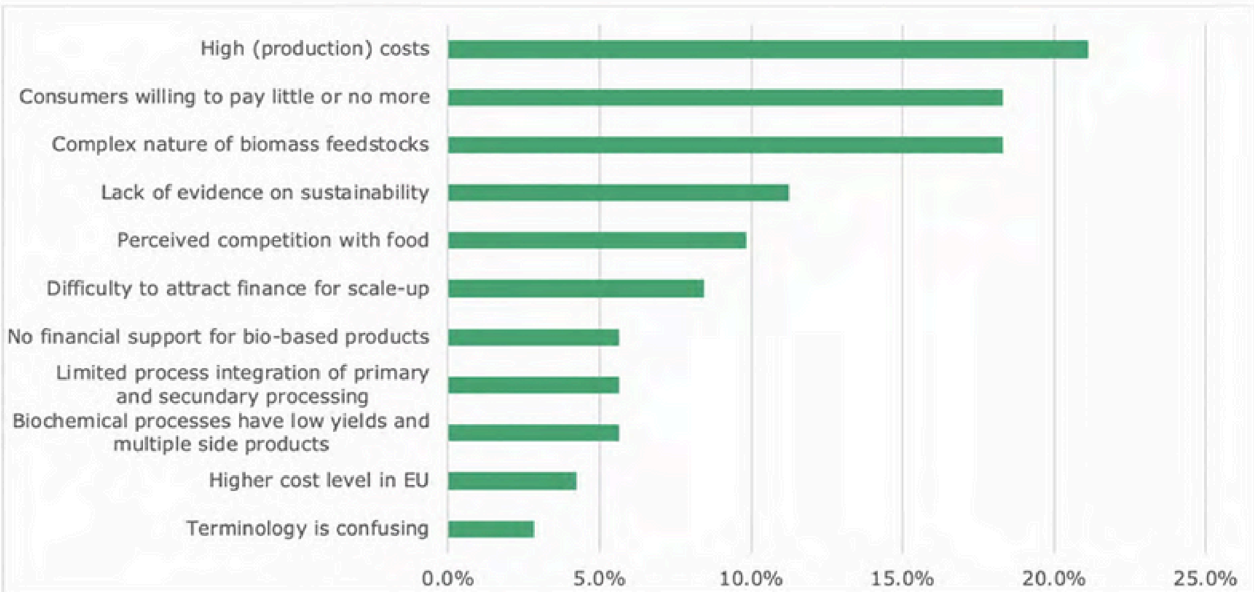


Figure 1: Top chart shows the rankings of the general drivers whilst the lower chart shows the rankings of the general barriers for biorefineries, as outlined in the EU Biorefineries Outlook 2030 report.

The database does not include the UK. Previously, the UK benefited from the BioPilots4U database of biorefining facilities, which was supported by the BioPilotsUK initiative. BioPilotsUK aimed to facilitate the commercialisation of biobased products by testing new technologies for businesses, helping to mitigate risks. However, this initiative, which originated from the 2018 UK Biorefineries Strategy, lost funding in 2021 when the Government's Net Zero Strategy replaced it. This shift in priorities reduced the focus on biorefining, and the database is no longer maintained.

The BioPilotsUK initiative aimed to;

- Support innovation
  - Facilitate collaboration between academia and industry to accelerate the development and commercialisation of biobased products and technologies.
- Bridge the gap
  - Connect industry and academia to help businesses access research expertise and scale up their innovations.
- Build capacity
  - Develop the UK's bioeconomy skills base through knowledge sharing and training.
- Inform policy
  - Provide evidence-based input to the government to shape future bioeconomy policies.
- Collaborate with NIBB (Networks in Industrial Biotechnology and Bioenergy)
  - Work with the Biotechnology and Biological Sciences Research Council's National Industrial Biotechnology Innovation Centre to advance promising technologies.

All of these objectives are still desired and continue to be supported by the six BBSRC NIBB groups.

- Algae-UK: Exploiting the algal treasure trove
- BBNet: Biomass Biorefinery Network
- Carbon Recycling – Converting waste-derived GHG into chemicals, fuels and animal feed
- E3B: Elements of Bioremediation, Biomanufacturing & Bioenergy: Metals in Biology
- EBNet: Environmental Biotechnology Network
- HVB: High Value Biorenewables Network

In August 2023, the UK government published a Biomass Strategy, primarily emphasising the use of biomass for carbon capture and storage, as well as its role in sustainable fuel and energy production. However, the strategy pays limited attention to the potential of biorefining or the diverse biomass sources available. While it mentions the development of the UK and Global Bioenergy Resource Model to assess overall biomass availability, it does not propose new mechanisms to track specific biomass streams or biorefined products. Furthermore, the report lacks details on how UK facilities must evolve and receive investment to support biorefining efforts.

Despite this, the biorefining sector in the UK continues to grow, as demonstrated by the increasing engagement of organisations such as the Biobased Industries Consortium and the High Value Biorenewables Network, reflecting sustained industry interest and activity.

In the UK, industrial growth in biofuels has primarily centred on first- and second-generation biodiesel facilities, which have since expanded to include bioethanol production from sugars. Notably, in 2013, the £350 million Vivergo bioethanol plant was launched in Hull. This facility, a joint venture between AB Sugar, BP, and DuPont, has the capacity to produce 420 million litres of bioethanol annually, making it the UK's largest bioethanol producer and the biggest single-source supplier of animal feed.

At full operation, Vivergo produces 500,000 tonnes of protein-rich animal feed annually, sufficient to nourish approximately 20% of the UK's dairy herd. The plant is also the country's largest wheat buyer, sourcing 1.1 million tonnes per year from local farms. Vivergo's bioethanol is estimated to achieve greenhouse gas savings exceeding 50% compared to conventional petrol.

A report by ECOFYS[1] in 2014 gives an overview of UK biofuel producers and demonstrated a total biofuel capacity of over 1,500 million litres a year, from sites across the UK (see figure 2).

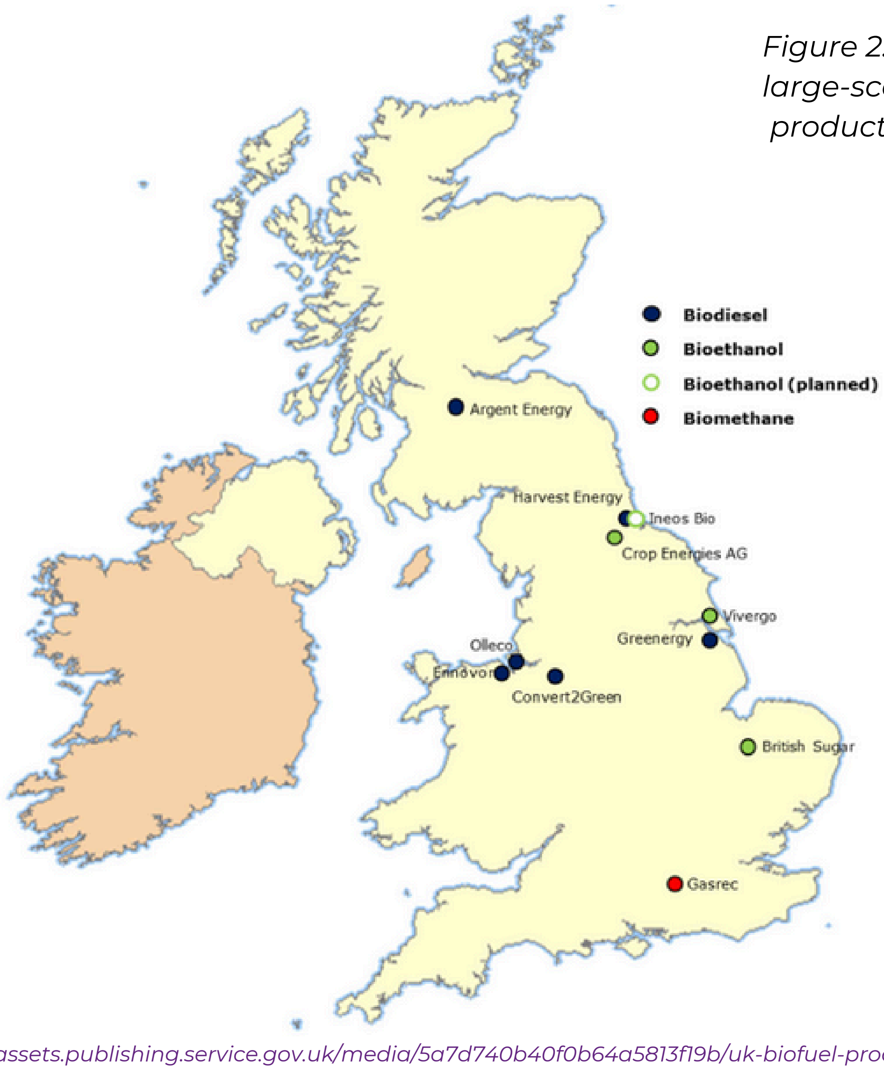


Figure 2: Operational and planned large-scale commercial biofuel production plants, ECOFYS

1. *https://assets.publishing.service.gov.uk/media/5a7d740b40f0b64a5813f19b/uk-biofuel-producer.pdf*

The UK's bioethanol sector has benefited from government policy and regulations to drive it. The Renewable Transport Fuel Obligation (RTFO) announced in 2005 had a target of 5% fuel to come from a renewable source by 2010. The RTFO order, instigated in 2007 with powers from the Energy Act 2004, has been amended several times to change target levels. In 2018 the Renewable Transport Fuels and Greenhouse Gas Emissions Regulations implemented RTFO targets at 9.75%, rising to 12.4% in 2032.

Meanwhile, the UK's biobased materials sector has not benefited from such regulation. It has, however, benefitted from a public interest in moving away from plastics. Public pressure has led to organisations such as the Ellen MacArthur Foundation and Environmental Groups driving industry and policy to make changes.

Sustainable biobased packaging has been particularly promoted over conventional fossil fuel-based plastic packaging, and the introduction of single-use plastic bags and plastic straw bans have followed. The UK has also carried out investigations to identify how it may support innovation in this biorefining arena, as demonstrated by the 2022 Innovate UK report into utilising biomass for the chemicals manufacturing sector, and recent reports and roadmaps that have come out by Zero Waste Scotland to promote research and industrial investment (See figure 3).

MILESTONES	CATEGORISATION	DELIVERY TARGET
In partnership, develop a hierarchy of materials of the 6 identified resource streams in relation to material end point.	Short Term	2020
Support the licencing process of feedstocks for biorefining and contribute to further studies to ensure sustainable exploitation.	Short Term	2020
Encourage and facilitate discussions to open channels between the IB sector, local government authorities and waste management companies to understand the current value chains of resource streams	Short Term	2020
Identify the opportunities to locally source feedstocks for current industry and emerging biobased manufacturing.	Short Term	2020
Expansion of existing equipment centres to support the development of new biorefining concepts.	Short Term	2020
The creation of new value chains and the development of sustainable supply chains for key feedstocks.	Short Term	2020
The adoption of novel technologies to further increase the sustainability and value creation from the various resource streams	Short Term	2021
The development of infrastructure to help support the scale up and commercialisation of new biorefining concepts in Scotland.	Short Term	2021
The development of a dedicated resource to lead on biorefining cluster activities in Scotland	Short Term	2021
Analysis and comparison to determine the best option to create a biorefining cluster in Scotland	Short Term	2021
Undertake supply development activities including the explorations of supply chains both nationally and internationally.	Medium Term	2022
Undertake technoeconomic analysis to better understand how products can be integrated into existing supply and value chains, or whether there would be a requirement for new developments.	Medium Term	2022
Establish a strong academic platform within wood biorefining and product development	Medium Term	2023
Support development and establishment of carbon capture and utilisation pilot scale facilities at an emitter site and co-localised with a commercial scale electrolysis plant operating on excess renewable energy.	Long term	2025
Gas fermentation pilot facilities will also be developed to help support the valorisation of CO_2 in Scotland	Long term	2025
Establishment of commercially operating biorefineries	Long term	2025
Establish Biorefinery Cluster in Scotland	Long term	2025

Figure 3; Scottish Enterprise funded Biorefinery Roadmap for Scotland

The findings from the UK reports released to date demonstrate that there is an interest by both business, academia, and the general public, to develop a sustainable biobased materials and chemicals sector which utilises locally sourced agriwaste.

Biobased materials vary significantly depending on their feedstocks, processing methods, and end applications. Feedstocks can often be used cyclically, with high-value compounds initially extracted, leaving residual material suitable for different or lower-value products. Given this complexity, a large-scale biorefinery like the Vivergo plant in Hull is unlikely to meet all the UK's needs for biobased chemicals and materials.

A more effective approach would involve building upon existing facilities across the UK that already possess some of the necessary processing technologies. Establishing a cooperative network of experts, facilities, and resource hubs linked in a chain could add value to feedstocks through further refinement while mitigating risks for businesses. This distributed model could enhance resource efficiency and better address the diverse demands of the biobased materials sector.

A UK-wide cooperative could be effectively established by leveraging the BBSRC NIBBS networks and the expertise of UK universities specialising in biorefining, fermentation, and biobased materials. Existing centres of excellence include Scotland's SRUC, as well as key facilities across England and Wales, such as the Biorenewables Development Centre in York, the Grantham Centre in Sheffield, the Biocomposites Centre in Bangor, and the Plant Biorefining group at Aberystwyth University. These institutions provide a strong foundation for fostering collaboration and advancing biorefining innovation nationwide.

In addition to these, Growing Kent & Medway offers extensive expertise in areas such as bioengineering, fermentation, biomaterials design, business mentorship, supply chain management, and lifecycle analysis. Strategically located within the London and South East England food and drink sector, particularly the fruit-growing industry, the consortium is well-equipped to support agile biorefining of locally sourced agricultural waste. This includes pre-treatment processes to reduce waste volume and emissions, as well as large-scale biorefining in partnership with established waste management companies.

By developing pre-treatment facilities and producing biofertilisers, the consortium can promote sustainable farming practices and unlock additional biorefining opportunities. Growing Kent & Medway ultimately aims to establish a comprehensive route to market for biobased products by leveraging feedstocks, facilities, and supply chain engagement to support the bioeconomy.

South East England’s agricultural and horticultural landscape

South East England’s crop production is supported by a vibrant food and drink sector that accounts for 11.8% of the UK’s total food and drink production industries, The majority of enterprises (85.7%) relate to crop and animal production, hunting and related service activities, and a further 11.8% of enterprises relate to the manufacture of food and beverages.

Subsectors of food & drink production industry enterprises

2021	Total Food and Drink Production Industries	Crop and animal production, hunting and related service activities	Fishing and aquaculture	Manufacture of food products	Manufacture of beverages	Crop and animal production, hunting and related service activities	Fishing and aquaculture	Manufacture of food products	Manufacture of beverages
Ashford	405	370	5	25	5	91.4%	1.2%	6.2%	1.2%
Canterbury	175	145	10	20	5	82.9%	5.7%	11.4%	2.9%
Dartford	30	25	0	5	5	83.3%	0.0%	16.7%	16.7%
Dover	175	155	5	10	5	88.6%	2.9%	5.7%	2.9%
Folkestone & Hythe	205	180	10	15	5	87.8%	4.9%	7.3%	2.4%
Gravesham	45	35	0	5	5	77.8%	0.0%	11.1%	11.1%
Maidstone	305	270	5	20	10	88.5%	1.6%	6.6%	3.3%
Sevenoaks	195	180	0	10	0	92.3%	0.0%	5.1%	0.0%
Swale	210	180	5	20	5	85.7%	2.4%	9.5%	2.4%
Thanet	80	50	10	10	5	62.5%	12.5%	12.5%	6.3%
Tonbridge and Malling	130	110	0	10	5	84.6%	0.0%	7.7%	3.8%
Tunbridge Wells	265	235	5	20	5	88.7%	1.9%	7.5%	1.9%
Kent	**2,220**	**1,930**	**60**	**170**	**65**	**86.9%**	**2.7%**	**7.7%**	**2.9%**
Medway	90	65	0	20	5	72.2%	0.0%	22.2%	5.6%
Kent + Medway	2,310	1,995	60	190	70	86.4%	2.6%	8.2%	3.0%
South East Region	11,560	9,905	295	990	370	85.7%	2.6%	8.6%	3.2%
England	98,320	87,205	1,685	7,265	2,165	88.7%	1.7%	7.4%	2.2%

Source: UK Business Counts
Presented by: Kent Analytics, Kent County Council

Figure 4: Crops Produced in South East England vs. the Rest of England

The biggest contributors to the region’s farming output are fruit, valued at £332 million, wheat, valued at £325 million, plants and flowers, valued at £178 million, and milk, valued £153 million.[2]

2 https://www.gov.uk/government/collections/aggregate-agricultural-accounts

In 2021, cereals farms accounted for 46% of farmed area in the region and grazing livestock farms covered an additional 21% of farmed area. The region which includes the county of Kent, described as the Garden of England' is also renowned for the production of nearly half of the UK's fruit (see figure 5).

Figure 5: farmed area by crops

Crops (thousand hectares)	South East England	England	South East England as % of England
Wheat	219	1,655	13%
Barley	104	816	13%
Oilseed rape	37	268	14%
Top fruit	9	21	44%
Small fruit	5	10	50%
Glasshouse (ha)	288	1154	25%

This scale of agriculture, horticulture and food and drink manufacture inevitably means the region experiences a high level of agriwaste and crop by-products. To date, the specific volumes of these materials and the variation in these materials has not yet been recorded. Nor has a comprehensive guide to their potential components been drafted, and as such, an appropriate list of applications for these potential renewable feedstocks proposed.

The aim of this report

Growing Kent & Medway aims to support the region's horticulturists and plant-based food and drink producers and processors in achieving economic growth while reducing environmental impacts.

Ongoing individual meetings with industry stakeholders have been carried out to identify what challenges the sector faces and how we can best support them. Biomass, Biorefining and Sustainable Packaging workshops have been held to examine documents such as the biorefining roadmaps proposed for Scotland, and the EU Biorefineries outlook, with a view to how South East England may best utilise its assets and generate this report to outline the skills, experience and facilities, shared amongst the region's researchers to carry out key activities and events to assist its implementation.

Feedback to date suggests that both nationally and internationally the need for networking to introduce end-to-end users of the supply chain, and to demonstrate examples of success, is required. Feedback also indicates the sector is technically well advanced but lacks quantitative information regarding the volume and variation in feedstocks for locally sourced compostable packaging.

Sustainable Packaging Conference, University of Kent, Sept '22

This feedback coincides well with the recommendation to develop a South East England agriwaste exchange platform. This involves the development of an agriwaste innovation platform to provide a matchmaking service to businesses, enabling them to exchange agricultural by-products, whilst simultaneously offering academics the opportunity to identify sources which may be mined and refined to create new compounds and materials.

The platform should support the utilisation of crop by-products and waste for both low-volume, high-value compounds for applications in sectors such as food and drink, construction, and manufacturing, as well as high-volume, lower-value compounds. These lower-value compounds could serve as growth media for crops or fungi, enabling further biorefining for high-value compounds. Additionally, they could be used to produce biofertilisers, providing a sustainable alternative for growers transitioning away from chemical farming practices, and to develop substrates for compostable packaging.

This report aims to highlight the assets which can support biorefining and support those industries looking to move away from fossil fuels and exploit agriwaste to improve resource efficiency and reach net zero goals. In doing so the report also aims to determine how Growing Kent & Medway can support the sector with networking engagement opportunities and providing fundamental information required by the biorefining sector with regards to what biorefining resources are available in the region to be utilised, and finally, where funding is most needed to provide the necessary research, infrastructure and expertise to utilise these resources and to promote an agriwaste innovation platform for the use of the agile biorefining industry in the UK.

Agriwaste and crop by-product availability

Economic value and consumer trends

The economic value of agricultural waste, also known as agriwaste or crop by-products, can vary widely depending on several factors, including the type of crop, the specific waste product, regional demand and supply, processing methods, and market conditions. Agricultural waste can include things like crop residues (stalks, leaves, husks), fruit and vegetable peels, stems, shells, and more

The economic value of agriwaste can be realised through various pathways:

Bioenergy production

Some agricultural waste can be used to generate bioenergy, such as biofuels (e.g., bioethanol, biodiesel), biogas, and biomass pellets. The economic value in this case depends on energy prices, government incentives, and the efficiency of conversion technologies.

1. **Biofuels:** The value of biofuels produced from agricultural waste can vary based on energy prices, conversion efficiency, and government incentives. Ethanol and biodiesel prices can range from a few cents to several dollars per gallon. In Quarter 2 2023 (April to June), the provisional demand for liquid biofuels was 870 million litres, 51 million litres (6.2 per cent) more than in the same quarter in 2022.

2. **Biogas:** Biogas produced from agricultural waste can be valued based on the cost of natural gas or other energy sources it displaces.

