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Cascade vision:

Regionally adaptive circular bioeconomy – added value, wellbeing and resource wisdom with cascade processing

Tuula Jyske, Kimmo Rasa, Pasi Korkalo and Johanna Kohl

NATURAL RESOURCES INSTITUTE FINLAND

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Foreword:

Global depletion of natural resources is increasing and with it, the need to assess the related dependencies in our economy and vulnerabilities in our self-sufficiency. This need has been further increased by the COVID-19 pandemic and Russia's invasion of Ukraine. We must improve our use of local renewable natural resources – the related logistics and their overall processing and reuse.

A circular economy is a comprehensive economic transition. The aim is to have an economy that functions within the carrying capacity of the environment. It is therefore based on developing a bioeconomy that revolves around renewable natural resources. Biomass, its compounds and its nutrients are used effectively and sustainably, while creating new business and regional well-being. The entire bioeconomy is based on the target-oriented and sustainable use of natural resources. A circular bioeconomy promotes the comprehensive re-use of processed raw materials, which in the best-case saves money and natural resources and reduces greenhouse gas (GHG) emissions. A circular bioeconomy would be a step or a leap forward from the current linear economic system in which materials are discarded after they are used. At their best, circular bioeconomy solutions significantly prolong the circulation of material value. For businesses and society, Luke's circular bioeconomy research provides research-based solutions for sustainable primary production; product manufacturing and service models; ensuring the security of supply and self-sufficiency; and in the longer term, the green transition in line with market conditions that produce added value.

In this report on cascading use in a circular bioeconomy, we describe future visions outlining the development paths for resource-wise use of biomass in Finland. We use examples to bring new regional opportunities for biomass processing to public awareness, their related challenges, and the measures and structural changes required to overcome them.

Our examples focus on the comprehensive use of biomass according to the principles of cascade processing and cascading use. Cascade processing is the processing of biomass into intermediate products, end products, and services that aims to use biomass to the full extent and comprises a chain of different operative units. The aim is that all main and side streams are used to avoid or minimise waste and loss. Our definition of cascading use also covers the reuse of products after their primary use.

The future never conforms to our expectations. It is therefore important to purposefully envision and analyse different possibilities. For example, this process already provides an insight into the different uncertainties and opportunities. When we consider the future, we increase our society's awareness of different needs for change. Too often, circular bioeconomy solutions are cast aside because they are not profitable today, because the investments they require are too large, or because the market for new biobased products is undeveloped. The purpose of this report is to examine the required long-term development paths in light of the changes in our operating environment.

Our visions are aimed at companies processing biomass or producing or designing bioproducts or services related to them, as well as all public sector decision makers and development organisations that support the development of a circular economy. We hope that the visions described here will encourage all circular bioeconomy stakeholders to think about how sustainability targets and the green transition can be achieved in society in the long term. The results of our vision work are intended to inspire further discussion and interpretation of what these visions could mean for companies' business activities, the development processes of different sectors, or regional development. This requires more extensive discussion of how the visions presented here could be made reality, what the required framework conditions would be, and what is possible in the long term.

Helsinki 17.1.2023, the authors

Content

1. Introduction

Short introduction to biomass cascade processing. What will regional circular bioeconomies in Finland look like 30 years from now?

Erkki Verkasalo, Olli Dahl and Marketta Rinne

In 2050, the trend of global **business and trade** and the **need for self-sufficiency and protectionism** of states and unions are competing visions, and fight over the same raw materials and energy in the product and service markets. Advances have been made in mitigating climate change, **replacing fossil energy and raw materials** such as plastic with **renewable raw materials**, but the strengthening of these targets in manufacturing, construction and transport is still required. Concerns about the state of the environment and the pressure to increase the sustainability of food production and secure the food supply for a growing population will have a significant impact on land use and the use of natural resources.

