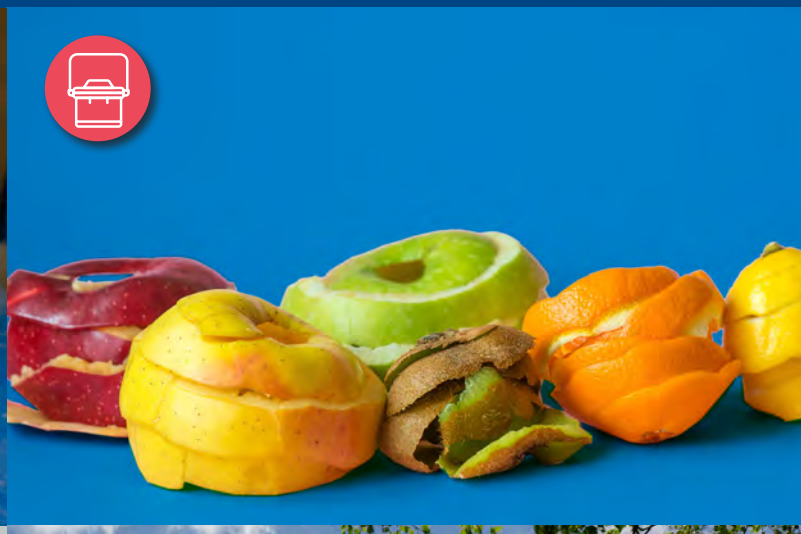
Biorefinery Roadmap for Scotland –
Building a Sustainable Future



Life Sciences in SCOTLAND

Chemical Sciences SCOTLAND

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FOREWORD

Our society is facing some significant challenges including: the rapid development of the bio-economy, the pressure to decrease greenhouse gas emissions and the increasing emphasis on sustainability.

Biorefining represents an opportunity to meet these challenges through the manufacture of innovative products and development of new processes and services using renewable biological resources instead of the more traditional use of petroleum-based feedstocks. Scotland has a long history of innovation, particularly in the biotechnology sector, from fermentation technologies used to produce whisky to the development of novel therapeutics. Scotland's Universities and industry have world class research expertise in chemistry, biology and engineering which form the bedrock of industrial biotechnology.

The National Plan for Industrial Biotechnology was launched in 2013 with the aim of increasing industrial biotechnology turnover from £189m to £900m by 2025. It was acknowledged that biorefineries would be a key to help achieve these goals and in 2015 the Biorefinery Roadmap for Scotland was published to support this ambition. Since the publication of the Biorefinery Roadmap, Scotland has developed many strengths in this sector and there have been several successes. In 2015, Scotland opened its first pilot scale biorefinery and Scotland's first demonstration scale biorefinery is currently being built.

This document is industry led and details the opportunities and support that is required over the next 6 years to realise commercial success for biorefineries in Scotland. I would urge manufacturing businesses in all sectors to explore and embrace how industrial biotechnology innovation can enhance and diversify their operations.

Roger Kilburn
Chair Scottish IB Development Group

INTRODUCTION

The growth of the Scottish Biorefining sector is crucial to reduce Scotland's dependency on fossil fuel resources and to increase our manufacturing capabilities, this sits firmly within the vision outlined by the Scottish Government's Climate and Energy Change Plans.

Biorefining also plays an important role in the Circular Economy, Scottish Government has recognised this importance with the publication of the strategy 'Making Things Last' in 2017 and by investing £18m through the Circular Economy Investment Fund (CEIF).

Biorefining represents an opportunity to manufacture innovative products and develop new processes and services using renewable biological resources instead of petroleum-based fossil feedstocks.

Virtually any carbon containing material can be converted into useful materials using either conventional chemistry or emerging biological processes, this is collectively termed Industrial Biotechnology (IB).

The Scottish Industrial Biotechnology Development Group (SIBDG), representing private and public organisations, has developed both the National Plan for Industrial Biotechnology and The Biorefinery Roadmap for Scotland and provides a steering role to determine the actions required under these two strategies.