In 2021, bioenergy products were a part of the UK's efforts to reduce greenhouse gas emissions and transition towards more sustainable energy sources. The economic value of biofuels can be assessed through various factors:

- **Production and Consumption**: The production and consumption of biofuels in the UK play a significant role in determining their economic value. This includes factors like the volume of biofuels produced, the number of biofuel plants, and the amount consumed by various sectors (e.g., transportation, industry).
- **Investments and Employment**: The investments made in biofuel production infrastructure, as well as the employment generated by the biofuel industry, contribute to its economic value. This includes jobs in farming (for feedstock production), processing facilities, and distribution.
- **Economic Benefits and Costs**: Assessments need to consider both the benefits (e.g., reduced greenhouse gas emissions, energy security) and the costs (e.g., subsidies, feedstock prices) associated with biofuel production and consumption.
- **Government Policies and Incentives**: Government policies and incentives, such as subsidies, tax credits, and mandates for blending biofuels with fossil fuels, can significantly impact the economic value of biofuels.
- **Market Trends and Demand**: The demand for biofuels in the UK market, as well as global market trends, affect their economic value. This includes factors like fluctuating oil prices, consumer preferences, and international agreements related to biofuels.
- **Environmental and Social Benefits**: The environmental and social benefits of using biofuels, such as reduced emissions and support for rural communities, can also contribute to their overall economic value.
- **Technological Advancements**: Advances in biofuel production technologies can influence the economic viability of biofuels by potentially reducing production costs and improving efficiency.

Since 2018, several new transport biofuels have emerged in the UK fuel mix. In quarter two 2023, transport biofuels other than biodiesel and biogasoline represented around 5 percent of total bioliquids demand. New fuels include bio LPGs (road transport) and bio aviation turbine fuel (air transport). Volumes of new fuels are growing quickly but are still volatile due to their recent introduction in the market.

In quarter two 2023, a total 20 million litres of bioliquids were consumed in non-transport sectors. This is around 2 per cent of all bioliquids consumption this quarter. Fuels include biodiesel supplied to non-road mobile machinery and bioliquids used by auto generators to generate electricity.[3]

3 https://assets.publishing.service.gov.uk/media/65130d40b23dad0012e706ce/ET_6.2_SEP_23.xlsx

Animal feed

Certain agriwaste can be processed and used as animal feed, contributing to the livestock industry. The value depends on the nutrient content of the waste, its suitability for animal consumption, and prevailing livestock feed prices.

The value of agricultural waste as animal feed depends on its nutritional content and its suitability for different livestock species. It can range from a few cents to a few dollars per pound.

In GB, poultry, pig and cattle feed accounts for nearly 90% of total animal feed production, including integrated poultry units (IPU).

- **Market Size:** The market size of animal feed in the UK encompasses the total value of all types of feed produced and consumed. This includes feed for livestock such as poultry, cattle, pigs, and other animals.
- **Production and Consumption:** The production and consumption of animal feed are key factors in determining its economic value. The volume of feed produced by manufacturers and the amount consumed by farmers and livestock producers are critical indicators.
- **Type and Composition of Feed:** Different types of animal feed (e.g., compound feeds, premixes, additives) have varying economic values based on their composition, nutritional content, and intended use.
- F**eed Ingredients and Costs:** The cost and availability of feed ingredients, including cereals, grains, protein sources (like soybean meal), vitamins, and minerals, influence the economic value of animal feed. Fluctuations in commodity prices can impact the profitability of feed production.
- **Livestock Industry Size and Trends:** The size and trends of the livestock industry in the UK are major drivers of the economic value of animal feed. Changes in livestock populations and production practices can impact feed demand.
- **Government Policies and Regulations:** Government policies related to agriculture, animal welfare, and food safety can affect the economic value of animal feed. Regulations regarding feed composition and labelling, for instance, may influence production costs and prices.
- **Export and Import Dynamics:** International trade of animal feed ingredients and finished products can influence the economic value of the animal feed industry in the UK. Changes in global markets, tariffs, and trade agreements can have an impact.
- **Technological Advances**: Innovations in feed formulation, manufacturing processes, and nutritional science can impact the efficiency and cost-effectiveness of animal feed production.
- **Environmental Considerations:** Growing awareness of sustainability and environmental concerns may influence the types of ingredients used in animal feed and the practices associated with their production.
- **Retail and Distribution Channels:** The distribution and retail networks for animal feed play a role in the overall economic value. Efficient distribution and competitive pricing can affect profitability.

Total poultry feed production (including IPU) was down 8% in May on year earlier levels. Poultry feed production has been declining for a number of months but the fall has been getting sharper since March. With soaring inflation and subsequent rises in cost of living it has been reported that demand for meat has been down across the board, with consumer demand for poultry down too.

Looking further ahead, the full impact of inflation and rising costs has not yet been felt, by both industry and consumers, and is expected to hit later in the year.

In GB, feed for dairy cows makes up over 70% of total cattle and calf feed. Total dairy feed production has been down on year earlier levels for the majority of the 2021/22 season. In latest forecasts released by AHDB, milk production is expected to be down 1% on year earlier levels this year. While a rise in the milk price has offset some of the increase in input costs, it's not expected to incentivise farmers to increase production.

It is likely that the dairy feed demand will remain subdued going forward due to soaring inputs. Some may utilise turn out and forage to try and offset rising feed costs. However, with ever increasing fertiliser prices too, this may affect the quality/ quantity of forage for this coming season.

Bioproducts and biorefining

Agriwaste can serve as a feedstock for producing various bioproducts, such as biobased chemicals, plastics, fibres, and other materials. The value depends on the market demand for these products.

The value of bioproducts derived from agricultural waste varies widely based on the specific product, market demand, and the degree of processing. It could range from a few dollars to hundreds of dollars per pound.

Organic fertilisers

Some agricultural waste can be composted or processed into organic fertilisers, contributing to soil health and crop productivity. The economic value is influenced by fertiliser prices and demand. The value of organic fertilisers made from agricultural waste depends on nutrient content and regional fertiliser prices. Prices could range from a few dollars to tens of dollars per pound.

The agricultural fertiliser demand worldwide has seen a slight but steady growth over the past decade. In 2020, it amounted to 188 million metric tons, and is forecast to surpass 208 million by 2025. The United Kingdom consumed approximately 1.4 million metric tons of chemical fertilisers in 2020, a quantity that has remained fairly stable in the last ten years.

Nitrogen is the most used fertiliser nutrient in the UK, with almost one million metric tons consumed in 2020. In that same year, fertilisers containing phosphorus and potassium reached a consumption of 174 and 253 thousand metric tons, respectively.

In 2021/2022

Overall, cereal, general cropping and horticulture farms had the highest application rates of inorganic fertilisers, whilst grazing livestock generally had the lowest. Compared to other farm types, dairy and pig & poultry farms had by far the highest application rates for all organic nutrient types.

In 2021/22, 28% of farms used soil nutrient software packages to help determine fertiliser applications. In comparison, the British Survey of Fertiliser Practice (BSFP) shows that 34% of farms in England used a computer program to record manufactured fertiliser application rates and 24% for organic manures.

Around one in five (18%) farmers used green manures in their arable rotations in 2021/22. The use of green manures in 2021/22 was found to be dependent on farm type, farm size and organic status.

Value-added products

Agriwaste can be processed into value-added products such as food additives, natural dyes, and extracts for pharmaceutical or cosmetic industries. The value depends on the uniqueness and quality of the product.

Value-added products derived from agricultural waste can have varying values depending on uniqueness and demand. Natural dyes, for instance, can range from a few dollars to over a hundred dollars per pound.

Natural dyes

The Europe natural dyes and pigments market size is anticipated to reach USD 2.18 billion by 2028. Key players in the market are carrying out research and development to expand their product offerings. For instance, in July 2021, GNT Group B.V., a company specialising in creating dyes from fruit, vegetables, and edible plants, expanded its range of plant-based EXBERRY colours by launching two new green shades made from turmeric and spirulina.

The Europe market for natural dyes and pigments has witnessed an increase in merger and acquisition activities by key players to strengthen their position in the market. As of 11th October 2021, Givaudan announced the acquisition of DDW The Color House which produces colours from natural sources like fruits, vegetables, and seeds and caters to the food sector.

Food additives

The UK food additives market is projected to record a CAGR of 3.02% over the next five years. The UK food additive market is significantly driven by growing demand for convenience food, primarily benefiting from additives like preservatives, sweeteners, etc. A growing number of health-conscious consumers are looking to avoid synthetic additives, and an increasing number of retailers are adding synthetic colours, enzymes, flavours, and thickeners to their list of unacceptable ingredients.

The demand for clean labels and organic and natural ingredients is increasing among consumers. The market players in the country are adopting new strategies like mergers, acquisitions, and partnerships to expand their product reach and bring innovation. For instance, in June 2022, Givaudan and Manus Bio, a bio manufacturer of natural products, announced the launch of BioNootkatone, a sustainable, natural, clean-label citrus flavour ingredient. BioNootkatone provides a refreshing, natural citrus taste that can be used in a variety of food and beverage applications.

Circular economy initiatives

Agriwaste can be used in circular economy models, where waste from one industry becomes a resource for another. This can lead to cost savings and resource optimisation.

Carbon sequestration and emission reduction

Using agricultural waste for carbon sequestration or as a feedstock for low-carbon products offers significant potential for climate change mitigation and compliance with environmental regulations.

The monetary value of carbon sequestration through agricultural waste can be difficult to quantify directly but may be linked to carbon credit markets and broader environmental benefits.

Globally, the carbon capture and sequestration (CCS) market was valued at USD 2.1 billion in 2022 and is expected to grow to USD 7.49 billion by 2030, with a compound annual growth rate (CAGR) of 19.9% from 2023 to 2030. North America leads the CCS market, driven by numerous high-capacity facilities and substantial investments in research and development. This growth is further supported by government funding initiatives, such as the U.S. Department of Energy's allocation of USD 12 million for direct air capture (DAC) technology research and development.

Meanwhile, the Asia Pacific region is expected to have the fastest growth rate in the Carbon Capture and Sequestration market. This growth can be attributed to numerous large-scale projects in the early stages of development and feasibility studies in countries like Australia and China. Additionally, the region benefits from high-volume storage locations, particularly across subsea oil and gas reservoirs, with EOR operations and government initiatives providing support for the market's growth

Research and innovation

Agriwaste can be used in research and innovation to develop new products or processes, potentially leading to intellectual property and commercialisation opportunities.

The monetary value of research and innovation using agricultural waste can be difficult to estimate. It might lead to intellectual property, patents, or commercialisation opportunities that can range from thousands to millions of dollars.

Consumer Trends

The economic value of agriwaste is often region-specific and can change over time based on technological advancements, market trends, and policy developments. Organisations and entrepreneurs interested in utilising agriwaste should conduct thorough market research and feasibility studies to assess the potential economic value based on their specific circumstances and the available options for processing and utilisation.

Several consumer trends related to agriwaste and crop by-products are emerging in response to increased environmental awareness, sustainability concerns, and a desire for healthier and more ethically produced products. Some trends related to agriwaste and crop by-products include:

Consumer Trends	**Description**
Upcycled Food Products	Using by-products that would be discarded to create new food products, reducing food waste and promoting sustainability.
Plant-Based and Natural Ingredients	Incorporating crop by-products into plant-based and natural products aligning with the demand for healthier and ethical options.
Functional Foods and Nutraceuticals	Utilising agriwaste for bioactive compounds and fibres in functional foods with potential health benefits.
Circular Economy Awareness	Meeting consumer demand for sustainable products by minimising waste and efficiently using resources.
Transparency and Traceability	Providing information about sourcing and production practices to meet the demand for ethical and transparent products.
Local and Artisanal Products	Utilising agriwaste connects with the trend of supporting local and artisanal producers, enhancing product uniqueness.
Packaging Innovation	Creating sustainable packaging materials from agriwaste to address concerns about excessive packaging waste.
Waste Reduction Initiatives	Aligning with eco-friendly consumer choices by offering products that contribute to waste reduction.
Ethical Consumption	Catering to consumers interested in supporting ethical and sustainable practices through responsible resource utilisation.
Educational and Awareness Campaigns	Participating in educational campaigns about sustainable consumption, highlighting the positive impact of agriwaste use.

In conclusion, agriwaste, often overlooked as a valuable resource, holds significant economic potential. However, its value is dynamic, influenced by regional factors, technological advancements, market trends, and evolving policies. To harness this potential, businesses and entrepreneurs must conduct thorough market research and feasibility studies to identify viable opportunities.

Emerging consumer trends, driven by environmental consciousness and health concerns, are creating new markets for agriwaste-derived products. By aligning with these trends and adopting innovative approaches to processing and utilisation, it is possible to unlock the full economic and environmental benefits of agriwaste.

Nim's Naturally invested in a grinding machine to find new purpose for their waste apple cores as part of our Growing Green project

Measuring the region's agricultural waste

Mapping tools and data sources

To effectively map and quantify agriwaste resources in South East England, a combination of geographic information systems (GIS) and remote sensing techniques can be employed. Here are some key tools and data sources:

GIS software

- ArcGIS: A powerful GIS software that allows for spatial analysis, mapping, and data visualisation.
- QGIS: A free, open-source GIS software suitable for smaller-scale projects and basic analysis.

Remote sensing

- Satellite Imagery: High-resolution satellite imagery from platforms like Sentinel-1 and Sentinel-2 can provide valuable information on land cover, crop types, and potential waste generation.
- Drone Imagery: Drones equipped with high-resolution cameras can capture detailed images of specific agricultural areas, enabling precise mapping of waste streams.

Data sources

- Defra Data: The Department for Environment, Food & Rural Affairs provides various datasets related to agriculture, including land use, crop types, and livestock numbers.
- Natural England: This organisation offers data on protected areas, habitats, and ecological surveys, which can be useful for identifying potential waste sources and sensitive areas.
- Local Authority Data: Local authorities often collect data on waste generation and management, including agricultural waste.

Categorising and quantifying agriwaste

To categorise and quantify agriwaste, a multi-faceted approach is necessary

1. **Identify waste streams**

- Crop Residues
  - Straw, stalks, and other plant material remaining after harvesting.
- Manure and Slurry
  - Animal waste products from livestock farming.
- Food Waste
  - Unsold or spoiled food products from farms and processing facilities.
- Plastic and Packaging
  - Waste from agricultural inputs like fertilisers, pesticides, and packaging materials.

2. Spatial analysis

- Use GIS to overlay maps of agricultural land use, crop types, and livestock density to identify potential waste hotspots.
- Analyse satellite and drone imagery to estimate crop yields and biomass production, which can be used to calculate potential waste quantities.

3. Field surveys and sampling

- Conduct field surveys to collect data on waste generation rates, composition, and management practices.
- Sample waste streams to determine their nutrient content, moisture content, and potential for recycling or energy recovery.

4. Data analysis and modelling

- Use statistical analysis to estimate total waste quantities and their spatial distribution.
- Develop models to predict future waste generation based on factors like climate change, agricultural practices, and policy changes.

By combining these tools and techniques, it is possible to accurately map and quantify agriwaste resources in South East England, providing valuable information for sustainable waste management and resource recovery strategies.

Satellite imagery analysis and waste quantification modelling

Satellite imagery analysis and modelling techniques can be used to accurately map and quantify agricultural waste in South East England, providing valuable data for sustainable waste management and resource recovery strategies.

Satellite imagery has revolutionised the way we monitor and analyse our planet. When it comes to agriculture, it provides a unique vantage point to track crop growth, soil health, and, crucially, potential waste streams.

Key techniques and considerations

1. **Spectral analysis**
    - NDVI (Normalised Difference Vegetation Index)
        - This index measures plant health and vigor. By analysing NDVI values over time, we can estimate crop biomass and potential residue generation.
    - Other vegetation indices
        - Indices like SAVI (Soil-Adjusted Vegetation Index) and EVI (Enhanced Vegetation Index) can provide more nuanced information about crop stress, water content, and nutrient levels.
2. **Object-Based Image Analysis (OBIA)**
    - OBIA allows for the segmentation of satellite images into meaningful objects like fields, forests, and water bodies. By classifying these objects, we can identify specific crop types and estimate their potential waste output.
3. **Time-series analysis**
    - By analysing a series of satellite images over time, we can track seasonal changes in crop growth, harvest timing, and residue management practices. This can help predict future waste generation patterns.
4. **Machine learning**
    - Advanced machine learning algorithms can be trained on labelled satellite images to automatically classify land cover, detect specific crop types, and estimate biomass. This can significantly improve the accuracy and efficiency of waste quantification.

Challenges and limitations

- **Cloud cover**
    - Cloud cover can obscure the ground surface, limiting the availability of clear images.
- **Atmospheric effects**
    - Atmospheric conditions can distort the spectral signatures of objects, affecting the accuracy of analysis.
- **Spatial resolution**
    - High-resolution imagery is ideal for detailed analysis, but it can be costly and computationally intensive.
- **Ground truthing**
    - Regular ground-based surveys are necessary to calibrate satellite data and validate the accuracy of estimates.

Waste quantification modelling

Once we have a clear understanding of the quantity of crop biomass and residue generated, we can employ various modelling techniques to precisely quantify waste streams from different agricultural sectors, including grape, hop, vegetable, and fruit production.

- **Statistical models**

Simple statistical models can be utilised to establish relationships between crop yield, harvest index, and other relevant factors to estimate waste generation. However, these models may not be sufficient to capture intricate interactions and nonlinear relationships that can significantly influence waste generation.

- **Process-based models**

Process-based models offer a more detailed approach by simulating the growth, development, and senescence of crops. These models consider factors such as climate, soil conditions, and management practices to provide more accurate estimates of waste generation and its composition. This level of detail is particularly valuable for crops like grapes and hops, where specific growth stages and harvesting methods can significantly impact waste generation.

- **Machine learning models**

Machine learning models, such as random forests and support vector machines, can be trained on historical data to predict future waste generation based on a variety of input variables. These models can be highly effective in capturing complex patterns and trends in waste generation, making them suitable for analysing large and diverse datasets from various agricultural sectors, including vegetable and fruit production.

By combining these modelling techniques, researchers and industry professionals can gain valuable insights into the quantity and composition of agricultural waste streams. This information can be used to develop strategies for reducing waste, improving resource efficiency, and promoting sustainable agricultural practices.

Integrating satellite imagery and modelling

By combining satellite imagery analysis with advanced modelling techniques, we can develop robust and accurate methods for quantifying agriwaste. This information can be used to optimise waste management practices, reduce environmental impacts, and promote sustainable agriculture.

Current capabilities for processing crop residues

The Kent and Medway region is becoming a hub for sustainable agriculture and waste management innovation, with a particular focus on the treatment and upcycling of crop residues. This effort is driven by collaboration among academic researchers, industry partners, farmers, and government initiatives, all working towards enhancing resource efficiency and promoting circular economy practices. The region boasts an impressive array of expertise, facilities, and equipment, which together create a fertile ground for developing innovative solutions for managing agricultural waste.

Expertise

- **Academic research**

The University of Kent is actively involved in researching sustainable agriculture practices, including the use of crop residues for biochar production, animal feed, and other value-added products. Research institutions and innovation centres may work on developing new and sustainable ways to treat crop residues.

- **Industry partnerships**

Local businesses and organisations are collaborating with researchers to develop innovative solutions for crop residue upcycling, such as using food waste to feed black soldier fly larvae for animal feed.

- **Farmers and agricultural practices**

Farmers may choose to handle crop residues on their own land using traditional agricultural practices like ploughing the residues back into the soil as organic matter or using them as mulch to retain moisture and control weed growth.

- **Composting facilities**

Some crop residues can be sent to composting facilities, where they are processed into compost that can be used as a soil conditioner or organic fertiliser. Composting providers in Kent include: Kent County Council composting sites, Viridor, Biffa, Waste Recycling Group (WRG).

- **Biogas plants**

In some cases, crop residues with high organic content can be sent to biogas plants, where they are anaerobically digested to produce biogas for energy generation. Biogas plants in Kent include: Green Create, The Farm Energy Company (Ebbsfleet AD).

- **Industrial processing**

Certain crop residues may be processed in industrial facilities to extract valuable compounds or to create products like essential oils, biofuels, or biobased materials. This can include multiple sectors, such as: biodegradable packaging manufacturers (e.g. Priory Direct, Crusader Packaging), biofuel producers (e.g. Rye Biofuels, Syntech Biofuel), pharmaceutical companies (e.g. Pfizer, G-pharm), cosmetics and personal care companies (Revolution Beauty), biochemical and biotechnology companies, or food and beverage industries.

- **Waste management companies**

Waste management companies may be involved in the collection and treatment of crop residues through various means, including composting or recycling. Waste management companies operating in the region include: Biffa, Viridor, Suez, Veolia, Cory Riverside Energy, DS Smith Recycling, Grundon Waste Management, Thanet Waste Services, and Eurokey Recycling.

- **Government initiatives**

Local authorities and government bodies are supporting initiatives to promote circular economy practices, including the upcycling of waste materials like crop residues.

Equipment

While specific equipment for crop residue treatment and upcycling may vary depending on the scale and type of operation, the region has access to the following

- **Agricultural machinery**

Traditional agricultural machinery can be used for initial processing of crop residues, such as chopping or shredding.

- **Bioreactors**

For biotechnological processes like anaerobic digestion or fermentation to convert crop residues into biofuels or other products.

- **Drying and storage equipment**

To prepare crop residues for further processing or storage.

- **Laboratory equipment**

For analysis and testing of crop residues and their potential uses.

Additional Resources

- **Low Carbon Kent**

This organisation focuses on promoting sustainable practices in the region, including waste reduction and upcycling.

- **Growing Kent & Medway**

This network connects businesses, researchers, and organisations to drive innovation in the food and drink sector, which may involve crop residue utilisation.