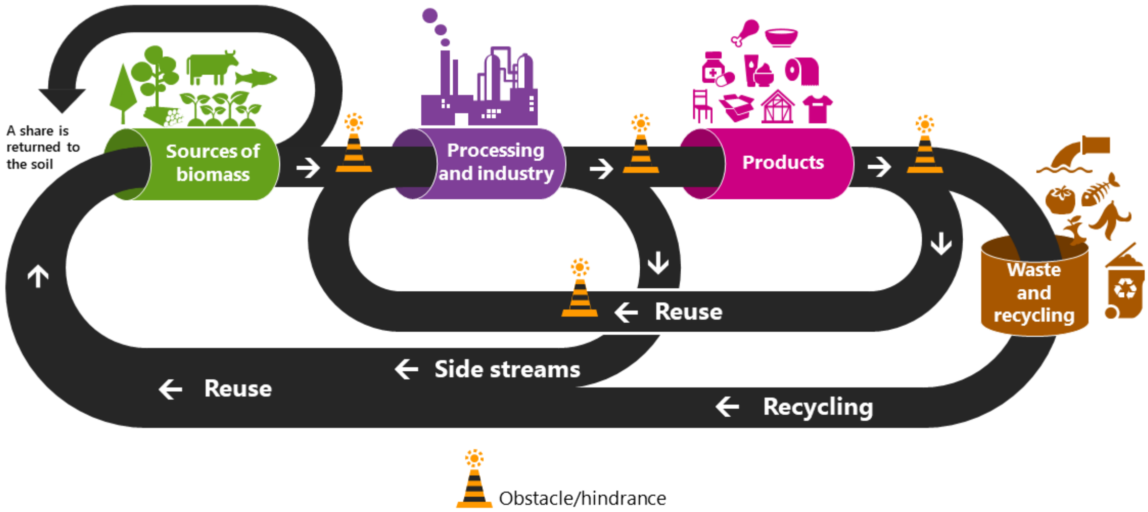


Figure 1. The circular bioeconomy is a precondition for life – regional activities and combining decentralised and centralised production models will enable the sustainable use of raw materials.

The definition of cascade processing

Cascade processing means that different valuable components and bioproducts are extracted from a raw material (biomass main or side stream) with a series of linked technological unit processes to enable the full use of biomass to make products, nutrients and energy with the highest possible added value, while avoiding the production of by-products that cannot be reused. Examples of cascade processing include extracting the valuable water-soluble phenolic compounds from the bark side stream of forest industry processes and steering the material rejected in the process to slow pyrolysis, i.e. to dry distillation, or anaerobic digestion (as one feed with the rest of the biomass), in which case the rejected material can be used to produce biochar, wood vinegar, digestate and energy (Rasi et al., 2019). The residue from the digestion process and the rejected material from the bark extraction can be used as a soil improvement agent (Peltoniemi et al., submitted).

Starting points and rationale – outlook to biomass processing in Finland in 2050

What if the limitations to the use of virgin biomass as raw material and the raw material and food shortages in 30 years have resulted in a rapid adoption of biobased hybrid solutions (combined with other raw materials) and in a significant increase in recycling and reuse, and in materials that were previously considered waste or by-products becoming important in cascading use and in food production and new ways to use bioenergy? There is a global shortage of wood-based materials and food products, and this also applies to Finland due to the increase in demand and the limited land area available for production and the restrictions placed on it – despite the fact that forest and agricultural production has been made more efficient in the area available for it.

Finland has many special characteristics in terms of biomass production. Our obvious strength is the large land area in relation to the size of the population, which makes Finland a biomass superpower in per capita terms. However, Finland has the smallest share of agricultural land of the total area of the countries in the EU, which highlights the importance of forest biomass production. The northern conditions also affect biomass production, especially the plant growth rate and the plants that can be grown here. In field use, the share of grassland is large due to our climate, but a variety of specialty cereals and plants is also cultivated that are suitable for protein, oil and bioactive compound production. Legumes (clovers, peas and beans) are cultivated because they can fix nitrogen from the atmosphere into a form that other plants can use, which adds biogenic nitrogen to the system. The number of species and crop yield of legumes have increased by 2050 because of the warming climate.

What if 'cascading' in 2050 is defined and applied in business according to national and regional starting points and needs, even though global and European regulation have harmonised operative principles and political solutions, and placed restrictions on trade practices? The opportunities for the use of biomass are primarily linked to land use, even though the benefits of using biomass as a raw material or basis for products are recognised – its uses and who can use land.

Digital transformation and the platform economy enable the circular bioeconomy. The versatile **use of data** and **artificial intelligence** steer the efficient circulation of raw materials and materials. Among other factors, the development of block chains enables the comprehensive use of biomass from the harvest to its end use to be planned. The information, technological and socioeconomic basis of digital transformation (Leinonen et al., 2017) are expected to remain in 2050, but radical innovations and experiments, as well as ethical questions, will challenge traditional techniques and technologies.