Scotland is ideally placed to build a globally competitive bio-based industry, due to the following key representative strengths:

- **Large volumes of Indigenous feedstock resources for biorefining**
- **Existing community of companies that are actively developing IB and has the bio-based materials that are essential as raw materials**
- **Significant existing industry with the logistics, utilities, services, land and skilled workforce necessary to develop biorefining**
- **Access to skills and training facilities**
- **Wealth of academic and industrial research expertise necessary to develop and support a bio-based sector**
- **Strong public sector commitment and support for Industrial Biotechnology Biorefining facilities may serve as a foundation and a catalyst to improve the competitiveness and sustainability of bio-based industries in Scotland.**

GLOBAL CONTEXT

Biorefineries exist across the world to convert biomass from primary raw materials and secondary (waste and by-product) materials into high value products.

In countries like Sweden and Finland, primary material feedstocks include forestry which are refined and used in areas such as the textile industry, the manufacture of medicine, foodstuffs, paints, biofuel, construction materials and hygiene products. There are over 200 biorefineries across Europe which have been identified by the Bio-based Industries Consortium using a broad range of feedstocks to produce a wide range of end products. To ensure Scotland remains competitive and captures its market share of the bioeconomy industry, both in the UK and globally, it is important to build on our strength.

To fully understand how to effectively build on our strengths, the Biorefining Working Group, (a sub group of SIBDG), commissioned work to investigate the biorefining ecosystem in 3 different regions. This involved identifying the critical success factors of these regions and how Scotland compared against these. The final output report has outlined recommendations for Scotland to take forward for the creation of a biorefining cluster, many of which are reflected within this next phase of activity. Innovation continues to play an integral part in biorefining to ensure the development of technology from lab scale through to commercial scale facilities.

OPPORTUNITY

To date, we have achieved modest success in biorefining at a commercial scale in Scotland, therefore the challenge over the next 6 years is to fully harness the opportunities Industrial Biotechnology and the application of biorefining and bioprocessing present.

In the last 5 years, there has and continues to be innovation mechanisms in place and readily available to support companies. However, it has become apparent there is a requirement to further analyse and identify support mechanisms for companies at pre-commercialisation stage. These disruptive technologies largely rest in small and medium sized enterprises (SMEs), representing more than 95% of IB companies, who have significant difficulty attracting the financial resources required due to the capital-intensive nature of technology commercialisation. Although funding mechanisms do currently exist across the public sector landscape, from Enterprise agencies, Zero Waste Scotland (ZWS), UK Research and Innovation (UKRI), European Union (EU) funding and Innovation Centre initiatives to name a few, these mainly focus on early stage development that do not need large capital equipment investment.

In 2017 Zero Waste Scotland published a report on the 'Biorefining Potential for Scotland' which highlighted that there are at least 27 million tonnes of bio-based materials, available from 4 predominant waste and by-product streams. Which could potentially be used as feedstocks in biorefining.

A bioresource data mapping tool was developed alongside the report and now provides a service available to all which can provide information and a clear visualisation of the geographical bioresource arisings across Scotland. This enables rapid assessment and quantification helping to inform circular economy and investment decisions.

Innovative solutions will be sought to create higher value from these existing resource streams, as well as to identify markets for such products. Given the recent legislation published by Scottish Government with the aim of achieving net 0% greenhouse gas emissions by 2045, the Biorefining Working Group has identified carbon dioxide (CO_2) as playing a key part in achieving these targets through utilisation as a key feedstock for biorefining in Scotland.

In addition through analysis of the data within the mapping tool and consideration of new value chains, the Biorefining Working Group, identified an additional five key resource streams as having the greatest potential to further develop Scotland's bio-based economy towards 2025. These are as follows:

- Whisky co-products
- Municipal Solid Wastes (MSW) & Food Processing By-products
- Agricultural Biomass
- Forestry Biomass
- Marine Biomass

WHISKY CO-PRODUCTS

CURRENT STATUS

The whisky sector directly generates more than £5 billion per year for the UK economy and the sector invests £1.7 billion in its supply chain annually. Diverse in size, the sector includes companies that operate a single distillery to large multi-national organisations with several facilities. There are 126 distilleries nationwide with another 40 in the planning and development stage.

The whisky industry produces several co-products (including draff, spent lees and pot ale) which have long been reused by the agriculture sector as animal feed and fertiliser. Developments in renewable technologies have opened new markets for these materials through valorisaton of key components, such as the production of energy mainly through anaerobic digestion (AD) processes to produce biogas.