Kent and Medway's commitment to sustainable practices is evident in its diverse expertise and infrastructure. Academic institutions, like the University of Kent, lead research in transforming crop residues into valuable products such as biochar, animal feed, and biofuels.

Farmers contribute by adopting traditional and modern agricultural methods, while composting and biogas facilities process organic waste into renewable energy and soil conditioners.

Industrial players in sectors like biofuels, biodegradable packaging, and cosmetics are actively engaging in crop residue upcycling, supported by waste management companies and government initiatives promoting circular economy principles.

The region is well-equipped with agricultural machinery, bioreactors, and laboratory facilities, enabling efficient crop residue treatment. Networks like Low Carbon Kent and Growing Kent & Medway further bolster collaboration and innovation, positioning the region as a leader in sustainable agricultural waste management.

De-husked Kentish cobnuts at Roughway Farm that will be processed into new materials, a project funded by Growing Green

Key crops of interest

The Kent and Medway region generates substantial crop waste from various sectors, including wine, hops, fruit, cereals, and vegetables. Each type contributes specific by-products such as grape pomace, hop stems, apple pomace, and cereal straw. Additional by-products from dairy and livestock farms, like whey, manure, and wool, are also noted.

Wine industry waste and sustainable management
The growing English wine industry produces large amounts of grape pomace, wastewater, yeast lees, and vine prunings. Key sustainable strategies for managing wine waste include composting, bioenergy production through anaerobic digestion, and nutrient recovery. Grape pomace and yeast lees offer potential in high-value applications, such as animal feed, skincare products, and bioethanol production.

Hop waste utilisation
Hop waste is notable but largely underutilised. Key by-products like spent hops can be repurposed in animal feed, fertilisers, and food products or transformed into biofuels. Extraction of xanthohumol and other compounds for pharmaceutical, cosmetic, and agricultural applications can bring added value to hop by-products.

Fruit and vegetable waste valorisation
Fruit and vegetable waste are abundant in Kent, where their management includes composting, anaerobic digestion, and sometimes landfill. However, valuable compounds like polyphenols, pectin, and carotenoids in fruit waste, and proteins, polyphenols, and essential oils in vegetable waste can support the development of food additives, antioxidants, natural dyes, and biofuels.

Cereal crop waste applications
Cereal waste such as straw and bran can be utilised in animal feed, bioenergy, and biomaterials. The industry benefits from these by-products by reducing waste and generating alternative revenue streams.

Industrial applications and pre-treatment requirements
For effective valorisation, pre-treatment processes for all waste types include grinding, drying, acid or enzyme treatment, and innovative extraction methods like ultrasound and microwave-assisted extraction.

Crop waste or by-products in high quantities in the Kent and Medway region

Crops that produce significant quantities of waste in the region include:

- **Wine/grape waste**

The English wine industry is rapidly growing, but it also generates significant waste, including grape pomace, wastewater, wine yeast lees, and vine prunings. Proper management of these waste products is crucial to minimise environmental impact and maximise resource utilisation.

- **Hop waste**

After the hops are harvested for the brewing industry, the remaining stems and cones can generate a substantial amount of waste. Kent is also home to several breweries and distilleries, which can produce by-products like spent grains after the brewing process.

- **Fruit waste**

Kent has extensive fruit orchards and fruit waste, such as apple pomace, can be generated during fruit processing or after the harvest.

- **Cereal crop residues**

After harvesting cereal crops like wheat, barley, and oats, there are often residues like straw and chaff that can be considered as crop waste.
Depending on the type of crops grown and agricultural practices, there might be additional biomass residues like straw, husks, or stalks

- **Vegetable residues:**

The region produces a variety of vegetables, and the residues from processing or harvesting operations can contribute to crop waste.

- **Fresh food processing waste**

Fruit and Vegetable Peelings/Trimmings: During fruit and vegetable processing or preparation, peelings, trimmings, and other non-edible parts can be generated as by-products.

Some additional farming by-products in Kent and Medway include:

- **Dairy By-products**

Kent has a significant dairy farming industry, and as a result, dairy by-products such as whey, milk solids, and other residues from milk processing can be generated.

- **Livestock Manure**

With various livestock farms in the region, such as cattle, sheep, and poultry, there is a considerable production of animal manure that can be used as a valuable organic fertiliser.

- **Wool**

There are sheep farms in Kent, the wool sheared from the sheep is a valuable by-product.

- **Fish Waste**

There are fish farms and fishing activities near Kent's coastal areas, fish waste, such as fish guts and scales, can be generated.

For the purposes of this paper these by-products will not be explored.

Key crops of interest

Grape waste

How much waste is produced in the region?

The English wine industry has experienced significant growth in recent years, with South East England emerging as a major producer. In 2022, this region boasted 1,945 hectares of vineyards, yielding a substantial 9,336 tonnes of grapes.[4]

However, this burgeoning industry also generates various waste products. One such by-product is grape pomace, which consists of the skins, seeds, and stems remaining after the juice is extracted from the grapes. In 2022, South East England's vineyards produced an estimated 2,334 tonnes of grape pomace, of which 584 tonnes were grape stems.

Another significant waste stream from winemaking is wastewater. South East England's wine industry generated approximately 9,336,000 litres of wastewater in 2022.[5] This wastewater can contain organic matter, nutrients, and other contaminants that require proper treatment to minimise environmental impact.

In addition to these primary waste products, the winemaking process also generates secondary waste streams. One such example is wine yeast lees, a by-product of the fermentation process. Wine yeast lees contain yeast cells, tartaric acid, and other inorganic compounds. While these lees can be a valuable source of nutrients for plants or animals, they also need to be managed responsibly to avoid environmental pollution.

Finally, the viticultural process itself generates waste in the form of vine prunings. These prunings can be used for various purposes, such as mulching or composting, but if not managed properly, they can contribute to soil erosion and nutrient loss.

4. Wine GB Industry Report, 2022 – 2023.
5. Sustainability of Wine Production. Sergi Maicas, Jose Juan Mateo. 11 Jan 20.20

Addressing the waste challenge

The English wine industry is increasingly recognising the importance of sustainable practices and waste reduction. By implementing innovative technologies and adopting circular economy principles, the industry can minimise its environmental footprint and maximise the value of its waste products.

Some potential strategies include:

- Composting
  - Grape pomace, vine prunings, and other organic waste can be composted to produce nutrient-rich soil amendments.
- Bioenergy
  - Certain waste streams, such as grape pomace, can be converted into biofuels or biogas through anaerobic digestion.
- Nutrient Recovery
  - Wastewater can be treated to recover valuable nutrients, such as nitrogen and phosphorus, which can be used as fertilisers.
- Product Upcycling
  - Wine yeast lees can be used to produce value-added products, such as nutritional supplements or skincare products.

By adopting these and other sustainable practices, the English wine industry can continue to grow and thrive while minimising its impact on the environment.

What is currently done with this waste?

Expanding on grape pomace and other wine by-products

While grape pomace, a by-product of winemaking consisting of skins, seeds, and stems, is often utilised as a fertiliser, its application requires careful consideration. Although it can enrich soil, excessive use can hinder crop germination due to the high concentration of polyphenols, which possess toxic properties.

Another potential use for grape pomace is as animal feed. It can be incorporated into lamb feed, with an optimal inclusion rate of 12.2%. However, excessive use, exceeding 30%, should be avoided due to the presence of polyphenols and lignin, which can negatively impact animal health. Additionally, grape pomace has shown promise in reducing methane emissions from dairy cattle by approximately 20%. This reduction is attributed to the presence of crude fat and condensed tannins in the pomace.

Wine yeast lees, a by-product of the fermentation process, and grape pomace can be further processed through distillation to produce pure ethanol.

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Grape stems and prunings

Unfortunately, grape stems and pomace are frequently disposed of in landfills. A more sustainable approach would be to utilise them as feedstock for anaerobic digestion, a process that generates biomethane or electricity. Similarly, grapevine prunings could be diverted from landfills and used for anaerobic digestion or composting.

By exploring innovative and sustainable methods for utilising these wine by-products, the industry can reduce its environmental impact and contribute to a more circular economy.

How easily can this waste be sorted and/or treated for transportation?

A significant advantage of viticultural and vinicultural waste is its inherent separability. Given that these by-products are generated at distinct stages of the winemaking process, they are often already segregated. This inherent separation simplifies the process of valorising specific waste streams, eliminating the need for labour-intensive and costly separation steps.

In terms of treatment, these wastes are generally non-hazardous and do not require specialised treatment before transportation. This simplifies logistics and reduces the associated costs. For instance, grape pomace, a common by-product, is often transported to nearby farms using tractor-trailers, a straightforward and efficient method.

By understanding the distinct characteristics of each waste stream, wine producers can effectively manage and utilise these by-products, contributing to a more sustainable and circular economy.

High-value compounds in grape waste

Grape waste, a by-product of the winemaking process, is a rich source of valuable compounds with a wide range of potential applications.

Polyphenols, a class of compounds with potent antioxidant and anti-inflammatory properties, are abundant in grape seeds and skins. These compounds, including anthocyanins, phenolic acids, resveratrol, flavonols, and flavanols, have been extensively studied for their potential health benefits.

- **Antimicrobial and antifungal properties**
  - Polyphenolic compounds derived from grape pomace have demonstrated antimicrobial and antifungal activity.
- **Antioxidant and anti-inflammatory effects**
  - These compounds have also been shown to possess antioxidant and anti-inflammatory properties.
- **Gut health**
  - Polyphenols from red wine have been found to modulate gut microbiota, which can positively impact human health.
- **Anti-cancer properties**
  - Extracts from grape waste have exhibited antitumor and anti-proliferative effects, with the specific grape variety influencing the efficacy of these extracts.

Enanthic ester, commonly known as cognac oil, is another valuable compound found in grape waste, particularly in wine yeast lees. This compound can be extracted through distillation and is used in the production of cognac and certain perfumes. Approximately 0.4 kg of enanthic ester can be obtained from one ton of wine yeast lees.

By harnessing the potential of these high-value compounds, the wine industry can reduce its environmental impact and contribute to the development of sustainable and innovative products.

What industrial applications might they be used for?

Polyphenols

In addition to their potential pharmaceutical applications, polyphenols, particularly anthocyanins, find diverse applications in various industries:

- Dye industry
  - The vibrant colours of anthocyanins make them attractive as natural dyes. By utilising these naturally derived pigments, industries can reduce reliance on synthetic, inorganic dyes, promoting more sustainable and environmentally friendly practices.
- Cosmetics industry
  - The pigmentation and antioxidant properties of anthocyanins make them valuable ingredients in the cosmetics industry. They are used in a wide range of topical skincare products, including creams, serums, and lotions, to protect the skin from oxidative stress and promote a youthful appearance.

By exploring and capitalising on the diverse applications of grape waste compounds, industries can contribute to a more sustainable and innovative future.

There are several other additional potential applications for grape waste compounds:

Food and beverage industry

- Natural food colourant
  - Anthocyanins can be used as natural food colourants, providing vibrant colours to a variety of food products, including beverages, candies, and baked goods.
- Antioxidant supplements
  - Polyphenol-rich extracts from grape waste can be used to create antioxidant supplements, promoting overall health and well-being.
- Flavour enhancers
  - Certain compounds found in grape waste, such as terpenes, can be used to enhance the flavour of food and beverages.

Other potential applications:

- Biofuels
  - Grape waste, particularly pomace, can be converted into bioethanol or biogas through fermentation processes.
- Animal feed
  - Grape pomace can be used as a feed additive for livestock, providing additional nutrients and improving animal health.
- Biodegradable plastics
  - Some research suggests that polyphenols from grape waste could be used to develop biodegradable plastics.

By exploring these diverse applications, the wine industry can maximise the value of its waste products and contribute to a more sustainable future.

What initial pre-treatment would be required?

Pre-treatment for extracting high-value compounds from grape waste

To effectively extract high-value compounds, such as polyphenols, from grape waste, various pre-treatment techniques can be employed. These techniques aim to disrupt the plant cell walls and release the target compounds into the extraction solvent.

Common pre-treatment methods

- **Physical methods**
  - Grinding or milling
    - Reducing the particle size of the grape waste increases the surface area available for solvent contact, enhancing extraction efficiency.
  - Drying
    - Removing moisture from the waste can improve the extraction process by reducing the polarity of the solvent and preventing microbial growth.
- **Chemical methods**
  - Acid or alkali treatment
    - Adjusting the pH of the grape waste can alter the solubility of polyphenols, facilitating their extraction.
  - Enzyme treatment
    - Enzymes **c**an be used to degrade cell wall components, making it easier to extract target compounds.

Extraction techniques
Once the grape waste has been pre-treated, various extraction techniques can be employed to recover the high-value compounds

- **Solvent extraction**
  - This traditional method involves using organic solvents to dissolve the target compounds. However, the choice of solvent and extraction conditions is crucial to maximise yield and minimise environmental impact.
- **Ultrasound-Assisted Extraction (UAE)**
  - Ultrasound waves can disrupt cell walls and enhance mass transfer, leading to improved extraction efficiency.
- **Microwave-Assisted Extraction (MAE)**
  - Microwaves can rapidly heat the sample, accelerating the extraction process and reducing energy consumption.
- **Supercritical Fluid Extraction (SFE)**
  - Supercritical fluids, such as carbon dioxide, can selectively extract target compounds with high efficiency and minimal environmental impact.

It is important to note that the optimal extraction technique depends on factors such as the target compound, the desired purity, and the scale of production. Additionally, combining different techniques can often lead to synergistic effects, further improving extraction efficiency and selectivity.

Ongoing research aims to develop more efficient and sustainable methods for extracting high-value compounds from grape waste, contributing to a circular economy and reducing the environmental impact of the wine industry.

Research tanks at Niab's Wine Innovation Centre, East Malling

Hop waste

How much waste is produced in the region?

Hop waste production in South East England is notable but difficult to quantify precisely without more specific data on post-harvest losses and processing waste. The region, especially Kent, Sussex, and Surrey, accounts for nearly half of the UK's hop production, sharing this responsibility primarily with the West Midlands.

Traditionally, hops are harvested and dried in oast houses, which are common across Kent and surrounding counties. However, these drying processes, along with other post-harvest handling stages, generate organic waste in the form of discarded bines (stems), leaves, and any unsuitable cones.

Hop waste is often repurposed rather than disposed of. Some farmers use it as a soil conditioner due to its organic matter content, while others work with local breweries or composting facilities to convert it into usable agricultural inputs. Efforts in South East England also include projects to improve hop resilience, which may reduce waste by enhancing crop yields and quality through climate-adaptive varieties.

What is currently done with this waste?

Spent hops, the primary hop waste product, are often used in a variety of ways:

- **Compost**
  - Spent hops are rich in nutrients and can be composted to create a valuable fertiliser for gardens and farms.
- **Animal feed**
  - Some farmers use spent hops as a feed supplement for animals like cows and pigs.
- **Fertiliser**
  - The nutrient content of spent hops makes them suitable for direct application to fields as a fertiliser.
- **Food products**
  - In some cases, spent hops are used in food products like bread, granola, and even snacks.
- **Bioenergy**
  - Spent hops can be processed to produce biogas or bioethanol, contributing to renewable energy sources.

The specific disposal methods used by breweries and farmers can vary depending on local regulations and resources. However, there is a growing trend towards finding innovative and sustainable uses for hop waste, reducing its environmental impact.

Expanding on hop waste utilisation

Spent hops, a by-product of the brewing process, are increasingly recognised for their potential as a valuable resource. Here's a more detailed look at how this waste product is being repurposed:

Agricultural applications

- Animal feed
    - Spent hops can be incorporated into animal feed, particularly for livestock like cattle and pigs. They provide a source of fibre, protein, and antioxidants.
- Fertiliser
    - The nutrient-rich composition of spent hops makes them an excellent natural fertiliser for gardens, farms, and landscaping. They can be composted or applied directly to soil to improve its fertility.

Food and beverage

- Food products
    - Spent hops can be used as a flavouring agent in various food products, including bread, beer bread, and even ice cream. Their unique bitter and slightly floral taste can add a distinctive flavour profile to these items.
- Beverages
    - Beyond beer, spent hops can be used to create unique tea blends. They can also be infused into water or other beverages to impart a subtle hop flavour.

Other innovative uses

- Biofuels
    - Spent hops can be converted into biofuels, such as ethanol, through processes like anaerobic digestion. This helps reduce reliance on fossil fuels and promotes sustainable energy practices.
- Textiles
    - Research is ongoing to explore the potential of using hop fibres to create textiles. This innovative approach could lead to the development of eco-friendly and sustainable clothing and other textile products.
- Packaging materials
    - Some companies are investigating the use of hop fibres as a component in biodegradable packaging materials. This could help reduce plastic waste and promote sustainable packaging solutions.

By finding creative and sustainable ways to utilise spent hops, the brewing industry can minimise its environmental impact and contribute to a more circular economy.

How easily can this waste be sorted and/or treated for transportation?

Hop waste in the UK can be easily sorted and treated for transportation due to several factors:

Established recycling infrastructure
The UK has a well-developed network of waste management companies specialising in brewery by-products. These companies have the expertise and resources to efficiently collect, sort, and treat hop waste from breweries of all sizes

Diverse recycling options
Hop waste can be repurposed in various ways:

- Animal feed
    - High in protein and fibre, spent hops can be used as a valuable feed supplement for livestock.
- Composting
    - Hop waste can be composted to create nutrient-rich soil amendments for agriculture.
- Bioenergy production
    - Hop waste can be converted into biogas through anaerobic digestion, generating renewable energy.
- Innovative food products
    - Some breweries are exploring the use of spent hops in food products like bread, snacks, and even beer.

Government support

The UK government promotes sustainable waste management practices, including the recycling of brewery by-products. This support encourages breweries to adopt responsible waste disposal methods.

Overall, the ease of sorting and treating hop waste in the UK is facilitated by a combination of established infrastructure, diverse recycling options, and supportive government policies. This makes it a relatively straightforward process for breweries to dispose of their hop waste in an environmentally friendly manner.

Here are some additional details about the recycling of hop waste in the UK

- Collection
    - Hop waste is typically collected from breweries by waste management companies. The waste is then transported to a recycling facility.
- Sorting
    - At the recycling facility, the hop waste is sorted to remove any contaminants, such as metal or plastic.
- Treatment
    - The hop waste is then treated according to its intended use. For example, hop waste that is going to be used for animal feed may be dried and pelletized. Hop waste that is going to be composted may be mixed with other organic materials.
- Transportation
    - Once the hop waste has been treated, it is transported to its final destination. This may be a farm, a composting facility, or a biogas plant.

The recycling of hop waste is an important part of the UK's efforts to reduce waste and promote sustainability. By recycling hop waste, breweries can help to reduce their environmental impact and conserve resources.

High-value compounds – Hop waste

Hop waste, particularly spent hops, contains several high-value compounds with potential applications in various industries. Some of the most notable compounds include:

- Xanthohumol
    - This prenylated flavonoid is known for its potent antioxidant, anti-inflammatory, and anticancer properties. It has attracted significant interest in the pharmaceutical and nutraceutical industries.
- Alpha and beta acids
    - These compounds contribute to the bitterness and aroma of beer. They also possess antimicrobial and antioxidant properties.
- Essential oils
    - Hop essential oils contain a complex mixture of terpenes, which contribute to the aroma and flavour of hops. These oils have potential applications in the fragrance and flavour industries.
- Polyphenols
    - Hops are rich in polyphenols, which are known for their antioxidant and anti-inflammatory properties. These compounds can be extracted from spent hops and used in various products, such as dietary supplements and skincare products.

By extracting and utilising these high-value compounds, the brewing industry can reduce waste and generate additional revenue streams.

High-value compounds in hop waste: A deeper dive

Xanthohumol

- Potent antioxidant
  - Xanthohumol has been shown to be a powerful antioxidant, capable of neutralising harmful free radicals.
- Anti-inflammatory properties
  - This compound exhibits anti-inflammatory effects, which may be beneficial in managing various inflammatory conditions.
- Cancer-fighting potential
  - Research suggests that xanthohumol may have anticancer properties, potentially inhibiting the growth of tumour cells.
- Neuroprotective effects
  - Studies have indicated that xanthohumol may protect brain cells from damage, making it a potential agent for preventing neurodegenerative diseases.

Alpha and beta acids

- Antimicrobial properties
  - These compounds possess antimicrobial activity, which can help inhibit the growth of harmful bacteria and fungi.
- Antioxidant effects
  - Alpha and beta acids contribute to the antioxidant properties of hops, helping to protect cells from oxidative damage.
- Sedative and anxiolytic effects
  - These compounds have been linked to sedative and anxiolytic effects, which may contribute to the calming and sleep-inducing properties of hops.

Essential oils

- Aromatic compounds
  - Hop essential oils contain a complex mixture of terpenes, which contribute to the distinctive aroma and flavour of hops.
- Antimicrobial activity
  - Some of these terpenes have antimicrobial properties, making them potential natural preservatives.
- Sedative and anxiolytic effects
  - Certain terpenes in hop essential oils, such as myrcene and humulene, have been associated with sedative and anxiolytic effects.

Polyphenols

- Antioxidant properties
  - Polyphenols are powerful antioxidants that can help protect cells from oxidative damage.
- Anti-inflammatory effects
  - These compounds have anti-inflammatory properties, which may be beneficial in managing various inflammatory conditions.
- Cardiovascular health
  - Polyphenols may help improve cardiovascular health by reducing cholesterol levels and blood pressure.