Biorefineries and range of raw materials in 2050

What if the bioeconomy has moved from managed natural forests to mostly planted and mixed forests, and to producing wood and other plants on the land areas freed from peat production and other 'waste land' that has been turned into forests? This development depends on the political steering of land use. According to international comparisons, good progress has been made with measures implemented in commercial forests and agriculture to sequester carbon and maintain biodiversity, but a larger share of forest and agricultural land has been decommissioned from commercial use. Due to this, the available production area of wood material and agriculture has decreased, but this is compensated by making production more efficient effective on the land area and, to some degree, by the growing conditions that have improved in the boreal zone due to climate change

The bioproduct and food industries now produce more with less and with a smaller number of employees, and the industries make use of recycled raw materials more than before. Biorefineries are clustered in areas and industrial parks and other industrial ecosystems where the supply of raw materials and energy (steam and electricity) is secure. Different forms of ‘green energy’ have developed considerably, they are defined in regulation, and industrial investments may only be based on their use.

The primary raw materials and side stream procurement areas are more expansive than currently and require resource- and energy-efficient logistic and organisational innovations. Sorting the different raw materials based on their intended use is important and verifying the origin of the materials is a key issue in raw material and product trade.

Large industries and small and medium size enterprises in 2050

What if business ecosystems or industrial symbioses that use a combination of virgin raw materials, by-products and waste are the most common production approaches in the use of biomass? In Finland, industrial solutions cover everything from group-level integrations to regional company networks and local industrial parks which are both linked to spinoff business activity for the comprehensive use of forestry, agriculture, aquaculture and industrial biomass and for ensuring an optimal environment for business and competitiveness.

In 2050, the cascading use of biomass is business as usual, and many new small- and medium-sized biorefinery businesses that are independent of the previous large industries (forest industry in particular) have been established especially in the areas in Finland where the large forest industry no longer sourcing its biomass. These new biorefineries increasingly employ people and enhance the regional economy. Training and education have been renewed to meet the need for circular bioeconomy competence.

What if medium and small biorefinery businesses use the side streams from the forest and agriculture industries and increasingly use fast growing biomass that is now cultivated on fields set up on wetlands, on rewetted former peat production areas, and in forests where the conditions that allowed the traditional dominant tree species to thrive have changed due to climate change (e.g. natural disaster and forest damage threaten conifers more than previously, and different species of broad-leaved trees are spreading in areas suitable for them)? A group of tree species and other plants have been selected as sources of biomass because they thrive in the climate that is now warmer and resistant to biotic natural damage (wind and storms, drought, pests and diseases spreading further to the north). The modest energy needs of medium and small biorefineries are covered with electricity that is mainly produced by the refineries themselves or in the industrial park where they are located. In 2050, biomass is used less extensively for heating than before. However, biomass is still part of future energy solutions (see Example 2, Figure 5), including the manufacture of fuel for vehicles. Instead, biomass is used in the manufacture of new fibre products, chemicals and various value-added products, and their use is optimised and more efficient.

The side streams of the biorefineries are refined into recycled fertilisers that can be used instead of mineral fertilisers and to replenish the carbon deficit of primary production (soil carbon loss). **The raw material and types of feed required in food production, animal husbandry and fish farming are increasingly sourced from plant, animal, and wood production biomass (main and side fractions), as are solutions for soil remediation and water treatment** (e.g. different water treatment polymers, or phytoremediation, i.e. soil remediation with plants).

Large forest industry continues to be responsible for a significant part of the forest use in large production facilities for which fibre-based packaging and construction material and products with high added value based on lignin, hemicellulose and extracts are increasingly important. In 2050, Finland has reduced the export of unprocessed pulp and is planning to extend the traditional forest industry value network to cover, for example, the textile industry in all parts of the supply and value chain. In biomaterial development, the focus has shifted from replacing fossil-based plastic to producing functional products, which means the natural characteristics of pulp and lignin are used to generate added value. In product design, biomimicking is more common than previously.

This new kind of forest industry does not directly employ people on the same scale as it did in the 2020s, but it still relies on a significant amount of different external services and contract work. Overall, **small and medium businesses are increasingly employing people**. A significant share of the small and medium biorefinery businesses has grown into global expert operators in the production and provision of technical services. **'Materials as a Service' solutions are common; operators no longer buy the ownership of materials but the right to use a recyclable material.** This is **enabled by digitalisation and cloud services**. Block chains enable materials to be tracked, which makes the chains work. Artificial intelligence has surpassed humans in intelligence, and advanced algorithms are used to plan and control logistics.