While these processes are highly valued, there are IB processes which could be adopted to help unlock even greater potential for these materials. The Scotch Whisky Association (SWA) research arm, Scottish Whisky Research Institute (SWRI), supports many aspects of the industry in Scotland including identifying opportunities to create higher value products from whisky co-products. A value chain exercise has been undertaken by SWRI and the Industrial Biotechnology Innovation Centre (IBioIC) to fully understand the supply chain opportunity and how the different technologies can be employed to fully exploit the feedstock and technology synergies.

Additionally, SWRI hosted a whisky co-product workshop in February 2019, bringing together innovative technology providers with distilleries and potential customer of products, such as aquaculture companies in Scotland to explore opportunities.

Using this as a template, similar workshops will be organised for the other five resource themes identified in this document.

OPPORTUNITIES

At the workshop several different opportunities were explored and innovative uses for whisky co-products were highlighted including:

- Utilisation of hydrolysis and fermentation processes on pot ale and draff to produce a carbohydrate fraction to generate commodity chemicals or biofuel. An existing example of this is by combining the whisky by-products, Celtic Renewables Ltd adapt the traditional Weizmann Fermentation process (also known as ABE fermentation) to a brand new and entirely novel substrate. Not only providing a sustainable disposal route for the by-products of one of the UK's largest and most iconic industries but also integrating renewable energy production with environmental sustainability and carbon reduction, by producing sustainable biobutanol as a direct replacement for fossil road fuel to help meet the EU mandates biofuel targets, together with a sustainable source of other high value products.
- Extraction of the protein fraction can also add considerable value. An existing example of this is being carried out by Horizon Proteins. They have developed processes for the recover and re-use of protein and energy from fermentation and distillery by-products. Their initial focus is to use their patented technology to extract underutilised proteins found in distillery by-products for use as a sustainable and nutritionally sustainable source of protein for salmon feed.

Our work at Horizon Proteins focuses on adding value to the Scotch whisky industry by helping to unlock the full potential of its co-products. The extraction of high-value protein from co-products is a unique biorefining opportunity for the whisky industry, and for Scotland."

Horizon Proteins

MUNICIPAL SOLID WASTES (MSW) & FOOD PROCESSING BY PRODUCTS

CURRENT STATUS

The majority of Scotland's population is found in the Central belt where Scotland's two largest cities, Glasgow and Edinburgh are located. In this densely populated area, significantly volumes of household, commercial industrial waste and food processing waste arise.

These wastes are feedstock opportunities for the Scottish biorefining sector. The chemical make-up of food waste is complex, containing varying amounts of carbohydrates, proteins, fats, and other minor components such as phenolics, vitamins and flavonoids. More food waste could be sent to anaerobic digestion (AD) facilities to produce biogas and fertiliser, but there is an opportunity to explore novel approaches to valorise food waste. This includes protein extraction, phosphorus recovery or use as a feed to produce insect protein for aquaculture markets.

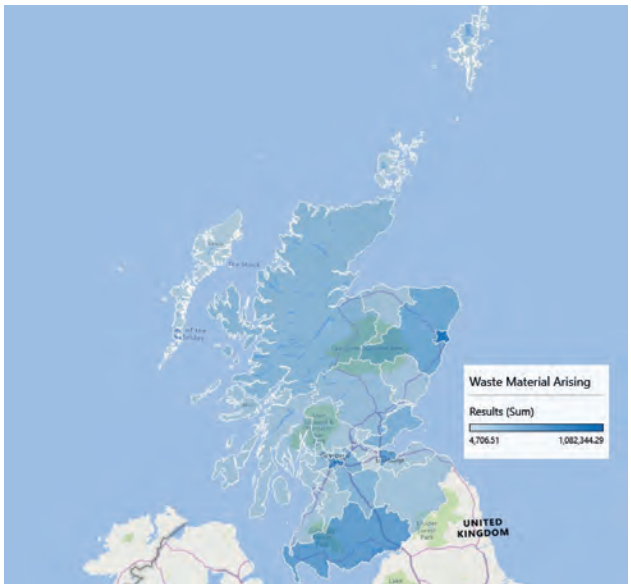

Figure 1: Geospatial mapping of Commercial and Industrial waste and selected food processing by-products arisings mapped across Scotland by Local Authority.