By extracting and utilising these high-value compounds, the brewing industry can not only reduce waste but also contribute to the development of new products with potential health benefits.

What industrial applications might they be used for?

The high-value compounds extracted from hop waste have a wide range of potential industrial applications. Here are some of the most promising areas:

Pharmaceutical industry

- Antioxidant supplements
  - The potent antioxidant properties of compounds like xanthohumol can be harnessed to develop dietary supplements.
- Anti-inflammatory drugs
  - The anti-inflammatory potential of hop compounds could lead to the development of new medications for various inflammatory diseases.
- Neuroprotective agents
  - Compounds with neuroprotective properties, such as xanthohumol, could be used to develop drugs for neurodegenerative diseases like Alzheimer's and Parkinson's.
- Anticancer drugs
  - The anticancer properties of certain hop compounds offer potential for developing novel cancer therapies.

Food and beverage industry

- Natural food additives
  - Hop-derived compounds can be used as natural preservatives, antioxidants, and flavouring agents in food products.
- Functional foods and beverages
  - These compounds can be incorporated into functional foods and beverages to provide health benefits, such as improved antioxidant status and reduced inflammation.

Cosmetics and personal care industry

- Skincare products
  - The antioxidant and anti-inflammatory properties of hop compounds make them ideal for use in skincare products like creams, lotions, and serums.
- Hair care products
  - Hop-derived compounds can be used to develop hair care products that promote hair growth, reduce hair loss, and improve hair health.

Agricultural industry

- Natural pesticides:
  - The antimicrobial properties of hop compounds can be utilised to develop natural pesticides for crop protection.
- Animal feed additives
  - Hop-derived compounds can be added to animal feed to improve animal health and productivity.

By exploring the diverse applications of hop waste-derived compounds, the brewing industry can contribute to a more sustainable and innovative future.

What initial pre-treatment would be required?

Initial pre-treatment of hop waste

The initial pre-treatment of hop waste will depend on the specific compounds of interest and the desired extraction method. However, some common pre-treatment steps include:

1. Drying
- Purpose: To reduce moisture content and improve handling and storage.
- Methods: Air drying, oven drying, or freeze-drying can be used, depending on the desired quality and efficiency.

2. **Grinding or milling**
- Purpose: To increase the surface area of the hop waste, facilitating efficient extraction.
- Methods: Hammer mills, ball mills, or other grinding equipment can be used to reduce the particle size.

3. **Cleaning**
- Purpose: To remove impurities, such as dirt, debris, and microbial contaminants.
- Methods: Sifting, washing, or other cleaning techniques can be employed.

4. **Size separation**
- Purpose: To separate different particle sizes, which can influence extraction efficiency and product quality.
- Methods: Sieving or other separation techniques can be used to obtain specific particle size fractions.

Specific pre-treatments based on extraction method:

- **Solvent extraction**
  - Drying: Essential for efficient solvent extraction.
  - Grinding: Increases the surface area, improving solvent penetration.
- **Supercritical Fluid Extraction (SFE)**
  - Drying: Necessary to avoid interference from water vapour.
  - Grinding: Can enhance extraction efficiency, but may not be essential.
- **Microwave-Assisted Extraction (MAE)**
  - Drying: Can improve extraction efficiency by reducing moisture content.
  - Grinding: Can increase the surface area, facilitating microwave penetration.

The specific pre-treatment steps will be optimised based on factors such as the target compounds, desired extraction yield, and the overall cost-effectiveness of the process.

A case study: Essel Innovation & Development Services and Goacher's Brewery Ltd

Essel Innovation & Development Services Ltd specialises in offering distinctive and healthy South Indian cuisine in the Maidstone area. They are developing sustainable packaging solutions from brewers' spent grain, aiming to create environmentally friendly products that contribute to the circular economy.

The challenge

Essel Innovation & Development Services, a purveyor of healthy South Indian cuisine in Maidstone, faced a significant challenge in aligning its commitment to sustainability with its packaging practices. Traditional packaging materials often contribute to environmental pollution and waste, hindering the company's goal of creating a truly eco-friendly dining experience.

The solution

To address this challenge, Essel embarked on an innovative project to develop bespoke packaging solutions derived from brewers' spent grain. By repurposing this brewing by-product, Essel aimed to reduce waste and emissions generated by both the brewing and food industries.

The impact

Essel was awarded funding from the Growing Kent & Medway Business Sustainability Challenge Fund to:

- Source raw materials
  - Purchase the necessary ingredients to produce sustainable packaging from brewers' spent grain.
- Optimize packaging design
  - Tailor the packaging to suit the specific needs of takeaway South Indian cuisine, ensuring optimal functionality and aesthetics.
- Conduct rigorous safety testing
  - Validate the safety and quality of the new packaging materials through comprehensive testing procedures.
- Establish a manufacturing process
  - Develop efficient manufacturing processes to produce the sustainable packaging on a larger scale.

The collaboration

Essel's partnership with Goacher's Brewery Ltd further strengthens the project's impact. By collaborating with a local brewery, Essel ensures a reliable supply of spent grain, reinforcing the circular economy approach.

Through this innovative project, Essel Innovation & Development Services is not only addressing a pressing environmental challenge but also inspiring positive change within the community. By embracing sustainable practices and fostering collaboration, Essel is setting a new standard for responsible business operations.

Fruit waste

How much waste is produced in the region?

South East England, a key region for fruit production, faces challenges in minimising fruit waste. Across the UK, an estimated £60 million worth of fruit and vegetables was wasted in 2022 due to labour shortages, with 40% of growers reporting crop losses as they struggled to harvest on time. This issue is particularly relevant to South East England, where large-scale farms like Hugh Lowe Farms strive to balance production with sustainability.

Hugh Lowe Farms exemplifies both the scale of fruit growing in the region and the efforts to address waste. The farm employs robotic pickers for strawberries, which help reduce losses caused by labour constraints, but inefficiencies persist, particularly during peak harvest seasons. These challenges highlight the need for regional collaboration and innovation to better utilise surplus produce and minimise waste.

What is currently done with this waste?

Here's a breakdown of what is currently done with this waste and its potential for sorting and treatment:

- **Food waste recycling**

Many households in South East England participate in food waste recycling programs, where fruit and vegetable waste is collected separately and sent to composting facilities. This transforms organic waste into valuable compost for agriculture.

- **Anaerobic digestion**

Some fruit waste is processed through anaerobic digestion, a biological process that breaks down organic matter in the absence of oxygen to produce biogas, which can be used for energy generation.

- **Animal feed**

Certain types of fruit waste, such as overripe or blemished fruit, may be suitable for animal feed, providing a valuable source of nutrients for livestock.

- **Landfill**

Unfortunately, some fruit waste still ends up in landfills, contributing to environmental problems like methane emissions and soil contamination.

How easily can this waste be sorted and/or treated for transportation?

Fruit waste can be relatively easy to sort and treat for transportation, depending on its specific type and condition:

- **Sorting**

Fruit waste can be sorted based on its composition (e.g., peelings, cores, whole fruit) and potential uses (e.g., composting, animal feed, anaerobic digestion). This sorting can be done manually or using automated sorting technologies.

- **Treatment**
  - Composting
    - Fruit waste can be directly composted or mixed with other organic materials to accelerate the composting process.
  - Anaerobic digestion
    - Fruit waste can be pre-treated to improve its digestibility and then fed into anaerobic digestion systems.
  - Drying
    - Fruit waste can be dried to reduce its weight and volume, making it easier to transport.

Challenges and opportunities

While there are opportunities to improve the management of fruit waste in South East England, some challenges remain:

- Inconsistent collection
    - Food waste collection systems can vary between different local authorities, leading to inconsistencies in the amount and type of fruit waste collected.
- Contamination
    - Contamination of fruit waste with non-organic materials can reduce its value for composting or anaerobic digestion.
- Infrastructure
    - A lack of sufficient composting and anaerobic digestion facilities can limit the options for processing fruit waste.

To address these challenges, increased investment in waste infrastructure, improved public education on food waste reduction and recycling, and stronger collaboration between stakeholders are essential. By optimising the management of fruit waste, we can reduce its environmental impact and contribute to a more sustainable future.

Tensei create new biomaterials from raspberry crop waste

High-value compounds in fruit waste

Fruit waste is a rich source of high-value compounds with various applications in the food, pharmaceutical, and cosmetic industries.

Here are some of the most prominent compounds:

- **Polyphenols**
  - Phenolic acids: These compounds possess strong antioxidant properties, protecting cells from oxidative damage. They are found in abundance in fruit peels and seeds.
  - Flavonoids: This group includes anthocyanins, flavonols, and flavanols, which are known for their anti-inflammatory and anticancer properties. They are often concentrated in the skin and flesh of fruits.

- **Pectin**

A complex carbohydrate found in the cell walls of fruits, pectin is used as a gelling agent in jams and jellies. It also has potential applications in the pharmaceutical industry as a drug delivery carrier.

- **Vitamins and minerals**

Fruit waste, particularly peels and seeds, contains essential vitamins like vitamin C and minerals such as potassium and magnesium. These nutrients can be extracted and used in dietary supplements or fortified foods.

- **Carotenoids**

These pigments contribute to the vibrant colours of fruits and vegetables. Carotenoids, such as beta-carotene and lycopene, possess antioxidant properties and can be converted into vitamin A in the body.

- **Fibres**

Fruit waste is a good source of dietary fibre, which promotes digestive health and can help regulate blood sugar levels. Fibre can be extracted and used as a functional ingredient in food products.

- **Oils**

Some fruit seeds, like those from citrus fruits and avocados, contain valuable oils that can be used in cooking, cosmetics, and as a source of biofuel.

By extracting and utilising these high-value compounds from fruit waste, we can reduce waste disposal and create sustainable, value-added products.

What industrial applications might they be used for?

The high-value compounds extracted from fruit waste have a wide range of industrial applications:

Food industry

- Natural flavourings
  - Fruit waste, particularly the peels and seeds, can be used to extract natural flavourings for food and beverage products. These natural flavours can replace synthetic additives and provide a more authentic taste.
- Dietary fibre
  - Fruit waste is a rich source of dietary fibre, which can be extracted and added to food products to improve their nutritional profile. This can help address the growing demand for high-fibre foods.
- Fermentation
  - Fruit waste can be used as a substrate for fermentation processes to produce various products, such as alcohol, vinegar, and fermented foods like kimchi and sauerkraut.

Pharmaceutical industry

- Drug delivery systems
  - Pectin and other polysaccharides extracted from fruit waste can be used as carriers for drug delivery, improving the bioavailability and efficacy of medications.
- Antimicrobial agents
  - Some compounds found in fruit waste, such as polyphenols, have antimicrobial properties and can be used to develop natural preservatives and disinfectants.
- Neuroprotective agents
  - Certain compounds, like anthocyanins, have been shown to have neuroprotective effects and may be beneficial in preventing neurodegenerative diseases.

Cosmetic industry

- Skin-lightening agents
  - Some compounds extracted from fruits, such as arbutin, have skin-lightening properties and can be used in cosmetic products to reduce hyperpigmentation.
- Hair care products
  - Fruit extracts can be used to improve hair health and condition, providing benefits like moisture, shine, and reduced hair loss.
- Sun protection
  - Carotenoids, particularly lycopene, have antioxidant properties that can help protect the skin from UV damage.

Other industries

- Textile industry
  - Fruit extracts can be used as natural dyes for textiles, reducing the environmental impact of synthetic dyes.
- Bioenergy
  - Fruit waste can be converted into biofuels, such as ethanol and biogas, through processes like fermentation and anaerobic digestion.
- Water treatment
  - Fruit waste can be used to remove pollutants from wastewater, such as heavy metals and organic dyes.

It is important to note that further research is needed to fully explore the potential of fruit waste as a source of high-value compounds. By investing in research and development, we can unlock the full potential of this valuable resource and contribute to a more sustainable future.

What initial pre-treatment would be required?

The initial pre-treatment of fruit waste will depend on the specific compounds you want to extract and the extraction method you choose. However, some common pre-treatment steps include:

1. **Washing and sorting**
   - Washing: Removes dirt, debris, and microorganisms.
   - Sorting: Separates different types of fruit waste and removes any foreign materials.
2. **Size reduction**
   - Cutting or grinding: Reduces the size of the waste material to increase the surface area for extraction.
3. **Drying**
   - Drying: Removes moisture to improve the efficiency of extraction and storage. This can be done through methods like air drying, oven drying, or freeze-drying.
4. **Heat treatment**
   - Blanching: Involves heating the waste material in hot water or steam to inactivate enzymes and improve the extraction yield.
   - Microwaving: Can be used to quickly and efficiently dry or extract compounds from fruit waste.

The specific pre-treatment steps will vary depending on the desired outcome. For example, if you want to extract heat-sensitive compounds like vitamins, you may need to use gentler methods like drying at low temperatures or using solvent extraction.

A case study: University of Kent and Rent a Cherry Tree

Rent a Cherry Tree offers individuals the opportunity to rent a cherry tree annually, allowing them to experience the tree's growth throughout the season and harvest their own cherries. In collaboration with the University of Kent, they are researching the health benefits of Kent cherry products, focusing on anthocyanin levels and prebiotic properties, to provide scientific insights for local growers.

The challenge

Reducing food waste and maximising nutritional potential

The University of Kent, renowned for its scientific research, partnered with Rent a Cherry Tree, a local Kent cherry grower, to address a pressing issue: food waste in the cherry industry. Despite being a high-value crop, a significant portion of cherries is deemed unsuitable for sale due to factors like bruising, discolouration, or minor blemishes. This wasted fruit not only represents a loss of resources but also a missed opportunity to harness its nutritional benefits.

The solution

Upcycling cherry waste into nutrient-rich foods

The collaborative project, titled "Upcycled Food: Getting the Goodness out of Kent Cherries," aimed to transform this waste into valuable, nutrient-rich products.

Researchers from the University of Kent's School of Biosciences, led by Dr. Marina Ezcurra and Dr. Jenny Tullet, worked closely with Michael Dallaway, the owner of Rent a Cherry Tree, to:

1. Identify health benefits
    - The team analysed different cherry products, including fresh fruit, juice, and dried cherries, to determine their specific health benefits. Research focused on the potential of cherries to combat inflammation, improve cognitive function, and support heart health.
2. Develop new foods
    - By extracting valuable compounds from cherry waste, such as anthocyanins and fibre, researchers were able to create innovative food products. These included:
        - Cherry-infused snacks: Healthy snacks like energy bars and fruit leather were developed, incorporating cherry powder and fibre to enhance their nutritional profile.
        - Functional beverages: Cherry-based beverages, such as juices and smoothies, were formulated to target specific health benefits, like antioxidant and anti-inflammatory properties.
        - Prebiotic foods: The team explored the prebiotic potential of cherry fibre, which can promote gut health by nourishing beneficial bacteria.

University of Kent

Rent a CherryTree
Grown with a personal touch

A case study: University of Kent and Rent a Cherry Tree (cont.)

The impact

A more sustainable and nutritious future

The successful collaboration between the University of Kent and Rent a Cherry Tree has had a significant impact on the local food industry and beyond: [8]

- **Reduced food waste**
    - By finding innovative uses for previously wasted cherries, the project has contributed to a more sustainable food system.
- **Enhanced nutritional value**
    - The development of new, nutrient-rich foods has provided consumers with healthier options.
- **Economic benefits**
    - The project has the potential to create new business opportunities and boost the local economy.
- **Scientific advancement**
    - The research has advanced our understanding of the health benefits of cherries and the potential of upcycling food waste.

This case study highlights the power of collaboration between academia and industry to address real-world challenges and create a more sustainable and nutritious future.

By harnessing the potential of food waste, we can reduce our environmental impact and improve public health.

Dr Marina Ezcurra and Dr Jenny Tullet, University of Kent, are working with Rent a Cherry Tree

8. *Upcycled Foods: Getting the goodness out of Kent cherries: https://www.growingkentandmedway.com/research-project-directory/details/19427*

Cereal waste

How much waste is produced in the region?

In South East England, cereal crop waste, particularly straw, plays a significant role in agricultural by-products. In 2024, an estimated 2.4 million tonnes of wheat straw was produced across England, including South East England, though this figure represents a 17% decrease from the previous year. Barley straw production increased, reaching around 1.7 million tonnes, largely due to increased spring barley planting. In addition, oats production in the region saw a rise in both the planted area and yield, leading to an estimated 206,000 tonnes of oat straw in 2024.

While precise data for South East England specifically isn't always detailed separately, this general estimate reflects trends in cereal production, with much of the waste being used for feed, bedding, or biomass energy. These figures underscore the importance of cereal crop by-products, which can be targeted for sustainable uses, including biorefining initiatives.

What is currently done with this waste?

- **Straw**
  - Animal feed
    - A significant portion of straw is used as bedding and feed for livestock, particularly cattle and horses.
  - Mulching
    - Straw can be used as mulch to suppress weeds, retain moisture, and improve soil health.
  - Bioenergy
    - Straw can be converted into biofuels, such as bioethanol or biogas, through various processes like anaerobic digestion.

- **Processing waste**
  - Animal feed
    - Bran, germ, and husks are commonly used as components of animal feed.
  - Food products
    - Some by-products, like wheat germ, are used in human food products due to their nutritional value.
  - Industrial applications
    - Certain components, such as cellulose fibres from straw, can be used in various industrial processes.

How easily can this waste be sorted and/or treated for transportation?

Cereal crop waste, particularly straw, is relatively easy to sort and transport. It is often baled into large, compact packages, making it convenient for handling and transportation. However, the moisture content of straw can influence its weight and transportation costs.

High-value compounds in cereal crop waste

Cereal crop waste, especially straw, is a rich source of cellulose, hemicellulose, and lignin, which can be converted into various value-added products.

- Biofuels
  - Straw can be used to produce bioethanol, biogas, or biohydrogen through processes like anaerobic digestion or thermochemical conversion.
- Biomaterials
  - Cellulose fibres from straw can be used to produce bioplastics, biocomposites, and paper products.
- Animal feed
  - Straw can be used as a feedstock for fungi to produce protein-rich feed for livestock.
- Soil amendments
  - Straw can be composted to improve soil fertility and structure.

What initial pre-treatment would be required?

Pre-treatment of cereal crop waste, particularly straw, is essential to enhance its value and facilitate its conversion into various products. Common pre-treatment methods include:

- Size reduction
  - Straw can be chopped or shredded to increase its surface area and improve its reactivity.
- Moisture adjustment
  - Adjusting the moisture content can optimise the efficiency of subsequent processes, such as enzymatic hydrolysis or fermentation.
- Chemical treatment
  - Chemical treatments, such as acid or alkali hydrolysis, can be used to break down complex polysaccharides into simpler sugars.

By exploring and implementing innovative technologies, we can maximise the value of cereal crop waste, contributing to a more sustainable and circular economy.

Vegetable waste

How much waste is produced in the region?

Exact figures for vegetable waste in South East England remain unavailable, but the region's prominence in horticulture suggests it contributes significantly to the millions of tonnes of agricultural waste generated nationally each year.

In South East England, horticulture accounts for 3.7% of farmed land, with a considerable portion dedicated to vegetables. These crops are particularly vulnerable to waste due to their perishability and the strict cosmetic and quality standards imposed by markets.

Initiatives such as "wonky veg" programs, which promote the sale of cosmetically imperfect produce, and improvements in supply chain management are among the measures being used to mitigate waste. However, the absence of systematic farm-level waste measurement makes it difficult to determine the exact scale of vegetable waste in the region, highlighting the need for better data collection and targeted interventions.

What is currently done with this waste?

The management of vegetable agricultural waste in Kent and South East England involves a variety of approaches, including:

On-farm management

- Composting
    - Vegetable waste can be composted on farms to create nutrient-rich soil amendments.
- Animal feed
    - Some vegetable waste, such as crop residues, can be used as animal feed.
- Direct application to fields
    - In some cases, vegetable waste can be directly applied to fields as a form of organic fertiliser.

Off-farm management

- Anaerobic digestion
    - Vegetable waste can be sent to anaerobic digestion plants, where it is broken down to produce biogas, which can be used to generate electricity or heat.
- Incineration
    - In some cases, vegetable waste may be incinerated to generate energy.
- Landfill
    - As a last resort, vegetable waste may be sent to landfill.

Specific initiatives and organisations in the region:

- WRAP (Waste & Resources Action Programme):
    - WRAP promotes sustainable resource use and has initiatives to reduce food waste, including agricultural waste.
- Local authorities:
    - Many local authorities in the region have programs to collect and compost food waste, which may include vegetable waste from households and businesses.
- Private companies
    - There are several private companies in the region that specialise in collecting and processing agricultural waste, including vegetable waste.

It's important to note that the specific methods used to manage vegetable agricultural waste can vary depending on the type of waste, the location, and the specific practices of individual farmers and businesses. However, there is a growing emphasis on sustainable waste management practices, and many efforts are being made to reduce the amount of vegetable waste that ends up in landfill.

How easily can this waste be sorted and/or treated for transportation?

The way agricultural vegetable waste is sorted and treated for transportation depends on its intended use. Waste is often sorted manually, separating organic material, plastics, and metals. Advanced technology like optical sorters can also automate this process by identifying and separating waste based on its physical and chemical properties.