The markets for forest and wood industry by-products have undergone a considerable expansion from the manufacture of pulp, paper and cardboard, and the traditional forms of bioenergy to the manufacture of new products in chemical, energy and textile industries, as well as in construction, battery and other technology industries. The pulp industry has been integrated into the value chains of these new industries, both in Finland and globally.

The circular economy requires new forms of entrepreneurship and new structures of ownership, as well as a high level of expertise on the natural resource economy. Generational handover of family businesses, improving the availability of skilled workers and experts, attracting young people to the industry, and managing training and education programmes are key actions when business operations are developed, and the strategies and practices of the cascading approach are implemented.

Wood products industry and wood construction in 2050

What if the wood products industry in 2050 is finally operating in its maximum scope and capacity, functions efficiently with completely closed loops within the limits of raw material availability, and has succeeded in significantly increasing the share of further processed value-added products in its turnover with new construction, interior design and wellbeing products? **Hybrid solutions with solid and composite wood products and other biomaterials are now standards in construction and in packaging for heavy loads.** In addition to more sparsely populated areas and towns, **wood and hybrid residential buildings of wood, concrete, steel and glass are also popular** in larger cities. The development of industrial wood and hybrid construction, successful building demonstrations, and updating the professional education and competence have made wood a viable construction material for building multistorey buildings. Indeed, wood is then often chosen for the basic material instead of concrete or steel. **The needs of residents and end users, as well as public regulation, are the primary guidelines in the selection of the construction method and materials.** Demand is ensured by the smaller carbon footprint and handprint of wood as a construction material, as well as the long lifecycles of the buildings, their recyclability, reusability and modifiability, high quality, introduction of eco-design and implementation of functionalities, not to mention the health and wellbeing benefits of the buildings for their residents and workers.

What if wood is a common material in 2050 in the construction of public service centres, schools and kinder gardens, business and office premises, and **infrastructure** and in built environment especially in the urban construction of rental and owner-occupied housing marketed with the arguments of sustainability? Wood has continued to increase its market share in the construction of detached houses and terraced houses, second homes and tourist attractions. The level of competence in industrial wood construction is high internationally, and wood construction exports have increased significantly. Building codes in line with the green transition, land-use planning, and environmental legislation support new wood construction and wood renovation in particular. **New cascade products made from construction, demolition and packaging wastes that contain wood support the circular economy** and can promote reconstruction and renovation, but most of all, they contribute to the raw material supply of cross-industry manufacturing that uses wood-related side streams.

Synergy between cities and sparsely populated areas

What if urbanisation and the centralisation of services have continued from now to 2050, but with a slowing-down trend? The vitality of rural areas has improved, and keeping sparsely populated areas inhabited is easier than before thanks to the previously mentioned advances of society and the business sector, and the progress of green transition. This requires a sufficiently large labour force and number of enterprises in the bioeconomies of regions. Pandemics and working from home have motivated more people to live and work in countryside and smaller towns, to buy second homes, and to use different ecosystem services more than previously.

Forestry, wood-using industries and enterprises of forest sector, as well as the sources of industrial side streams, are now located more often outside urban areas. In parallel, various wood-based products are used and wood-based constructions are in cities. Most construction and household waste are also generated in cities. The integrated system constitute an important positive interaction between the rural areas and cities and the balanced development of Finnish society.

Proposals for public actions	
Steering method	
Legislation and regulation	• The re-definition of the cascading principle and its application in national legislation and regulation taking into account Finland's needs and opportunities in the use of materials and energy are a prerequisite for the positive development of biomass cascading use. • Conditions of environmental permits and public funding for new biorefineries and forest industry investments: requiring a plan for the use of side streams and excess energy, support for the full use of streams with the aim of creating closed material, energy and water loops and extremely efficient energy solutions. • Using statutory obligations, subsidizing and taxation policies, and public procurement regulations to promote the substitution of fossil raw materials and energy sources with renewable sources. • Using statutory obligations, subsidy and tax policies, and public procurement regulations to promote nutrient and carbon circulation, e.g. recycled fertilisers, biochar and biogas, carbon and greenhouse gas sequestration, and reuse of materials.
Indicators and steering	• Comprehensive instructions for the calculation of carbon footprints and handprints and their application to industry and consumer products, e.g. in construction, housing and workplaces. • Updating building codes and other regulation to support and enable renovation, modification, reconstruction and greenfield construction, and recycling construction, demolition and packaging waste. • Including a requirement in building permits and plot leasing terms and conditions to provide a material, waste and life cycle plan for buildings or structures, and a comprehensive definition of emission limit values and waste management responsibilities covering the entire life cycle of a building. • Prohibiting the landfilling of industry and construction waste (with a transition period).
Training and education	• A national training and business coaching programme that ensures future competence in the circular bioeconomy and the green transition.
Funding	• Wood and hybrid construction: extensive use of the green transition RDI and investment aids and financing options granted by European and national bodies (public and private). • Regional policy programmes and focused funding programmes that strongly support the green transition and new industry ecosystems for biorefining and industries using wood in any form and for balancing the vitality between cities and rural areas.