OPPORTUNITIES

In the Circular Economy Strategy – *Making Things Last*, the Scottish Government introduced a ban on municipal biodegradable waste to landfill by 2021 and a target to send no more than 5% of all waste to landfill by 2025. Furthermore, the Scottish Government has published a 'Food Waste Reduction Action Plan' to reduce food waste in Scotland by 33% by 2025. Key focus areas were the bioeconomy and Food & Drink sector. Alongside existing processing methods for MSW and food processing by-products, additional value can be extracted to be utilised in biorefining for the development of novel processes.

Examples of this include:

- The bakery industry. Bakery processing by-product can be found in large volumes in more populated areas and presents a homogenous feedstock opportunity. Jawbrew - a micro-brewery, utilising waste bread to produce beer. The potential of bakery waste still needs to be further developed to understand its full biorefining potential.
- The seafood industry has significant biorefining potential. Novel processes are under development to valorise waste from this industry. Examples include Cuantec, who extract biologically a naturally occurring biopolymer, chitin from fish processing waste, then deacetylate it to obtain chitosan. Mixing chitosan with other biopolymers and natural substances to create a flexible anti-microbial and compostable bioplastic film, to be used as food packaging, reduces plastic pollution ending up in landfill and in nature; furthermore its anti-microbial characteristic will extend the shelf life of fresh food.'

Scotland has a unique opportunity within its grasp. It could become a global leader in the BioEconomy, lauded for its understanding and best practice of Circular Economy solutions, executed with Zero Waste objectives and respect for the Natural Capital around us. CuanTec is championing this approach with our compostable antimicrobial solutions for food packaging, taking waste from the shellfish industry and creating packaging that extends shelf-life of fresh seafood, while making a positive impact on the plastic pollution issue."

AGRICULTURAL BIOMASS

CURRENT STATUS

There are many agricultural residues that are of interest due to the large volumes, the fact they are unused or a combination of both.

For example, farm slurry and manure arisings across the main enterprise types of: beef, dairy, poultry, pig and sheep accounts for greater than 14 million wet tonnes being generated in Scotland every year. In addition, some on-field and harvested waste material are also of interest given their volumes and biochemical composition – namely, carrots and potatoes. In terms of current use of these materials, slurries and farm yard manures are used for biogas and soil improvers.

There are considerable amounts of straw arisings from barley, wheat, oat and oilseed rape. Conservative estimation of available straw in Scotland amounts to more than 1,650,000 tonnes which would be sufficient to source a commercial scale cellulosic biorefinery if located close enough to the processing site. Aberdeen and Aberdeenshire alone have more than 450,000 tonnes of straw arisings which has been identified as an opportunity for this area. Of particular interest are the residual root vegetables with a potential resource of 440,000 tonnes, which are currently not used and form a better feedstock for biorefining and fractionation into higher value products.

"CelluComp have derived a high-value material, with remarkable performance properties in multiple applications, from agri-food by-product feedstocks. Biorefining provides us opportunities to create a more sustainable future."

Cellucomp

OPPORTUNITIES

There are several opportunities within this area to be explored further, including investigating technology associated with processing straws into higher value products in Scotland. There are examples of this technology being utilised at commercial scale elsewhere in the world, which could be used as a starting point for investigation.

Scottish based companies have investigated producing higher value products from roots and vegetables and processing waste, for example potato peel which is rich in starch and would be an easy source of fermentable sugars.

Existing biorefining technology in Scotland includes CelluComp who extract nano-cellulose fibres of root vegetables (primarily from sugar beet pulp, a by-product of the sugar industry) to develop Curran®. Curran® can be a vital component of many water-based products providing performance enhancement in applications such as paints and coatings, inks, personal care, home care, paper, food, concrete, drilling fluids, composites and in many of these applications enabling the reduction of less desirable components in the products. '

Another opportunity to be further explored is understanding what other value chains utilising agricultural biomass could be developed. This includes the consideration of potentially creating new primary sources to be utilised within biorefining and bioprocessing to generate high value products. We are currently exploring new opportunities for an indigenous sugar value chain to underpin biomanufacturing in Scotland.