Organic waste can be composted or undergo anaerobic digestion. Composting breaks down organic matter into nutrient-rich soil amendments, while anaerobic digestion produces biogas for energy generation. Wet waste may be dried to reduce weight and volume, and waste is often baled for easier transport and storage.

Transportation typically involves trucks, but rail or maritime transport can be used for larger quantities or longer distances. It's crucial to maintain strict hygiene practices to prevent disease and pest spread, minimise environmental impact through efficient and sustainable transportation methods, and adhere to local and national regulations for safe and legal waste transport.

By effectively sorting and treating agricultural vegetable waste, it can be transformed from a waste product into a valuable resource.

High-value compounds in vegetable waste

Agricultural vegetable waste is a surprisingly rich source of high-value compounds. These compounds have potential applications in various industries, from food and cosmetics to pharmaceuticals and biofuels.

Here are some of the most valuable compounds found in agricultural vegetable waste:

- **Polyphenols**
  - These powerful antioxidants have been linked to various health benefits, including reduced risk of heart disease and cancer. They are abundant in many fruits and vegetables, and their concentration is often higher in waste than in edible parts.
- **Carotenoids**
  - These pigments give fruits and vegetables their vibrant colours. They have antioxidant properties and are precursors to vitamin A.
- **Pectin**
  - This soluble fibre is commonly used as a thickening and gelling agent in food products. It can be extracted from various fruit and vegetable waste, such as apple pomace and citrus peel.
- **Proteins**
  - Vegetable waste can be a valuable source of protein, which can be used to produce animal feed, food supplements, or even plant-based meat alternatives.
- **Lipids**
  - Some vegetable waste, such as oilseeds and nutshells, contains valuable lipids that can be extracted and used for various purposes, including biodiesel production.
- **Vitamins and minerals**
  - Many vitamins and minerals, such as vitamin C, potassium, and magnesium, can be recovered from vegetable waste.

By extracting and utilising these high-value compounds, we can reduce waste, create sustainable products, and promote a circular economy.

What industrial applications might they be used for?

Agricultural vegetable waste, often overlooked, is a valuable resource containing a variety of high-value compounds. These compounds, including polyphenols, carotenoids, pectin, proteins, lipids, vitamins, and minerals, have potential applications in various industries.

The food industry can benefit from natural colourants, flavourings, functional food ingredients, and food additives. The cosmetics industry can utilise these compounds for antioxidants, natural colourants, and moisturisers. In the pharmaceutical industry, they can serve as antioxidants, antimicrobial agents, and anti-inflammatory agents. Additionally, the biofuel industry can leverage these compounds for bioethanol and biodiesel production.

The high-value compounds extracted from agricultural vegetable waste have a wide range of potential industrial applications:

Food industry

- Natural colourants and flavourings
  - Carotenoids, anthocyanins, and other pigments can be used to colour food products naturally.
- Functional foods
  - Polyphenols and other bioactive compounds can be added to foods to enhance their nutritional value and health benefits.
- Food additives
  - Pectin, for example, can be used as a thickener, gelling agent, or stabiliser in various food products.

Cosmetics industry

- Antioxidants
  - Polyphenols and other antioxidants can be used in skincare products to protect the skin from damage caused by free radicals.
- Natural colourants
  - Carotenoids and other pigments can be used to colour cosmetics naturally.
- Moisturisers
  - Pectin and other polysaccharides can be used as moisturising agents in skincare products.

Biofuel industry

- Bioethanol
  - Sugars extracted from vegetable waste can be fermented to produce bioethanol, a renewable fuel.
- Biodiesel
  - Lipids extracted from vegetable waste can be converted into biodiesel, another renewable fuel.

Pharmaceutical industry

- Antioxidants
    - Polyphenols and other antioxidants can be used to develop drugs to treat various diseases, such as cancer and heart disease.
- Antimicrobial agents
    - Some compounds extracted from vegetable waste have antimicrobial properties and can be used to develop new antibiotics.
- Anti-inflammatory agents
    - Certain compounds can be used to develop drugs to treat inflammatory diseases, such as arthritis.

By extracting and utilising these high-value compounds, we can reduce waste, promote sustainability, and create innovative products that benefit both human health and the environment.

What initial pre-treatment would be required?

The initial pre-treatment of agricultural vegetable waste will depend on its intended use. However, some common pre-treatment steps include:

1. **Sorting and segregation**
- Separating different types of waste (e.g., organic, plastic, metal) to ensure efficient processing. Removing contaminants like soil, stones, and foreign objects.

2. **Size reduction**
- Chopping or grinding the waste into smaller particles to increase surface area and facilitate subsequent processes like drying, extraction, or composting.

3. **Washing**
- Removing dirt, pesticides, and other contaminants from the waste, especially if it's intended for food or feed applications.

4. **Drying**
- Reducing moisture content to improve storage stability, reduce transportation costs, and enhance the efficiency of subsequent processes. This can be achieved through methods like air drying, solar drying, or mechanical drying.

5. **Heat treatment:**
- Inactivating enzymes and microorganisms to prevent spoilage and improve the quality of the waste. This can involve processes like pasteurisation or sterilisation.

The specific pre-treatment steps will vary depending on the desired end product and the specific properties of the vegetable waste. For example, if the goal is to extract high-value compounds, more intensive pre-treatment may be required to break down cell walls and release the compounds.

A case study: Fermenti - Fermenting the future of food

Fermenti specialises in creating innovative fermented treats by combining traditional lacto-fermentation with freeze-drying technology, preserving live cultures and nutrients. Collaborating with nutritionists, microbiologists, and pastry chefs, they have developed products containing 3 billion CFU from 35 different live cultures.

The Challenge

Fermenti, a gut health start-up, recognised the pressing issue of food waste and the potential of fermentation to create nutritious and sustainable snacks. The company aimed to develop a new range of functional snacks using rescued fruits, vegetables, and food manufacturing by-products.

The Solution

Fermenti's innovative approach involved combining traditional fermentation techniques with modern food technology to produce a range of fermented snacks. By fermenting rescued food, the company not only reduces food waste but also enhances the nutritional value of the products.

The impact

Fermenti was awarded funding from the Growing Kent & Medway Business Sustainability Challenge to:

- Develop new products
    - Create a range of fermented snacks using rescued ingredients, expanding their product line and market reach.
- Collaborate with industry leaders
    - Partner with Nim's Crisps to leverage their expertise in food manufacturing and distribution, facilitating the scaling of Fermenti's operations.
- Conduct scientific research
    - ndertake laboratory testing to analyse the nutritional and health benefits of their fermented products, providing scientific evidence to support their claims.
- Educate the next generation
    - Organize fermentation workshops in schools to raise awareness about the gut microbiome, the benefits of fermented foods, and the importance of sustainable food practices.

fermenti

A case study: Fermenti - Fermenting the future of food (cont.)

The collaboration

Fermenti's partnership with Nim's Fruit Ltd strengthens their commitment to reducing food waste and promoting sustainable food systems. By collaborating with an established food manufacturer, Fermenti can access a wider market and benefit from their expertise in production and distribution.

Through this innovative project, Fermenti is not only addressing the issue of food waste but also promoting healthier eating habits and supporting local communities. By combining traditional fermentation techniques with modern technology, Fermenti is shaping the future of food, one fermented snack at a time.

Fermenti coco bites

Other crops - mushroom waste

How much waste is produced?

The UK's mushroom production is forecast to grow steadily over the next few years. By 2026, it's expected to reach 109,020 metric tons - up from 103,200 metric tons in 2021 (Reportlinker.com). Commercially, mushrooms are grown on lignocellulosic biomass substrates such as wood chips, straw, sawdust, and agricultural residues. Whilst mushroom farming converts these low-value biomass residues and waste streams into higher-value food, it generates its own waste stream in the form of spent substrate. Spent mushroom substrate (SMS) is the substrate remaining after the mushroom growth cycle and is considered a waste as it cannot be used for further cycles.

SMS is produced in large quantities with most mushroom farms producing about 3-5 kg of SMS per kg of fresh mushrooms. There are about 13-14 mushroom farms in South East England. Most farms in the UK are small or medium farms with very few large farms. Although the productivity can vary widely, on average, small farms produce about 300 kg of fresh mushrooms per month. This amounts to about 900 to 1500 kg per month of spent substrate being generated per farm.

Current practice in waste management and ease of handling

SMS is light, free of weeds and disease, rich in organic matter, and easy to sort and transport. Traditionally, SMS has been disposed of either by incineration, spreading on land, landfilling, or composting. Mushroom farmers are increasingly moving away from incineration towards the utilisation of SMS for agricultural and other applications. For example:

- **Composting**

This is currently the most common application of SMS. The high organic content of SMS makes it a useful component in the composting process, contributing to the overall nutrient content of the compost. It is often mixed with rotted horse and chicken manure. Some farms compost the substrate themselves, use part of it for their fields (if available) and sell the excess. Others sell the SMS to companies for further processing. One tonne of bulk mushroom compost costs around £75-100 making it an inexpensive fertiliser. However, SMS often contains chalk and peat (https://www.rhs.org.uk/soil-composts-mulches/compost) and therefore is no longer recommended for horticultural use, due to damage to peatland ecosystems. SMS is also alkaline in nature and therefore not suitable for fruit crops or crops that require acidic conditions.

- **Soil amendment**

SMS is rich in organic matter and other nutrients and it can be used as a soil amendment to improve soil structure, fertility, and water retention.

- **Mulching**

Some gardeners use SMS as a mulch around plants. It helps retain soil moisture, suppresses weeds, and releases nutrients into the soil as it breaks down.

- **Land reclamation**

In some cases, SMS is used in land reclamation projects, where it can help restore soil quality in areas affected by erosion or other environmental disturbances.

- **Animal bedding and feed**

Depending on its composition, SMS can be used as bedding for livestock. SMS has also been tested as a component of animal feed.

- **Energy production**

In certain bioenergy systems, spent mushroom substrate can be used as a feedstock for biogas production through anaerobic digestion or as a source of biomass for bioenergy production.

- **Research**

Researchers may use spent mushroom substrate in studies related to soil ecology, microbiology, or sustainable agriculture practices.

High-value compounds in SMS

During their growth and metabolism, mushrooms secrete several types of metabolites and bioactive compounds including polysaccharides, polyphenols, polyaromatic compounds, pigments, and enzymes in the form of a liquid called mushroom exudate. The composition of the exudate depends on the species of mushrooms. The exudate remains in the spent substrate and the excess collects at the bottom of the mushroom growth bags or containers. The bioactive compounds in the exudate have been recently explored for their fungicidal, antibiotic, antioxidant, cytotoxic, and other useful properties.

Pre-treatment methods

The pre-treatment methods include solvent extraction to extract crude mixtures of bioactive compounds from the exudate. The type of solvent would depend on the type of bioactive compounds. For instance, polysaccharides and glycoproteins can be extracted using hot water extraction, acid or alkali extraction or ethanol precipitation. Polyphenols and polar compounds can be extracted using alcohols. Enzymes are extracted using water or buffers and non-polar compounds using solvents such as hexane. Crude mixtures extracted by solvent extraction can then be separated using chromatography techniques.

Industrial applications

Once purified, these compounds can be used in nutraceutical, cosmetic, and pharmaceutical applications. Crude extracts have been explored for their fungicidal and antibacterial properties for plant disease control. Some examples of bioactive compounds, their extraction methods, and applications are provided below:

Bioactive compound	Extraction solvent	Properties
Polysaccharides	Hot water/ethanol	Antibacterial, antioxidant, anti-inflammatory activities
Crude polysaccharides	Water	Protection from plant disease
Polyphenols	Alcohol	Antioxidant activity
Enzymes	Water/buffer	Degradation of lignin and cellulose

figure 6:. Bioactive compounds in Spent Mushroom Substrate

The mushroom industry, though generating valuable food, also produces a significant amount of spent mushroom substrate (SMS). Traditionally viewed as waste, SMS is undergoing a transformation. Its rich organic content and ease of handling make it a versatile resource with a range of potential applications.

Beyond its current uses in composting, soil improvement, and mulching, SMS offers exciting possibilities. Research is exploring the extraction of valuable bioactive compounds from the mushroom exudate, potentially leading to applications in nutraceuticals, cosmetics, and pharmaceuticals. SMS could even play a role in sustainable agriculture through its use in plant disease control.

This shift in perspective on SMS highlights a move towards a more sustainable future for the mushroom industry. By maximising resource efficiency and exploring the full potential of this by-product, the industry can minimise waste and create valuable new products.

Mushrooms growing in spent grain from whiskey distillation at Canterbury Brewers and Distillers, following Growing Kent & Medway funding

Key crops of interest - Conclusion

This table offers a comprehensive view of each type of waste, allowing for specific industrial applications based on the unique properties and compounds present in each. By maximising the use of these high-value compounds, industries can promote sustainability and reduce reliance on raw resources.

Crop/ agricultural source	Type of waste produced	High-value compounds	Industrial applications
Wine/grape	Grape pomace (skins, seeds, stems)	Polyphenols (resveratrol, anthocyanins), crude fat, tannins	Nutraceuticals, animal feed (reduces methane emissions), biofuel (bioethanol), antioxidants, compost, natural dyes
	Wastewater	Nutrients (nitrogen, phosphorus)	Fertilisers (through nutrient recovery)
	Wine yeast lees	Yeast cells, tartaric acid, enanthic ester (cognac oil)	Nutritional supplements, skincare products, ethanol production, compost
	Vine prunings	Organic material	Mulching, composting, anaerobic digestion for bioenergy
Hops	Spent hops (after brewing)	Xanthohumol, polyphenols, alpha and beta acids, essential oils	Pharmaceuticals (antioxidants, anti-inflammatories), animal feed, fertilisers, functional foods, biofuels, natural pesticides
	Hop bines (stems)	Organic fibre	Compost, biodegradable packaging materials
	Leaves and unsuitable cones	Organic matter	Soil conditioners, compost
Fruit waste	Apple pomace	Polyphenols, pectin, dietary fibre	Nutraceuticals, natural food colourants, animal feed, antioxidants, thickening agents (pectin), biofuels
	Peelings and trimmings	Vitamins, polyphenols, carotenoids	Cosmetic ingredients (antioxidants), food supplements, natural colourants, biofuels
	Cores and seeds	Polyphenols, oils	Food flavourings, antioxidants, dietary supplements, animal feed

Figure 7: Summary of industrial application for key crop waste

Crop/ agricultural source	Type of waste produced	High-value compounds	Industrial applications
Cereal crops	Straw	Cellulose, hemicellulose, lignin	Biofuels (bioethanol, biogas), bioplastics, compost, soil amendments, mushroom cultivation
	Bran	Fibre, proteins, vitamins (e.g., B vitamins)	Animal feed, functional foods, dietary fibre supplements
	Germ	Proteins, vitamins, oils	Nutritional supplements, animal feed, functional food ingredients
	Husks	Fibre, lignin	Bioplastics, animal feed, soil conditioners
Vegetable residues	Peelings and Trimmings	Polyphenols, carotenoids, vitamins (A, C, E), fibres	Natural food additives, antioxidants, moisturisers in cosmetics, functional food ingredients, biofuels
	Crop Residues (stalks, leaves)	Cellulose, fibres	Biofuel (biogas, bioethanol), compost, animal bedding
	Other Non-Edible Parts	Fibres, organic matter	Compost, soil amendments, animal feed

Figure 7: Summary of industrial application for key crop waste (cont).

The agricultural waste in Kent and Medway holds immense potential for sustainable and profitable reuse. By focusing on high-value compounds and innovative industrial applications, these by-products could be transformed from environmental burdens into resources supporting diverse sectors, from pharmaceuticals to biofuels.

Sustainable practices like anaerobic digestion, composting, and nutrient recovery, coupled with advanced extraction techniques, are central to maximising the value of agricultural waste while minimising its environmental footprint. This approach aligns with a circular economy model, positioning the region as a leader in resource-efficient agricultural waste management.

High-value chemicals and materials sourced from agriwaste

Agricultural waste, often considered a mere by-product, is emerging as a treasure trove of valuable compounds with immense potential for various industries. From pharmaceuticals to food and energy, these underutilised resources hold the key to a more sustainable and circular economy. This chapter delves into the extraction of high-value chemicals and materials from diverse agricultural waste streams, such as wine and grape waste, hop waste, fruit waste, cereal crop residues, and vegetable residues. By harnessing the power of these natural resources, we can reduce our reliance on non-renewable sources and create a greener future.

Valuable chemicals derived from agricultural waste

The previous chapter deduced that high-value chemicals and materials can be sourced from agricultural waste, with varied feedstocks offering unique compounds valuable for industries spanning pharmaceuticals, food, biofuels, and more. Here's an overview:

- **Wine/grape waste**
  - Polyphenols
    - Abundant in grape seeds and skins, these compounds offer antioxidant and anti-inflammatory benefits. Uses include pharmaceuticals for supplements, nutraceuticals, cosmetics, and natural dyes. Polyphenols, like resveratrol and anthocyanins, also have health benefits relevant to gut health, anti-cancer therapies, and cardiovascular support.
  - Enanthic Ester (Cognac Oil)
    - Found in wine yeast lees, this compound is used in perfumes and cognac production.

- Biofuel potential
  - Grape pomace can be transformed into bioethanol or biogas, offering renewable energy applications. Vine prunings can also serve in anaerobic digestion to produce bioenergy.

- **Hop waste**
  - Xanthohumol
    - This potent antioxidant with anti-cancer properties holds promise for nutraceuticals, pharmaceuticals, and skincare. Its neuroprotective potential also makes it a candidate for Alzheimer's and Parkinson's therapies.
  - Alpha and beta acids
    - Known for their antimicrobial properties, these acids are valued in pharmaceuticals and natural preservatives, and contribute to the aroma of beverages.
  - Essential oils and polyphenols
    - Hop essential oils and polyphenols are applied in skincare, as antioxidants, and in the flavour and fragrance industries, providing natural preservatives and flavouring agents.

- **Fruit waste (e.g., apple pomace)**
  - Pectin
    - Extracted from fruit peels, pectin serves as a thickening agent in food products and is used in pharmaceuticals as a drug carrier.
  - Polyphenols and carotenoids
    - Carotenoids offer antioxidant benefits for skincare and dietary supplements, while polyphenols provide food colourants, cosmetics ingredients, and biofuels.
  - Oils
    - Certain seeds (like those from apples) yield oils used in cosmetics and biofuels, enhancing sustainability in these industries.

- **Cereal crop residues**
  - Cellulose and hemicellulose
    - Straw waste, rich in cellulose, is processed into bioplastics, bioethanol, and biogas, supporting both energy and material sectors with biodegradable solutions.
  - Bran and germ
    - Used in functional foods, animal feed, and dietary supplements, bran and germ are valued for their protein, fibre, and vitamin content.
  - Husks
    - Leveraged in bioplastic production and as soil conditioners, cereal husks offer biodegradable material alternatives.

- **Vegetable residues**
  - Polyphenols, carotenoids, and vitamins
    - Found in vegetable trimmings, these compounds serve as natural food additives, antioxidants in cosmetics, and components in biofuels.
- **Fibres**
  - Residues like stalks and leaves contain cellulose, which can be transformed into bioplastics, bioethanol, and other biodegradable products.

By leveraging these high-value compounds, industries can reduce reliance on non-renewable sources and contribute to a circular economy, transforming agricultural waste into valuable, sustainable products.

High-value compounds sought by industry

In the push toward sustainable practices, several high-value compounds derived from agricultural waste are increasingly sought after by the chemical manufacturing sector and other industries.

Here's a breakdown of key compounds established in Chapter 3 and why they are in demand to industry:

- **Polyphenols (from grape, hop, and fruit waste)**
  - Sectors
    - Cosmetics, pharmaceuticals, food, and nutraceuticals.
  - Uses
    - Known for antioxidant and anti-inflammatory properties, polyphenols like resveratrol, anthocyanins, and other phenolic acids are in high demand for natural skincare products, dietary supplements, and as natural preservatives in food products.
  - Sustainable benefits
    - Polyphenols offer greener, plant-based alternatives to synthetic antioxidants and preservatives.

- **Pectin (from fruit waste)**
  - Sectors
    - Food, pharmaceuticals, and personal care.
  - Uses
    - Commonly used as a gelling agent in food products, pectin also has applications in drug delivery systems and as a thickener in cosmetics.
  - Sustainable benefits
    - Pectin provides a plant-based, biodegradable alternative to synthetic thickeners and emulsifiers.

- **Xanthohumol (from hop waste)**
  - Sectors
    - Pharmaceuticals and nutraceuticals.
  - Uses
    - Sought after for its potential in anti-inflammatory, antioxidant, and anticancer applications, xanthohumol is increasingly explored for therapeutic drugs and dietary supplements.
  - Sustainable benefits
    - This natural compound reduces the need for synthetic bioactives, aligning with the demand for plant-based, low-impact medical and wellness products.

- **Essential oils and terpenes (from hop waste)**
  - Sectors
    - Fragrance, cosmetics, food and beverage.
  - Uses
    - Essential oils and terpenes extracted from hops are used for natural flavours, fragrances, and in aromatherapy. They are valuable as natural alternatives to synthetic flavouring and aromatic compounds.
  - Sustainable benefits
    - Terpenes support the trend of moving away from petrochemical-derived fragrances and flavours.