2. Example visions

Example 1: A vision of operative models based on regional cascade processing technologies and value networks formed by circular bioeconomy operators

Kimmo Rasa, Pasi Korkalo, Jyri Maunuksela, Hannu Ilvesniemi, Saija Rasi, Marleena Hagner and Marja Uusitalo

A decentralised biorefinery based on cascade processing aims to use the different types and seasonally varying biomasses available in the region (Figure 2A). The biorefinery produces both end products and intermediate products that are transported for further processing. Some of the nutrients and carbon in the biomass returns to the soil of the region. Examples of regional biomass side streams include straw, bark, sawdust, manure, plant residues, fish waste, municipal biowaste and sewage sludge. Logistics are handled with convertible road vehicles in a radius of about 50 kilometres of the biorefinery. Logistics solutions that maximise transport efficiency, hygiene and other safety aspects are used. Inside the range of operations is a port that enables the long-distance transport of raw materials and products with ships.

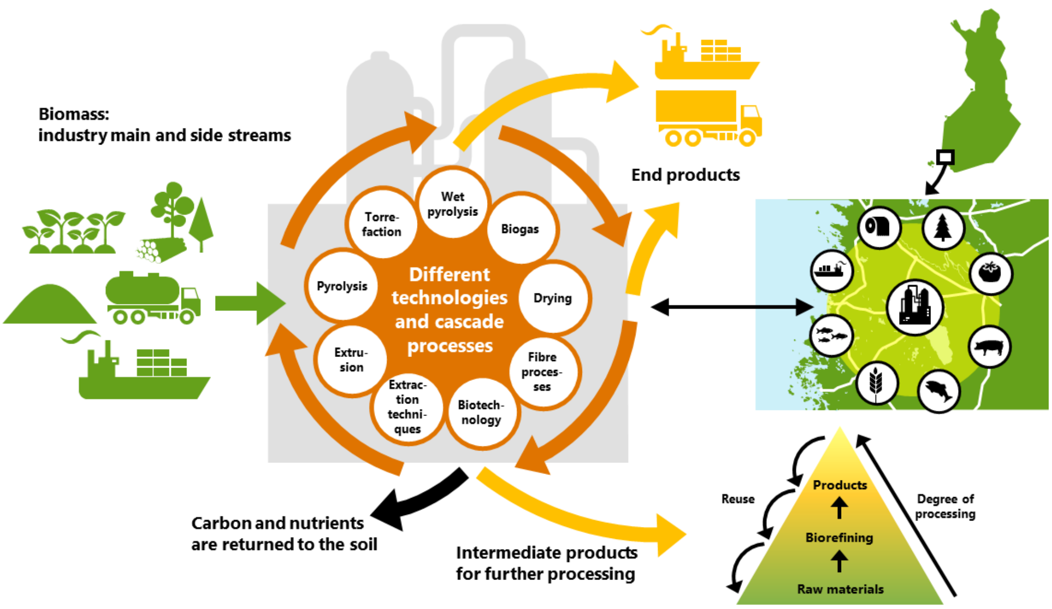
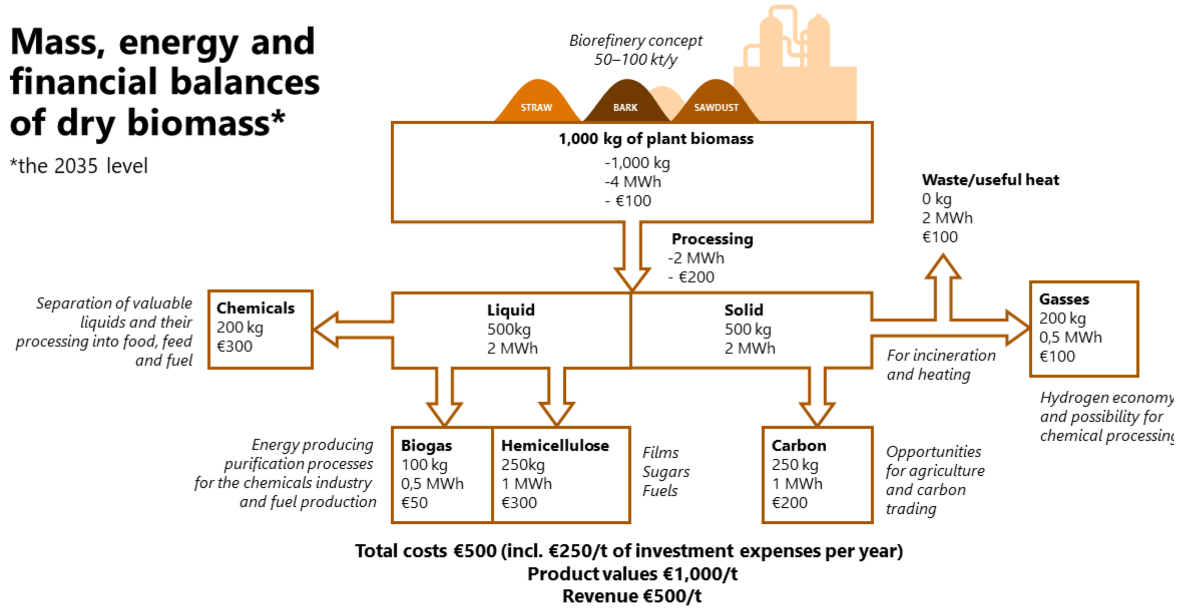