"The James Hutton Institute views biorefining as an absolute necessity for life going forward and can be considered as a route to help deliver the Sustainable Development Goal 12: Responsible Production and Consumption. Globally we need to be using sustainable feedstocks, reducing waste and ensuring that production processes are, at the very least, greenhouse gas neutral. The James Hutton Institute has embraced biorefining as a mechanism to deliver this in several projects, and with IBioIC, will continue on this path."

James Hutton Institute

FORESTRY BIOMASS

CURRENT STATUS

In regions with established large-scale forest industries, such as Scandinavia and North America, there are several examples of operating wood-based biorefineries. Comparatively, in Scotland, there are currently 7 million tonnes of timber harvested per year and there is potential for this to rise to 10 million tonnes by 2030.

While the majority of the roundwood goes to saw mill, panel board and paper processors, there are substantial volumes that is today used for biomass based combined heat and power. Further to these uses, large volumes of forest and sawmill (brash, saw dust and woodchips) residues are collected to be used for panel board and wood pellet manufacture, animal beddings and similar products.

OPPORTUNITIES

A conservative estimate of forest residues and co-products that could be made available for biorefining in Scotland is around 200-300 thousand oven dry tonnes, which is estimated to be enough for a commercial scale biorefinery. The most viable ways forward to build the forest based biorefining industry in Scotland are to attract inward investment of commercial scale ready technology providers and simultaneously work with the Scottish wood supply chain companies to expand their capabilities into this field through collaboration and partnerships with biorefinery technology providers. In addition to the industrial activities, it is also of vital importance to grow the academic expertise in both wood processing as well as upgrading of the extracted wood components into high value products and applications.

On their commercialisation journey, pyrolysis and bioprocess-based technologies have typically reached pilot and demonstration scale, whereas modern pulp mills now have or are developing more product and revenue streams from their operations. Products from these mills, besides pulp, are tall oil, surplus of energy and electricity also new products like lignin-based fibres, cellulose based textiles and biogas.

Engaging with the Industrial Biotechnology support network in Scotland is key for us to find the right partnerships and collaboration in the forestry biorefinery supply chain to demonstrate and commercialise our technology."

Nova Pangaea Technologies

MARINE BIOMASS

CURRENT STATUS

Scotland has one of the longest coastlines in Europe and has an abundant supply of commercially important species of seaweed primarily located off the west coast and Islands. Although the seaweed industry in Scotland is still in its infancy, it has the potential to develop to provide a significant impact through the application and production of various products.

Scotland's pristine environments, favourable growth conditions and academic expertise have led to Scotland rapidly becoming one of the leaders in European seaweed cultivation. The Scottish Association for Marine Science (SAMS) currently has two seaweed hatcheries and work with partners worldwide to develop this technology.

Scotland is also home to the Culture Collection of Algae & Protozoa – one of the most diverse of its kind in the world with ca 3000 strains of marine and freshwater algae, protist and seaweed.

OPPORTUNITIES

While other regions, such as Asia, are primarily targeting lower value uses for seaweed, Scotland's marine biotechnology cluster is focused on the higher end of the value chain such as speciality products, cosmeceuticals, nutraceuticals, pharmaceuticals, food and supplements.

Both macro (seaweed) and microalgae have been recognised as having potential to be used as a feedstock for biorefining. Potential uses of algae include the production of pharmaceuticals, nutraceuticals, in sewage and wastewater treatment and synthetic fuels. The ability to engineer microalgae for use in the production of novel pharmaceuticals and chemicals is becoming increasingly important.

The biorefining of kelp was identified as an important feedstock for the extraction of high value products. Industry estimated that high value extractives from kelp (Laminaria Hyperborea in particular) could contribute up to £300 million per annum by 2030. Scottish Government is reviewing the framework for wild seaweed harvesting and this has effectively stalled activity in this area. Working with key stakeholders, we will identify responsible ways in which we can utilise seaweed in Scotland for future use in biomanufacturing.

Oceanium is developing an innovative seaweed biorefinery which will use a zero-waste process to transform farmed Scottish seaweed into food ingredients, nutraceuticals and biopackaging. By succeeding in its primary aim of developing sustainable, biodegradable and ocean-safe biopackaging Oceanium will put Scotland at the forefront of marine bioprocessing and establish a new value chain for industrial biotechnology."