- **Cellulose and hemicellulose (from cereal crop residues)**
  - Sectors
    - Packaging, bioplastics, and construction materials.
  - Uses
    - Cellulose derived from straw and other cereal waste is used to create biodegradable plastics, compostable packaging, and construction materials.
  - Sustainable Benefits
    - These compounds help reduce plastic waste by providing biodegradable alternatives to petroleum-based plastics, crucial in packaging and disposable products.

- **Bioethanol and biogas (from various agricultural residues)**
  - Sectors
    - Energy, transportation, and manufacturing.
  - Uses
    - Produced from grape, fruit, and cereal wastes, bioethanol and biogas are alternative fuels that reduce dependency on fossil fuels.
  - Sustainable benefits
    - These renewable energy sources lower greenhouse gas emissions, particularly when used to offset traditional fossil fuel consumption in transport and manufacturing.

By incorporating these agricultural waste-derived compounds, industries are aligning with circular economy principles and responding to market demand for greener alternatives across sectors.

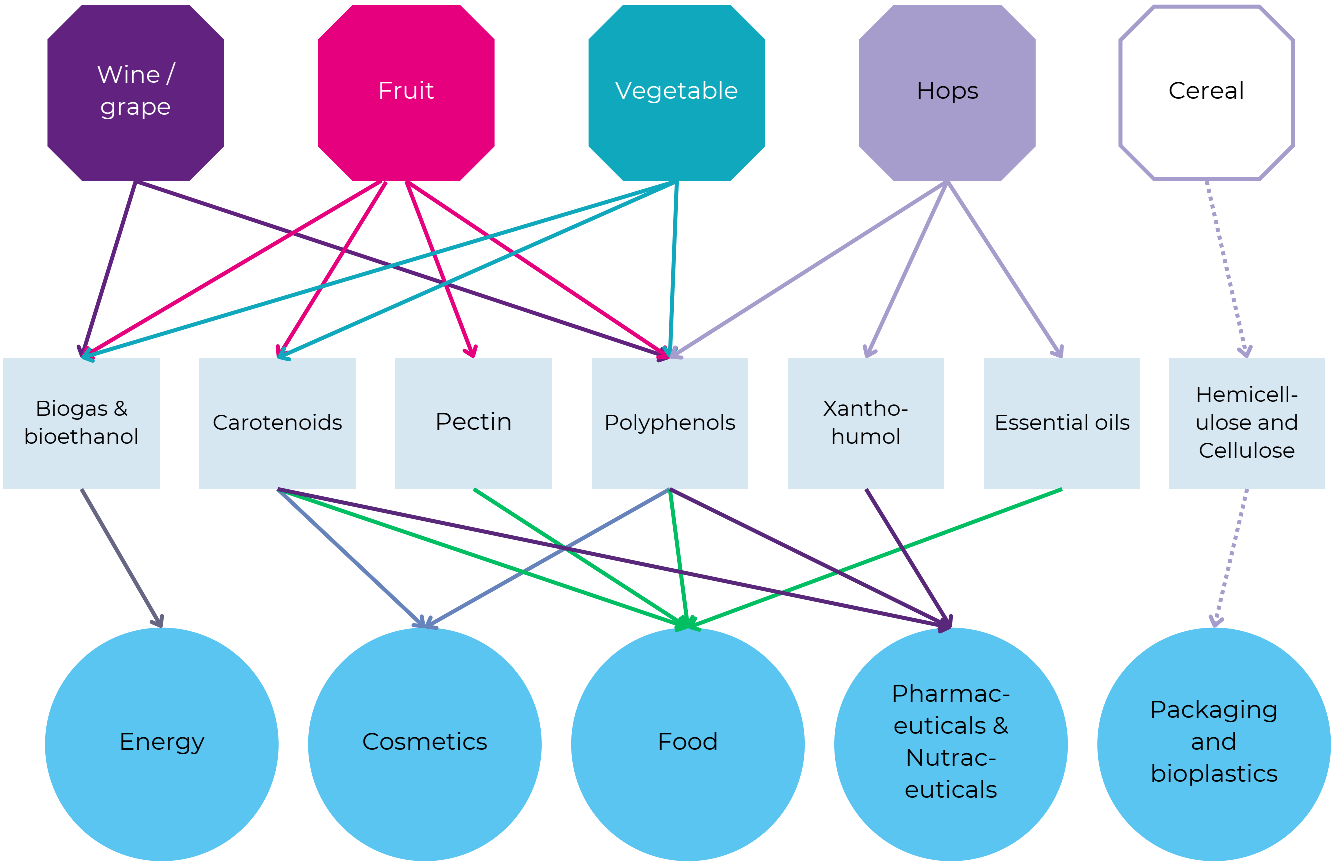

Figure 8: Crops and their key elements and uses

The transformation of agricultural waste into high-value chemicals and materials marks a significant step towards a sustainable future. By leveraging the untapped potential of these resources, industries can reduce their environmental footprint, minimise waste, and create innovative products that benefit society.

From polyphenols with potent antioxidant properties to cellulose for biodegradable plastics, the possibilities are vast. As research and technology continue to advance, we can expect to see even more innovative applications for agricultural waste, driving a circular economy that prioritises resource efficiency and environmental responsibility.

Recommendations and next steps

To fully realise the potential of agricultural waste as a valuable resource, the following recommendations and next steps are crucial:

- **Research and development**

Continued investment in research and development is essential to explore new extraction techniques, optimise existing processes, and identify novel applications for agricultural waste-derived compounds.

- **Industry collaboration**

Fostering collaboration between agricultural producers, waste management companies, and chemical manufacturers can facilitate the efficient collection, processing, and utilisation of agricultural waste.

- **Policy support**

Governments and policymakers should implement supportive policies and incentives to promote the sustainable use of agricultural waste, such as tax breaks, subsidies, and regulations that encourage waste reduction and recycling.

Consumer awareness

Educating consumers about the benefits of products derived from agricultural waste can drive demand and support sustainable practices.

Technological advancements

Investing in advanced technologies, such as biotechnology and nanotechnology, can improve the efficiency and scalability of extracting high-value compounds from agricultural waste.

By embracing these recommendations and actively working towards a circular economy, we can unlock the full potential of agricultural waste and create a more sustainable and prosperous future for generations to come.

Lower value products utilising high volumes of agriwaste feedstocks

Agri-food waste, a by-product of our modern food system, presents a significant environmental challenge. However, it also offers a wealth of opportunities for innovation and sustainability. By repurposing this low-value but high-volume waste, we can create a more circular economy, reduce our environmental footprint, and address global challenges such as food security and climate change.

This chapter explores three innovative approaches to utilising agri-food waste for lower value products:

1. **Feedstock for high-protein animal feed and organic fertiliser**

Harnessing the power of nature, we can transform organic waste into a valuable protein source. Black Soldier Fly larvae efficiently convert food waste into nutrient-rich biomass, providing a sustainable alternative to traditional protein sources like soy.

2. **Biofertilizers for sustainable agriculture**

Composting food waste yields nutrient-rich organic matter that can revitalise soils and reduce reliance on synthetic fertilisers. This natural approach promotes soil health, enhances crop growth, and minimises environmental pollution.

3. **Compostable packaging for a greener future**

By utilising food waste-derived bioplastics or mushroom mycelium, we can create eco-friendly packaging solutions that decompose naturally. This innovative approach reduces plastic pollution and promotes a circular economy in the fresh produce sector.

These innovative approaches demonstrate the potential of agri-food waste to contribute to a more sustainable future. By harnessing the power of nature and adopting circular economy principles, we can transform waste into valuable resources, addressing environmental challenges while fostering a more resilient and sustainable food system.

Feedstock for high-protein animal feed and organic fertiliser

Agrifood waste, a substantial global challenge, presents a significant opportunity for innovation and sustainability. By transforming this waste into valuable resources, we can mitigate environmental impact and address pressing food security concerns.

One promising approach is the utilisation of Black Soldier Flies (BSF) as a natural waste management solution. These insects efficiently convert organic waste into nutrient-rich biomass, which can be processed into high-protein animal feed. This sustainable alternative to traditional protein sources like soy offers several advantages:

- Reduced environmental impact
  - By diverting organic waste from landfills and reducing the need for soy cultivation, BSF farming can help mitigate deforestation, soil erosion, and water pollution associated with traditional agriculture.
- Sustainable protein source
  - BSF larvae provide a high-quality, sustainable protein source for livestock and aquaculture, contributing to a more resilient and environmentally friendly food system.
- Nutrient recovery
  - The BSF larvae's ability to break down complex organic matter into valuable nutrients can improve soil fertility and reduce the need for synthetic fertilisers.
- Circular economy
  - BSF-based waste management promotes a circular economy by transforming waste into valuable resources, minimising waste, and conserving resources.

Black soldier fly larvae

A case study: Inspro - Transforming food waste into valuable resources

Inspro is a UK-based company that is at the forefront of sustainable food waste management. By harnessing the power of Black Soldier Fly (BSF) larvae, Inspro is transforming organic waste into high-quality animal feed and fertiliser.

The Challenge

The UK faces significant challenges related to food waste and animal feed sustainability. Every year, the UK imports 2 million tonnes of soymeal for animal feed, a practice that is both economically and environmentally unsustainable due to fluctuating prices, transportation costs, and deforestation. Additionally, the UK generates approximately 9.5 million tonnes of food waste annually, contributing to a substantial portion of the country's greenhouse gas emissions.

The Solution

Inspro addresses these challenges by employing a bioconversion process that leverages the appetite of BSF larvae. These larvae are voracious feeders, capable of consuming a wide range of organic waste, including excess and spoiled fruit and vegetables.

The process

1. **Waste collection**
    a. Organic waste is collected from various sources, such as food processing plants, supermarkets, and households.
2. **Larval feeding**
    a. The collected waste is fed to BSF larvae in controlled environments.
3. **Larval growth**
    a. The larvae rapidly consume the waste, converting it into biomass.
4. **Harvesting**
    a. Once the larvae reach maturity, they are harvested.
5. **Product creation**
    a. The harvested larvae can be processed into:
        - High-protein animal feed
            - The larvae are dried and ground into a nutrient-rich feed for poultry, fish, and other livestock.
        - Organic fertiliser
            - The remaining larval biomass can be composted to produce a high-quality organic fertiliser.

A case study: Inspro - Transforming food waste into valuable resources (cont)

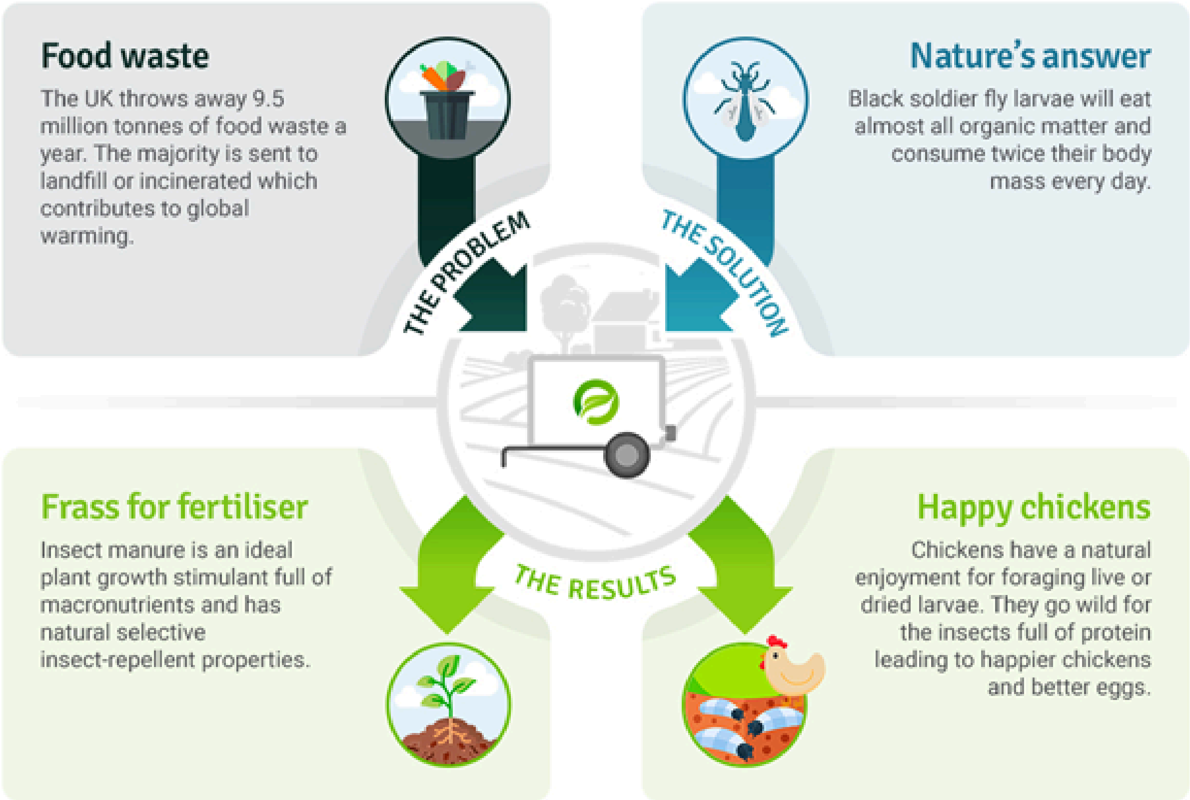

Figure 9: The Inspro Black Soldier Fly process

The impact

- **Reduced food waste**

By diverting organic waste from landfills, Inspro helps to reduce greenhouse gas emissions and conserve resources.

- **Reduced reliance on imported feed**

By producing high-quality animal feed domestically, Inspro helps to reduce the UK's dependence on imported soymeal, mitigating associated environmental and economic impacts.

Sustainable animal feed

The high-protein animal feed produced by Inspro is a sustainable and environmentally friendly alternative to traditional feed sources.

A case study: Inspro - Transforming food waste into valuable resources (cont)

- **Improved soil health**

The organic fertiliser produced by Inspro enhances soil fertility and promotes plant growth.

- **Circular economy**

Inspro's approach aligns with the principles of the circular economy, minimising waste and maximising resource efficiency.

Future outlook

Inspro's innovative solution has the potential to revolutionise the way we manage food waste and produce sustainable animal feed. By expanding its operations and collaborating with other stakeholders, Inspro can contribute to a more sustainable and resilient food system.

Conclusion

Inspro's pioneering work in bioconversion demonstrates the power of nature-based solutions to address pressing environmental challenges. By transforming food waste into valuable resources, Inspro is leading the way towards a more sustainable and resilient food system.

By embracing innovative solutions like BSF-based waste management, we can move towards a more sustainable and resilient food system, addressing both environmental and food security challenges.

A chameleon at Princess Christian's Farm, Tonbridge, trials feeding exotic animalsi with black soldier fly larvae, as part of Inspro's trials

Creation of biofertilizer as an alternative to chemical fertilisers

Another promising application of agri-food waste is the creation of biofertilizers. By composting food waste, we obtain nutrient-rich organic matter that can be directly applied to soils or incorporated into other crop media. Biofertilizers offer a sustainable alternative to chemical fertilisers, promoting soil health, improving plant growth, and reducing the environmental risks associated with synthetic inputs.

The process of biofertilizer creation

- **Composting**

Organic waste, such as food scraps, plant residues, and animal manure, is decomposed through a controlled process called composting. Microorganisms break down the organic matter, releasing nutrients like nitrogen, phosphorus, and potassium.

- **Fermentation**

In some cases, the compost is further fermented to enhance nutrient availability and microbial activity.

- **Application**

The resulting biofertilizer can be applied directly to the soil or used to inoculate seeds or seedlings.

Composting and fermentation for biofertiliser

Composting and fermentation are key processes in creating biofertilizers from various organic feedstocks, including fruit, grape, hops, vegetables, cereal crops, and mushrooms.

Composting

Composting is a controlled aerobic decomposition process where microorganisms break down organic matter into a nutrient-rich humus-like substance. This process is vital for creating a balanced biofertilizer.

Key factors for effective composting

- Carbon-Nitrogen ratio (C:N)
  - A balanced C:N ratio (around 30:1) is ideal for optimal microbial activity.
- Moisture content
  - The compost pile should be kept moist but not waterlogged.
- Oxygen supply
  - Aeration is crucial for aerobic microorganisms to thrive. Regular turning of the compost pile promotes oxygenation.
- Temperature
  - The temperature of the compost pile should reach 55-60°C to kill pathogens and weed seeds.
- Microbial activity
  - A diverse microbial population is essential for efficient decomposition.

Composting with specific feedstocks

- Fruit, grapes, and hops
  - These high-sugar feedstocks can attract pests and mould if not composted properly. Mixing them with carbon-rich materials like straw or wood chips can help balance the C:N ratio.
- Vegetables and cereal crops
  - These are good sources of nitrogen and can be composted directly. However, it's important to avoid composting diseased plant material to prevent the spread of pathogens.
- Mushrooms
  - Mushroom compost is a rich source of nutrients. It can be added to the compost pile to enhance its microbial activity and nutrient content.

Fermentation

Fermentation is a process where microorganisms break down organic matter in the absence or limited presence of oxygen. This process can further enhance the nutrient availability and microbial activity of the compost.

Types of fermentation for biofertilizer

- Aerobic fermentation
  - This involves the use of oxygen-loving microorganisms to break down organic matter. It can be used to produce liquid fertilisers that are rich in nutrients and beneficial microbes.
- Anaerobic fermentation
  - This process occurs in the absence of oxygen and can produce biogas as a by-product. It can be used to create solid or liquid biofertilizers that are rich in organic matter and plant nutrients.

Fermentation with specific feedstocks

- Fruit and vegetables
  - These feedstocks can be fermented to produce liquid fertilisers that are rich in organic acids, vitamins, and minerals.
- Cereal crops
  - Cereal crops can be fermented to produce a variety of biofertilizers, including those that can solubilize phosphorus and potassium.
- Mushrooms
  - Mushroom compost can be fermented to produce a liquid fertiliser that is rich in beneficial microbes and plant growth hormones.

By carefully controlling the composting and fermentation processes, it is possible to create high-quality biofertilizers that can improve soil health and plant growth.

Benefits of biofertilizers

Biofertilizers offer numerous benefits for both the environment and agriculture:

- Soil health
  - Biofertilizers significantly improve soil structure, increase water-holding capacity, and enhance nutrient retention. This leads to healthier soils that can support robust plant growth.
- Sustainable agriculture
  - By reducing reliance on chemical fertilisers, biofertilizers contribute to sustainable agriculture practices. This helps to minimise the environmental impact of farming and promote long-term soil fertility.
- Environmental benefits
  - Biofertilizers play a crucial role in minimising soil erosion, water pollution, and greenhouse gas emissions. This helps to protect our environment and mitigate climate change.

- Plant growth
  - Biofertilizers promote root development, nutrient uptake, and overall plant health. This results in healthier, more productive plants and higher crop yields.

Common types of biofertilizers

- Compost
  - A versatile biofertiliser that can be used for various crops. It improves soil structure, adds nutrients, and enhances microbial activity.
- Vermicompost
  - Produced by earthworms feeding on organic waste, vermicompost is rich in nutrients and beneficial microorganisms. It improves soil fertility and plant growth.
- Green manure
  - Leguminous plants, such as clover or alfalfa, are grown and then incorporated into the soil to add organic matter and nitrogen. This practice improves soil structure, fertility, and water-holding capacity.
- Microbial inoculants
  - These contain specific microorganisms, like bacteria or fungi, that promote plant growth and nutrient uptake. They can be used to enhance nutrient availability and improve plant health.

By embracing biofertilizers, we can create a more sustainable and resilient agricultural system, ensuring food security for future generations while protecting our planet's resources.

A biodigester at Niab's Park Farm site

The creation of a single use compostable sustainable packaging

Sustainable packaging for fresh produce

In the UK, the packaging industry has undergone significant changes driven by consumer demand, especially following the environmental influence of the "Blue Planet" documentary. This shift has been largely supported by the packaging, food, and drink industries, which have actively embraced initiatives like the WRAP and Ellen MacArthur Foundation's *Plastics Pact*. Between 2018 and 2020, these efforts led to a 10% reduction in consumer packaging, a 46% decrease in problematic or unnecessary plastics, and an 80% drop in PVC packaging since 2018 (WRAP, *Eliminating Problem Plastics Version 4*, WRAP, 2022).

In addition to these reductions, the sector has invested in research and innovation to develop sustainable packaging solutions for all products. However, food and drink products, which account for 46% of all plastic packaging, present particular challenges. These items require specialised barrier functions to prevent food spoilage and limit the associated carbon footprint—functions that traditional plastic packaging was designed to provide.

Any alternative packaging solution must address several challenges while remaining lightweight, so it does not increase carbon emissions during transport. For fresh produce, agriwaste-based products offer a promising solution. These materials can be used to create lightweight coatings or bioplastics that not only continue to capture carbon dioxide but also help reduce emissions throughout the fresh produce supply chain. By utilising waste and leveraging biomolecules to prevent spoilage, these alternatives could improve resource efficiency and create a circular system. Such packaging could be composted alongside food waste, with the resulting digestate being used in crop cultivation.

One key advantage of agriwaste-based packaging over recycled plastics is that it eliminates the need for virgin plastic altogether. Additionally, if this packaging escapes into the environment, it poses a much lower risk to wildlife and reduces contamination in soil, water, and air. This approach aligns with sustainability goals by offering an environmentally safer, closed-loop alternative to traditional plastics.

Biorefined agriwaste has the potential to generate large volumes of material for packaging with minimal reliance on fossil fuels, making it a valuable resource for the food and drink supply chain as it works to meet net-zero goals. This could be achieved through relatively simple pulp-pressing techniques, where research into various agricultural by-products could lead to the development of standardised protocols for both single-use and reusable wholesale packaging solutions. These materials can be extracted relatively easily from agriwaste at the laboratory scale, and with appropriate adaptations, this process could be implemented at paper mills, anaerobic digestion sites, or even on-farm locations for initial pre-treatments. This approach would reduce the carbon footprint associated with packaging while promoting sustainability throughout the supply chain.

Further refining agriwaste could lead to the development of films or coatings with specific properties tailored to packaging individual fresh produce items. These coatings can be made from various biological sources. Waxes, such as beeswax, shellac, and carnauba, have long been used to create a glossy appearance on fruits while acting as a barrier to moisture loss and spoilage. Additionally, polysaccharides like starch, cellulose, and sugar-ester-based coatings have been used, often combined with natural antioxidants to prevent spoilage and discoloration in fresh produce.

For example, companies like Apeel have successfully introduced coatings that extend the shelf life of produce in international markets. In the UK, products such as Agricoat's Semperfresh could benefit from sourcing ingredients for their edible coatings from local agriwaste. Chitin, a biomolecule, has been traditionally used to create chitosan coatings for fresh produce and is also utilised in compostable packaging films. This material can be sourced from agriwaste in South East England, providing a sustainable alternative to conventional plastic packaging.

Both biorefining for film and coating, and pulp-pressing agriwaste offer a way of utilising an already existing and large scale resource that currently is managed as waste, and can offer further economic value in the process.

Addressing the technical challenges for using plant crop waste to replace plastic packaging

Plastics are highly effective as packaging materials due to their versatility and ability to preserve the quality of fresh produce, processed foods, and even hot food and drinks. However, the long lifespan of many plastics has contributed to a severe global plastic pollution crisis. Moreover, plastics derived from fossil fuels are increasingly viewed as unsustainable due to their environmental impact and reliance on non-renewable resources.

A key sustainability goal is to replace conventional plastic packaging with alternatives made from agricultural waste. To ensure these alternatives do not exacerbate food waste, it is essential that they match or surpass the functional qualities of plastic packaging. Additionally, these new materials must be either biodegradable or recyclable to reduce environmental harm and support circular economy principles. This approach aims to address the plastic pollution issue while promoting sustainability across the food packaging industry.

This chapter explores two types of packaging developed from agricultural waste as alternatives to plastic: moulded pulp containers and trays, and plant-derived films. Both types offer sustainable packaging solutions by utilising by-products from agriculture, reducing the need for plastics and their associated environmental impacts. Moulded pulp packaging, often derived from wood, straw, or other agricultural fibres, is commonly used for trays and containers due to its biodegradable nature. On the other hand, plant-based films, made from materials such as starches, cellulose, or plant-derived polymers, are being increasingly explored for their ability to serve as lightweight, biodegradable alternatives to conventional plastic films in food packaging.

Coffee pots made from seaweed-based polymer blends by Coronex, through a Growing Kent & Medway funded trial

Moulded pulp for punnets and containers

Plastics are manufactured to be lightweight, strong, resistant to moisture absorption, chemically stable, and capable of withstanding high temperatures. Ideally, materials made from pulp would replicate all these characteristics.

Moulded pulp, derived from plant fibres, can be effectively used to produce packaging that protects items from physical damage, such as egg cartons, fruit trays, and packaging for fragile items like glass bottles. When compared to plastic alternatives, the primary challenge for moulded pulp is maintaining strength, especially in the presence of moisture.

However, further challenges emerge when moulded pulp is used for punnets and containers in direct contact with food. In these cases, it is critical for the material to match plastics in terms of low chemical reactivity and minimal chemical migration. The packaging for hot meals and beverages presents an additional challenge, requiring materials with high heat resistance.

Moulded pulp packaging, however, is resource-intensive to produce. According to Mordor Intelligence (2019), the pulping industry faces environmental regulation challenges in the US, as it is water, energy, and pollution-intensive, particularly in comparison to the production of polystyrene. This regulation poses a significant barrier to the growth of the moulded pulp market.

Processes involved in the manufacture and moulding of pulp

Traditionally, the moulded pulp and paper industries have relied on wood pulp or recycled paper and cardboard. However, in recent years, there has been a shift towards using agricultural waste as a raw material. Pulp is primarily made from lignocellulose, a complex mixture of cellulose fibres bound by lignin and hemicellulose. The quality of pulp produced from different agricultural sources varies depending on the length of the fibres, as longer fibres typically provide greater strength (Rattanawongkun et al., 2020). Additionally, the pulp's quality is influenced by the initial composition of the raw materials and, crucially, the amount of lignin retained in the final pulp, as lignin can accelerate discoloration.

The first stage of pulping aims to separate the cellulose fibres from the lignin. Depending on the method used, mechanical, chemical, or biochemical processes may be employed. Mechanical pulping offers a high yield but produces shorter fibres and retains more lignin. In contrast, chemical pulping results in lower yields but produces higher-quality pulp with longer fibres, leading to greater strength. The most common chemical pulping method is Kraft pulping, an alkaline process where lignin is removed using sodium hydroxide and sodium sulfide. This process takes place in a digester at around 175°C for 2-5 hours. Kraft pulping has largely replaced the older "soda" process, which only used sodium hydroxide.

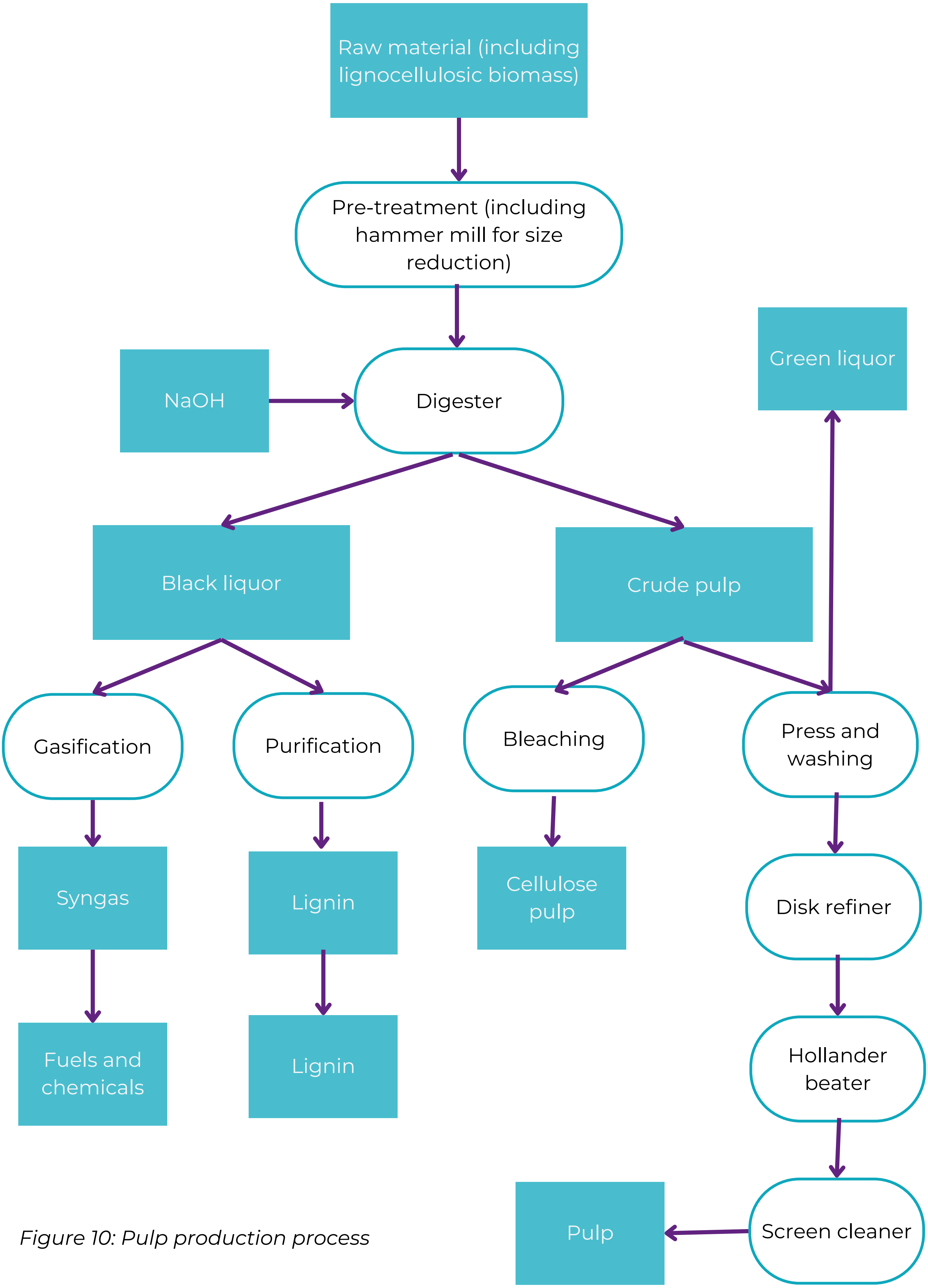

Figure 10: Pulp production process

Once the pulp has been extracted from the waste product, there are several different processes that can be used to mould the pulp into the final product. Four of these are described in Semble et al (2022); One cast and transfer moulding are simpler and are used to produce relatively thick moulds of 6-8 and 3-5 mm respectively.

Thermoforming and dry thermoforming can produce thinner moulds of 0.4 – 1.5 mm. As the processes become more sophisticated, the industry is learning to use the moulding process to alter and improve the characteristics of the final product. Thus manipulation of the temperature during mould forming can be used to control the strength, density and hygroscopicity. Dry thermoforming techniques have been developed to produce laminate structures to further optimise characteristics. Additives and coatings are particularly important to manipulate barrier properties.

The basic material properties of packaging substrates that influence their quality and safety are:

- Mechanical properties
- Barrier properties
- Migration properties
- Chemical reactivity.

These material properties may be affected by different stages of the manufacturing process described above; raw pulp origin, method and degree of pulping (beating), mould shape and forming conditions, pressing and drying conditions and finishing methods. The sections below consider how each set of properties can be manipulated and also how they can be tested.

Mechanical strength

Mechanical strength is determined by factors such as tensile stress-strain behaviour, which measures the material's tendency to deform under pressure, and the storage modulus, which indicates the loss of rigidity when heated.

In food packaging, particularly containers, crush and collapse resistance is crucial, especially during shipping, storage, and exposure to high heat and moisture. Moulded pulp typically has lower tensile strength than plastics (except for expanded polystyrene), but it maintains strength better at higher temperatures.

Moisture absorption in pulp can significantly reduce its strength—by 5–10% for every 1% increase in moisture—whereas plastics generally do not absorb moisture.

As described, controlling heat profiles during the moulding process has become more advanced, allowing manufacturers to enhance strength and reduce moisture absorption. By selecting specific hot pressing temperatures, manufacturers can leverage the varying glass transition points of different components to improve cellulose purity.

Higher moulding temperatures (220–250°C) can increase the crystallinity index of cellulose, which reduces its hygroscopicity and results in a stronger, less porous structure that is more resistant to moisture absorption (Dislaire et al., 2021). Various testing standards are available, most of which require precise control of temperature and humidity to evaluate the material's performance (Semple et al., 2022).

Barrier properties

Numerous additives have been tested to enhance the physical structure of moulded pulp (such as foam control, fibre linkages, and strength) as well as to improve its surface characteristics, including moisture repellency, oil and grease resistance, and mould control. The selection of appropriate additives is crucial for the recyclability and biodegradability of the final product.

A significant challenge lies in producing moulded pulp containers that can withstand hot liquids and steam, such as those used for coffee cups or microwaveable food. Currently, most commercial solutions involve a thin layer of heat- and moisture-resistant plastic, like PET, which hinders both recycling and biodegradability.

Chitosan, a natural additive, shows promise as a replacement for plastic coatings. Chitosan is derived from chitin, which is found in the exoskeletons of crustaceans (like crabs and shrimp) and in the cell walls of fungi, suggesting the potential for utilising waste from mushroom farms. After purification and chemical modification, chitosan can be dissolved in water and used to create barrier films (Chenite et al., 2001). It can also be added in its dissolved form to wet pulp sheets before pressing (Gällstedt & Hedenqvist, 2006). Additionally, chitosan is effective as a dry-strength additive. Recent advancements have improved its moisture and oxygen barrier properties through chemical modification and blending with other biopolymers (Haghighi et al., 2020).

Other naturally sourced, non-toxic films and linings, referred to as "cross-linked biopolymers," have also been developed to improve the oxygen and moisture barrier properties (e.g., water vapour permeability and liquid resistance) as well as oil resistance in food paper and pulp products, while maintaining full biodegradability (Khwaldia et al., 2010; Dumée, 2022; Triantafillopoulos & Koukoulas, 2020).

To assess the effectiveness of these materials, standard tests have been developed to measure liquid water absorption, water vapour uptake, and oil absorption. Oil absorption is typically tested by observing the spread of droplets of reference permeants such as castor oil, toluene, and n-heptane.

Thermal conductivity (λ) is influenced by material density, moisture content, and ambient temperature. Low thermal conductivity, which offers good insulation, is particularly advantageous for preserving fresh and processed foods. However, when containers hold hot liquids, low conductivity can pose safety risks, such as increased chances of scalding for consumers. No standardised tests have yet been developed to address this concern.

Migration properties and Chemical reactivity

Wherever feasible, the use of toxic chemicals in moulded pulp is minimised, and direct printing on moulded pulp is typically avoided. However, concerns remain about certain components, such as nanoclay particles in nanocomposite packaging. Therefore, it is crucial to prevent any migration of chemicals from the packaging into food.

The migration of substances from food contact materials is regulated under the EU's harmonised legal framework, specifically Regulation (EC) No 1935/2004. This regulation sets out overall migration limits for all possible compounds, as well as specific migration limits for individual substances that are considered high-risk. Testing involves using standardised food simulants designed to replicate the behaviour of real foods, ensuring that the packaging does not release harmful substances during use.

Woody material from pruning Kent vineyards

Bioplastics

Plastic films are useful as packaging because they are water resistant, oil resistant, low gas permeability, low migration, transparent,

Films from bioplastics

Bioplastics were initially developed using starches and polysaccharides extracted from edible crop parts (e.g., corn kernels, potatoes, and sugar beets), grown specifically for this purpose (Madival et al., 2009). However, the current focus is shifting toward utilising agricultural by-products, or "waste," that remain after the main crop has been harvested.

Currently, about 50% of bioplastics are derived from starch, often combined with glycerol glycol or polylactic acid. Other biopolymers such as cellulose, chitin, and alginates are also used to create bioplastic films. Experimental bioplastics have been produced from agricultural waste, including proteins, carbohydrates, and, to a lesser extent, lipids (Duguma et al., 2023). Additives such as glycerol, starch, pectin, and chitin (often converted into chitosan) are commonly used to improve film properties. While commercial production typically uses extrusion, which allows for precise temperature and pressure control, experimental trials often rely on simpler methods like solvent casting due to limited laboratory equipment.

To reduce bioplastic costs, researchers have explored the use of fillers, such as straw or starch, although these tend to negatively affect the strength and quality of the films. For instance, the addition of wheat straw has been shown to consistently decrease the mechanical properties of the resulting composites (Dixit & Yadav, 2019; Lendvai & Patnaik, 2022), and such fillers can increase the water vapour transmission rate (WVTR). These drawbacks can be mitigated by reducing the particle size of fillers (e.g., using nanocellulose extracted from soybean waste rather than powdered soybean waste) and by applying surface treatments like alkalinization or acidification (Merci et al., 2019; Gigante et al., 2020; Lendvai & Patnaik, 2022).

Compared to petroleum-based plastics, bioplastics tend to have lower oxygen and water vapour barrier properties, reduced thermal resistance, and weaker mechanical properties, and they are more expensive to produce (Zhong et al., 2020). Bioplastics typically have a density of about 1.2 g/cm^3, a relatively low softening temperature of around 60°C, and thermal resistance up to 70°C (Pavlovskay et al., 2020). On the positive side, certain bioplastics derived from agricultural waste have demonstrated antimicrobial properties. For example, fruit waste—such as peel powder, pomace, and peel extract—has been favoured for developing antioxidant films, due to its high content of polyphenols and other antioxidant compounds (Panzella et al., 2020).

Furthermore, anthocyanin-rich films have been shown to change colour based on pH, making them useful for indicating the freshness of protein-rich food products by detecting microbial spoilage or the production of volatile amines (TVB-N). Additional details on biopolymers with potential applications in intelligent food packaging can be found in the works of Amin et al. (2022), Bhargava et al. (2020), Nemes et al. (2020), and Wu et al. (2018).

Biodegradation of packaging from agricultural waste and how to test it.

To reduce packaging-related pollution, it is essential that packaging materials are either biodegradable or recyclable, while also ensuring they remain functional during use. Packaging must meet specific standards to be considered biodegradable. According to ISO/DIS 17088, packaging must satisfy four key composting criteria: (1) **Biodegradation** (the breakdown into water, CO2, and cellular biomass by natural microbes like bacteria and fungi), (2) **Disintegration** (breaking down into small fragments), (3) **No negative impact** on biological processes, and (4) **Absence of toxic substances** in the final compost (such as harmful metals and non-degradable polymers) (Muniyasamy et al., 2013). For newly developed materials, it is crucial to prioritise meeting biodegradation requirements over their mechanical and barrier properties (Siracusa et al., 2008).

Moulded pulp, in general, meets compostability standards, but the use of additives can influence its ability to compost effectively. For instance, high lignin content may slow down the composting process. Additionally, although bioplastics are made from renewable resources, their biodegradability depends on their molecular structure, not simply their origin. Not all bioplastics break down naturally—some may be non-degradable due to their molecular makeup (Zhong et al., 2020).

To assess the composting rate of packaging materials, various standardised methods have been developed. These include controlling factors like soil temperature, moisture content, and composition. Monitoring tools measure CO2 evolution, weight loss, and the loss of material properties over time. Standards such as EN, ASTM, and ISO provide guidelines for evaluating biodegradability through specific tests, including the measurement of CO2 and CH4 emissions, oxygen consumption, and changes in the physical properties of the material (Jamróz et al., 2022; Suriyatem et al., 2019). Key standards for testing agricultural waste-based films' biodegradability include ASTM D5338:15/ISO 14855–1:2012 and ISO 20200 (Sánchez-Safont et al., 2019).

Recycling

Recycled fibre is permitted in Europe but with strict guidelines. The situation in the UK is evolving, but clearly there is a need for appropriate infrastructure if this is to be an efficient route.

Key challenges and capability gaps

Key challenges for moulded pulp packaging that have not yet been resolved

- There is a need to improve the efficiency of manufacture for example by using pre-treatments and adapting the pulping techniques to address the high use of resources for production.
- Increase our understanding of the composition of pulp from different sources and how this can be exploited to influence physical and chemical characteristics.
- Developing technologies and infrastructure for recycling and reusing recovered fibre
- Use of top-sealed film requires a surface that can bond to film. There is a need for processes/additives/coatings that enable this to be achieved without compromising recyclability/compostability
- Achieving Surface characteristics to allow moulded pulp to be used with hot liquids or microwaveable foods

Key challenges for moulded pulp packaging that have not yet been resolved

- Manufacture of bioplastics with lower oxygen and water vapour transmission rates, and greater thermal resistance.
- Reduce the cost of bioplastic production.

The Biocomposite Centre at Bangor University is the leading academic research group in the UK focused on moulded pulp. While work on agricultural waste-based films is more widespread, institutions with access to extruder technology—such as Brunel University and the Biocomposite Centre—are at the forefront of this field (Bangor University, 2022; Brunel University, 2023). These groups are exploring innovative methods for creating bioplastic films and packaging from agricultural waste, with a focus on sustainable, eco-friendly alternatives to traditional materials.

Commercial packaging companies are clearly investigating the potential for both moulded pulp and bioplastic films. A detailed analysis of progress within these companies is beyond the scope of this report. However, a few products that have been commercialised are noteworthy.

- NatureFlex™ by Futamura is a cellulose-based film certified compostable
- Sirane Earth bag uses paper and water-based coatings
- Paptic® has developed a new heat-sealable, fibre-based material.

The way forward within South East England

To address the challenges associated with moulded pulp and film production in the Growing Kent & Medway region, it is crucial to establish collaborative research initiatives. These efforts should ideally involve partnerships between academic institutions and commercial entities, such as packaging companies like Sirane, Amcor, and Smurfit Kappa, as well as consultancy firms such as MAPCAP, Biotech Services, Solutions4Plastics, and Nextek. These collaborations can help address technical hurdles while advancing the development of sustainable alternatives.

Furthermore, setting up a dedicated research unit focused on compostability testing would be essential. This unit should have the capacity to rigorously assess the environmental impact of materials and evaluate their ability to decompose in natural environments. Such a facility could play a pivotal role in ensuring that new packaging solutions meet compostability standards, which is a key requirement for sustainability and regulatory compliance (Muniyasamy et al., 2013).