CARBON DIOXIDE (CO_2)

CURRENT STATUS

Carbon dioxide is the most abundant carbon gas which can be utilised in a circular way. CO_2 is estimated to account for 81% of all greenhouse gas emissions in the UK. It is produced from a variety of fossil fuel and biogenic sources including power stations, refineries, steel manufacturing, cement manufacturing, chemical manufacturing, agriculture, distilleries, breweries, paper mills, landfill, sewage and anaerobic digestion plants. Within Scotland industrial emissions of CO_2 total over 10.7 million tonnes per annum.

Our society and economy are carbon based. While energy vectors can be decarbonised, manufacturing will always require carbon. Our circular economy opportunity is to increasingly replace oil and gas, a source of both energy and carbon in the linear economy (make, use, dispose) with more sustainable sources of carbon (CO_2 /biomass) and renewable energy in the circular economy.'

The valorisation of CO_2 through chemical or IB processes is relatively recent, driven by policies and regulations to limit the emission of greenhouse gases and to move towards a circular, low carbon economy. The current uses for CO_2 are dependent on its purity. If relatively pure it is used to carbonate drinks, as a coolant/dry ice, for pressurised containers, preservative in food packaging, or as a solvent (supercritical CO_2) e.g. for coffee decaffeination. CO_2 is also used as a 'working fluid' in enhanced oil and gas recovery (EOR). With additional energy input, CO_2 can be converted by chemical or biological processes into commercially valuable chemicals and products, in doing so carbon is sequestered from the lifetime of the product. IB processes have several advantages over chemical synthesis using CO_2 including reduced energy costs, a higher tolerance of contaminants and conversion at lower concentrations.

In addition to carbon storage, the utilization of carbon dioxide as a feedstock presents the prospect for novel routes to platform chemicals. Ingenza are working to understand how the value of CO_2 can be realized."

Ingenza

OPPORTUNITIES

A number of IB processes to valorise CO_2 are currently being developed including the development of microbial systems which can be used for a range of applications including biofuel production and in the production of protein as new food source. There are many companies in Scotland already active in the development of technologies valorising CO_2 in manufacturing including Ingenza.

Carbon Capture and Utilisation (CCU) and Carbon Capture and Storage (CCS) are interrelated but not interdependent and have different scales of deployment. Large scale deployment of CCS is essential for climate mitigation in the future. CCU, with clean energy, is an enabler for low carbon manufacturing.

Mapping & compositional analysis of industrial CO_2 emissions is required to de-risk and facilitate technology providers to come to Scotland. Renewable energy development will be a key factor in future opportunities in CCU.

As a first step toward the utilisation of CO_2 as a feedstock, an action plan for CCU in Scotland is currently being produced as part of the Interreg Northern Connections programme. The plan will embed the innovation support system across the value chain ranging from capturing CO_2 to valorisation of it, providing clarity on the wide range of support available to move forward CCU activity. Companies working across the value chain will also be mapped out as part of the value chain demonstrating the current capability in Scotland to deliver CCU related projects. Emerging gaps on capabilities or innovation support will then be addressed as part of the Northern Connections programme and in partnership with Scottish stakeholders.

Our microalgae use the remaining nutrients from food grade processes to produce omega-3 oils. By coupling the co-products of food and drinks production, with the aquaculture sector, we are able to close the circular economy loop, allowing us to provide quality, economically accessible aquaculture products."

MiAlgae

NEXT STEPS

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

CONCLUDING REMARKS

Scotland has identified the biorefining opportunity and has been actively focusing on it for around 5 years, since the publication of the first National Plan for Industrial Biotechnology. In that time, Scotland has significantly raised its profile in this area and already has many strengths and successes as described earlier in this Roadmap.

The Next Steps or Milestones put forward give a testing framework for developing a detailed action plan. This will rely on adequate resources and nimbleness to optimise the probability of further and growing successes.

It is important to acknowledge the achievements of the various Enterprises and Initiatives to date, and there is the target to offer continuing meaningful support and collaboration from the Biorefining Working Group looking forward.

All stakeholders across private, public and academic areas will need to continue to work in partnership to line up investments and activities towards delivering against the phase 2 Biorefinery Roadmap for Scotland. Only by fostering a shared dynamism will we realise the potential to establish a sustainable and vibrant biorefinery industry for the future benefit of society and the economy.

Iain Lang
Industrial Chair of Biorefining Working Group

This document has been prepared by Scottish Enterprise

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