Agricultural waste as feedstock for fungal growth

Agricultural waste holds significant potential as a feedstock for fungal growth, particularly in developing sustainable, single-use compostable packaging for the fresh produce sector. By utilising bioplastics derived from food waste or leveraging the natural growth of mushroom mycelium, it is possible to create eco-friendly packaging solutions that decompose naturally, helping to reduce plastic pollution and promote a circular economy.

Fungal fermentation of agricultural residues primarily produces lignocellulolytic enzymes, such as laccases, peroxidases, cellulases, and hemicellulases. Fungi commonly used for the production of these enzymes include *Trichoderma reesei*, *Aspergillus niger*, and *Phanerochaete chrysosporium*. These enzymes are typically produced through solid-state or submerged fermentation processes using lignocellulosic biomass, which includes various agricultural residues like crop stalks and leaves (Haghighi et al., 2020; Pardo et al., 2019).

Cellulases

Cellulases are a group of extracellular enzymes that break down the glycosidic bonds in cellulose. These enzymes are widely utilised across various industries for their ability to hydrolyze cellulose and modify materials. In the paper and pulp industry, cellulases aid in biomechanical pulping, fibre modification, and deinking, improving pulp viscosity and quality. In textiles, cellulases are employed for biostoning, biopolishing, biobleaching, and biofinishing, enhancing the texture and appearance of fabrics. Furthermore, cellulase-based laundry detergents have gained popularity for both domestic and commercial applications, improving the cleaning process.

In the bioethanol industry, cellulases play a key role in enzymatic saccharification, converting cellulose into fermentable sugars essential for ethanol production. Additionally, in the food and beverage sector, cellulases are used in breweries and juice production plants for processes such as extraction, clarification, and enhancing the texture and flavour of juices (Chang et al., 2015; Sun & Cheng, 2002).

Hemicellulases

Hemicellulases are enzymes that break down hemicelluloses, including compounds like xylans, xyloglucans, and glucomannans. Their applications are similar to cellulases in industries such as bioethanol production, breweries, paper and pulp processing, and textiles. In the bioethanol sector, hemicellulases assist in breaking down the complex sugars found in hemicelluloses into fermentable sugars. In brewing, they help with the extraction of fermentable sugars and the clarification of beverages. In the textile and paper industries, hemicellulases are used for fiber modification and pulp processing, enhancing the quality of materials (Chandra & Bura, 2013).

Additionally, xylanases, a subclass of hemicellulases, are employed in commercial coffee preparation to treat coffee grounds before brewing, improving the flavor and efficiency of the process (Bauer et al., 2014). These enzymes also have potential applications in other industries, such as animal feed production and food processing, where they help improve the digestibility and nutritional quality of feed and food products (Xu et al., 2012).

Ligninolytic enzymes

These enzymes can break down lignin through various mechanisms. Fungi produce crucial ligninolytic enzymes such as laccase, versatile peroxidase, and lignin peroxidase, which are vital for the degradation of lignin in agricultural residues. Given the complex and resistant nature of lignin in biomass, these enzymes are essential in pre-treating lignocellulosic materials to release cellulose and hemicellulose, which are key components in biofuel production and other industrial processes. Enzymatic pre-treatment is considered an environmentally friendly alternative to traditional chemical and physical methods, offering selective degradation of lignin to access cellulose and hemicellulose for conversion into fermentable sugars.

While enzymatic methods alone are less commonly used due to the high cost of enzymes, a combination of enzymatic and chemical approaches is often employed for delignification. This method is particularly useful for treating lignin-rich wastes, such as agricultural residues and effluents from the paper and pulp industry, making it an attractive solution for waste valorization and improving the sustainability of biomass processing (Hassan et al., 2017; Sánchez et al., 2019).

Life cycle analysis

This chapter provides insights into using Lifecycle Analysis (LCA) to assess the environmental and economic benefits of utilising agricultural waste in South East England, with a particular focus on the extraction and production of new compounds from agri-food waste. Here's an overview of how LCA could be applied to agri-food waste valorisation, along with examples of potential high-value products.

Life Cycle Analysis (LCA) is a comprehensive methodology used to assess the environmental impacts associated with a product, process, or activity throughout its entire life cycle, from raw material extraction to disposal. LCA takes into consideration various stages, including production, transportation, use, and end-of-life management. LCA aims to provide insights into the potential environmental consequences of different choices and can be used to guide decision-making towards more sustainable options.

When applied to the valorisation of plant crop waste, LCA can help evaluate the environmental benefits and trade-offs associated with different valorisation pathways.

By conducting an LCA for plant crop waste valorisation, stakeholders can make informed decisions about the most sustainable and environmentally friendly ways to manage agricultural residues. This can lead to reduced environmental burdens, enhanced resource efficiency, and support the transition towards a more circular and sustainable economy.

Goal definition and scope

- Functional unit
    - Clearly define the unit of analysis, such as the production of 1 kg of bioethanol from corn stover or the production of 1 ton of compost from food waste.
- System boundary
    - Establish the boundaries of the system, determining which processes to include in the analysis. For instance, consider the entire life cycle, from crop cultivation to the end-of-life treatment of the final product.

Inventory

- Data collection
    - Gather quantitative data on all inputs and outputs associated with the valorisation process, including:
        - Raw materials (crop waste)
        - Energy consumption (fossil fuels, electricity)
        - Water usage
        - Chemical inputs (fertilisers, pesticides)
        - Emissions (greenhouse gases, air pollutants, water pollutants)
        - Waste generation
- Data quality assessment
    - Ensure data accuracy and consistency through rigorous data quality checks and potential uncertainty analysis.

Impact assessment

- Categorisation
    - Classify environmental impacts into categories such as climate change, acidification, eutrophication, human toxicity, and ecotoxicity.
- Characterisation
    - Quantify the magnitude of each impact category using appropriate impact assessment methods (e.g., CML, ReCiPe).
- Normalisation
    - Relate the impacts to reference values to facilitate comparison across different impact categories and systems.
- Weighting
    - Assign relative importance to different impact categories based on societal values and preferences.

Interpretation
Interpret the results of the impact assessment in the context of the study's objectives and scope. Identify which stages of the valorisation process contribute most to the overall environmental impacts and which impact categories are most affected.

- Identify hotspots
  - Determine the stages of the valorization process that contribute most significantly to environmental impacts.
- Evaluate trade-offs
  - Consider potential trade-offs between different impact categories and identify opportunities for optimization.
- Sensitivity analysis
  - Assess the impact of uncertainties in data and assumptions on the overall results.
- Draw conclusions
  - Provide clear and concise conclusions about the environmental performance of the valorization process and identify potential improvement areas.

Analysis
Assess the influence of uncertainties in data and assumptions on the results. Sensitivity analysis helps to understand the robustness of the findings and the potential impact of variations in the input parameters.

Improvement options
Based on the analysis, identify opportunities to improve the environmental performance of the valorisation process. This could involve optimising energy use, reducing emissions, or finding more efficient ways to utilise the crop waste.

Examples of products from agrifood waste valorisation

Grape pomace utilisation

This paper highlights the significant volume of grape pomace produced in the winemaking process. This by-product contains polyphenols, which can be extracted for use in pharmaceuticals, cosmetics, and as antioxidants in food products. Additionally, grape pomace can be processed into bioethanol, reducing reliance on fossil fuels and contributing to lower carbon emissions.

LCA application

By evaluating the energy and resources needed to process grape pomace into polyphenols or bioethanol versus its disposal in landfills, LCA can reveal net environmental benefits. For instance, transforming grape waste into bioethanol could lower greenhouse gas emissions compared to fossil fuels, making it a more sustainable choice.

Spent hops in bioproducts and bioenergy

Hop waste, generated from the brewing industry, contains valuable compounds like xanthohumol and essential oils, which have applications in pharmaceuticals and cosmetics. Spent hops can also be processed into biogas through anaerobic digestion, offering a renewable energy source.

LCA application

Assessing the lifecycle impacts of using spent hops for bioenergy versus landfill disposal would show reductions in methane emissions. Additionally, the extraction of compounds like xanthohumol could reduce the need for synthetic chemicals, decreasing the overall environmental impact of pharmaceutical production.

Fruit and vegetable waste for natural dyes and biofuels

This paper notes that fruit and vegetable waste, rich in polyphenols and pigments, can be processed into natural dyes for the food and textile industries. Furthermore, this waste can be converted into biofuels or animal feed, offering alternatives to conventional fuel sources and synthetic dyes.

LCA application

An LCA comparing the impacts of producing natural dyes from vegetable waste versus conventional synthetic dyes would likely show reduced emissions and chemical pollution. Additionally, using fruit waste for biofuel production would help in achieving renewable energy targets and decrease reliance on fossil fuels.

Cereal crop residues in biodegradable packaging and biochar

Cereal crop residues like straw can be used as substrates for compostable packaging or converted into biochar, which can improve soil quality and sequester carbon.

LCA application

By evaluating the lifecycle impacts of creating biodegradable packaging from cereal straw versus traditional plastic, LCA can help quantify the reduction in plastic pollution and greenhouse gas emissions. Biochar production from straw could also yield environmental benefits by capturing carbon and enhancing soil fertility, reducing the need for synthetic fertilisers.

Orchards are grubbed to make way for new trees.
The waste material could be used for biochar.

Specific considerations for agriwaste high-value compounds

- **Land use**

Evaluate the impact of land use changes for agricultural production, considering factors such as soil degradation, biodiversity loss, and water usage.

- **Water usage**

Assess water consumption during cultivation, processing, and product use, and identify potential water pollution risks.

- **Chemical inputs**

Consider the use of fertilisers, pesticides, and other chemicals in agriculture, and their potential environmental and health impacts.

- **Energy consumption**

Evaluate energy use for cultivation, harvesting, transportation, processing, and end-of-life treatment.

- **Waste generation**

Assess the quantity and quality of waste generated throughout the life cycle, including solid waste, wastewater, and emissions.

- **Social impacts**

Consider potential social impacts, such as labour conditions, local community development, and ethical sourcing of raw materials.

By conducting a comprehensive LCA, it is possible to identify opportunities for improvement and develop strategies to minimise the environmental footprint of high-value compounds derived from agricultural waste. This information can be used to inform decision-making, promote sustainable practices, and enhance the overall sustainability of the bioeconomy.

Infrastructure and investment required to demonstrate and scale-up activities

In 2021, the UK made significant strides toward reducing greenhouse gas emissions, promoting green energy production and usage. The report highlights the economic benefits biofuels offer, but it raises an important question: Does the current infrastructure align with the potential for biofuels' growth, or is additional development needed? Answering this question is becoming more challenging due to limited governmental reporting and unclear data, despite Net Zero transition goals set by the NFU and the government.

However, some organisations are demonstrating the positive impact of biofuels. For instance, Kent Renewable Energy Limited utilises local biomass, burning Kentish wood to generate 27 megawatts of power. This energy production not only powers thousands of homes but also recycles heat to provide energy for Discovery Park, Kent's leading science park. This initiative prevents 100 tons of CO_2 emissions annually.

This success story reflects the region's effective use of biomass and the integration of modern technology to stay ahead in the green energy market. Additionally, The Association for Renewable Energy and Clean Technology (REA) reports that biomass currently contributes to 11% of the UK's electricity supply. The UK ranks among 12 European peers in terms of readiness to meet decarbonization targets. Still, the REA stresses the need for greater investment in energy storage, alternative energy sources beyond wind and solar, and industry-wide energy flexibility to meet future demands.

Organisations such as Biomass Energy, based in Kent, caution that the 'net emissions' market is becoming oversaturated. They highlight the importance for biomass consumers to carefully vet their suppliers, noting that 44% of biomass consumed in the UK comes from wood sources, including logs, chips, bark, and sawdust. Without proper oversight, this could lead to unsustainable or unethical logging practices in order to meet growing demand. However, this report emphasises that wood biomass is not the only option—Kent and Medway, rich in agricultural resources, can provide alternative biomass supplies. The challenge lies less in sourcing biomass and more in raising awareness and investing in innovative technologies.

Biomass production and consumption in the UK have experienced significant growth in recent years. Biomass Energy reports that over 800 biomass plants have opened, with another 9,000 planned for the coming years. This surge demonstrates the increasing demand for biomass and the potential for a circular economy, where biomass can be used to reduce waste and contribute to the UK's transition to Net Zero. To fully realise these benefits, however, there is a pressing need to integrate carbon capture technologies into biomass energy production, helping to reduce greenhouse gas emissions as the industry expands.

We believe the primary challenge for the biomass industry lies not in infrastructure, but in awareness and investment. A significant proportion of farms already have an understanding of biomass and are likely to explore ways to supplement their income by either selling waste materials for biomass energy or utilising the biomass on-site. With a proven model now in place and a growing share of the UK's energy derived from biomass, the next step for the industry is to encourage forward-thinking companies to invest time and resources into exploring alternative biomass fuels and optimising biomass utilisation.

This perspective is further supported by the 2014 ECOFYS report, which, although some may argue is outdated, still provides valuable insight into the upward trend of biomass production and usage. The report highlights the lack of comprehensive data, yet reinforces the growing demand and potential of biomass as an energy source.

ECOFYS, a leading consultancy specialising in renewable energy, energy efficiency, and climate policy, produced a report analysing the production capacity of UK biofuel producers at the time. The report highlights a total capped production capacity of 1.5 billion litres per year. The largest biofuel producer, Crop Energies (formerly known as Ensus) in Teesside, had a capacity of 400 million litres, producing bioethanol from wheat feedstock. This demonstrates the scale of biofuel production in the UK and underscores the growing role of renewable energy sources in the country's energy landscape.

The report notes that Crop Energies has significantly benefited from an initial £250 million build cost, followed by an additional £1.1 billion in investments to maintain the site's competitive edge. This facility employs approximately 100 staff, with an additional 2,000 jobs generated across the broader supply chain. Despite the considerable investment required for such large-scale operations, smaller biorefineries demand much less capital. Crop Energies serves as a key example for investors, demonstrating that there is a thriving market in biofuels—one that continues to grow.

The ECOFYS report further highlights the substantial expansion of the biofuel market, showing an upward trend in bioethanol production and the stagnation of biodiesel production in the years that followed. However, the data ceases in 2016, limiting the scope of more recent trends.

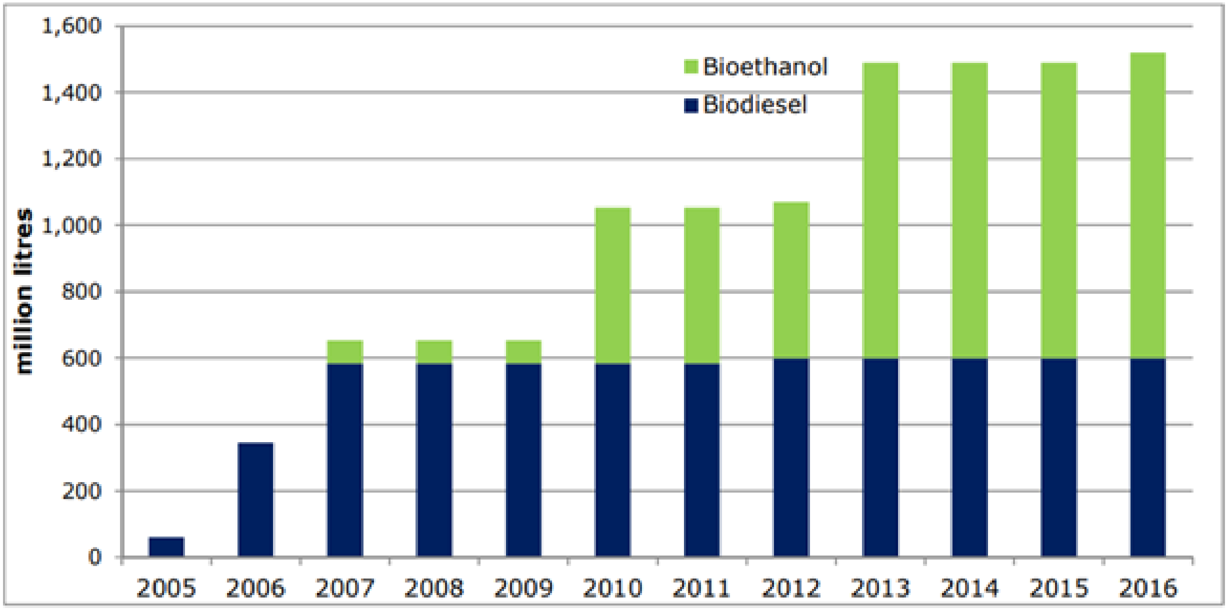

Figure 2: Cumulative production capacity of commercial scale UK bioethanol and biodiesel plants (operational and planned). Figure excludes biomethane production as the capacity is still small relative to the total.

Governmental data on UK cropping areas, which are used to produce biofuels (specifically biodiesel and bioethanol to supply the UK road transport market picks up where the ECOFYS reports left off:

All UK crops used as biofuels (RTFO Year(e)(f))	**Total volume of biofuels from UK grown crops(million litres)**	**Implied tonnage of crop ('000 tonnes)(a)**	**Implied area '000 ha**	**% of UK total arable area(b)**
2015/16(c)	195.5	960	49.3	0.8%
2016/17(c)	217.3	757	69.2	1.2%
2017/18	217.0	921	61.5	1.0%
2018/19(d)(e)	110.2	639	27.2	0.5%
2019(f)	98.8	722	19.1	0.3%
2020 prov.	114.7	605	35.8	0.6%

Source: Department for Transport RTFO data, Agriculture in the UK.

The data reveals a significant decline in crop production during 2018/19, which can largely be attributed to the extreme heatwave that affected much of Europe during that period, significantly disrupting agricultural output. This environmental event had a marked negative impact on crop yields. However, by 2020, production levels rebounded, returning to pre-2019 levels, suggesting a recovery from the heatwave's effects.

As mentioned earlier in this chapter, there is a notable lack of detailed data available to form a clear understanding of the UK's biofuel market and the infrastructure supporting it. This data gap creates challenges, particularly when addressing more specific aspects of biofuel production or usage, such as non-grain-based biofuels or biofuels derived from waste products.

This absence of clarity may understandably make businesses hesitant to invest heavily in infrastructure for the biofuel market, especially in South East England. However, as this report indicates, bolstered by available data, the biofuel market demonstrates continuous innovation and growth, despite the challenges posed by adverse weather conditions and economic factors over the past decade. Additionally, with government and NFU deadlines for reaching net-zero emissions approaching rapidly, more businesses will be compelled to explore strategies for improving their carbon footprint. Transitioning to alternative fuels, such as biofuels, will likely be one of the first steps in this process.

Recommendations and next steps

South East England has a unique opportunity to lead in the sustainable use of agricultural waste and crop by-products, leveraging these resources to support a biobased circular economy.

This section outlines strategic recommendations aimed at transforming regional agriwaste into valuable bioproducts, reducing environmental impacts, and enhancing economic growth. By focusing on research and development, infrastructure investments, supportive policy, consumer engagement, and collaboration across sectors, these recommendations offer a roadmap to foster innovation and create a thriving market for biobased products derived from local agricultural residues. Embracing these steps can help South East England become a model for sustainable resource management and a key player in the UK's shift towards a low-carbon, circular economy.

Research and development

- Invest in new extraction techniques
  - Further research into efficient extraction and processing methods is essential to optimise yields of high-value compounds from various agricultural waste sources.
- Pilot testing and scaling
  - Develop pilot projects to refine processes and assess the commercial viability of bioproducts derived from agricultural residues.

Infrastructure and technology investment

- Processing facilities
  - Establish or retrofit facilities in South East England to handle, process, and upcycle a variety of agricultural by-products, from high-value compounds to biofertilizers.
- Technological advancements:
  - Encourage the adoption of advanced processing technologies, such as biorefining and fermentation, to enhance product quality and yield. Leveraging biotechnology and nanotechnology can also improve the efficiency and scalability of high-value compound extraction.

Policy and regulatory support

- Incentivise sustainable practices
  - Implement supportive policies, including tax incentives or subsidies, to encourage the collection, processing, and utilisation of agriwaste.
- Standardisation and certification
  - Develop regulatory standards for biobased products to streamline market entry and build consumer trust.

Consumer awareness and market development

- Educational campaigns
  - Promote the benefits of biobased products derived from agricultural waste to increase consumer demand and support market growth.
- Certification and labelling
  - Implement clear labelling and certification for biobased products to communicate their environmental benefits to consumers and enhance transparency.

Stakeholder collaboration and knowledge sharing

- Networking opportunities
  - Facilitate connections between agricultural producers, waste management firms, technology developers, and manufacturers to build a robust supply chain for agriwaste-derived products.
- Regional innovation platforms
  - Support initiatives to connect agricultural waste suppliers with potential users and promote innovations in sustainable packaging, biobased chemicals, and other products. While the Growing Kent & Medway project will conclude, its legacy will endure, leaving a lasting impact. Furthermore, the consortium will continue to encourage collaborations and explore alternative funding opportunities to sustain this activity in the region.

Data collection and mapping

- Agriwaste mapping and quantification
  - Use GIS tools and satellite imagery to map agricultural waste generation across the region accurately. Improved data collection will aid in planning resource allocation and identifying high-priority areas for waste processing infrastructure.
- Track economic and environmental impact
  - Implement monitoring systems to quantify the economic benefits and environmental impacts of converting agricultural waste into valuable products, providing feedback for continuous improvement.

By embracing these recommendations, stakeholders in South East England can unlock the full potential of agricultural waste, contributing to both economic development and environmental sustainability.

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