Figure 2A. In the future, regional decentralised production will provide jobs and business opportunities to cities and rural communities. The comprehensive use of biomass can be achieved with cascade processing concepts. In the figure, the sources of biomass are located within a 50-kilometre radius of the biorefinery.



Kuva 2B. Example of biomass use in cascade processing, its economy, mass and energy balance and versatility of products. The aim is to increase the efficiency of biomass use in stages in the future. The profitability predicted to be achieved in 2035 is outlined in Figure 2B (stage d). The target levels are formed as follows: (a) Securing the profitability of current new types of biorefinery investments in the short term and introducing a new way to see things in the bioindustry environment. The main goal is the more extensive use and further processing of by-products. (b) Making the comprehensive use of biomass more efficient and increasing the use of renewable energy (see Figures 3 and 5). (c) Making processing more efficient for valuable products. (d) Replacing the lower-level product solutions such as incineration and fibre production with other product solutions and processed products (textiles, chemicals, carbon products, nutrients). In Figure 2B, the liquid fraction is reused as chemicals and in material and biogas production. Fibre and lignin can be separated from the solid fraction, or it can be used for pyrolysis as it is to produce energy, char and chemicals for different uses (Figure 4, https://naturpolis.fi/mannynkuoresta-arvotuotteeksi-olisiko-se-mahdollista-koillismaalla/, Rasa et al., 2021)

Process technologies are partly based on modular solutions, which makes them easily scalable and transportable if necessary. The basic technologies of an adaptive biorefinery include anaerobic digestion in biogas production, thermochemical conversion techniques, such as torrefaction, pyrolysis and hydrothermal carbonization suitable for dry and wet biomass, different extraction techniques, and the required liquid separation and drying techniques. In addition to solar and wind energy (Figure 5), the adaptive facility can utilize the energy fractions produced in the biogas and pyrolysis processes while producing added-value products and recycled fertilizers, depending on the current configuration of the facility. Completely new process technologies and their combinability promote resource-wise material processing (Figure 2B). (Ho et al., 2022; Kotilainen et al., 2021; Lokka et al., 2021; Viherä-Aarnio et al., 2022)

The run sequence of the processes and the possibility to adapt process parameters enable the efficient use of the different biomasses typically varying between the seasons. In addition, the processes and products can be adjusted based on demand in the markets. Due to mobile module-based solutions, some of the used technology can be placed in the immediate vicinity of the biomass source, which means that raw materials can be pre-processed into intermediate goods in the source of biomass. The benefits of this method include the possibility to produce raw material which is easier to store and transport. Examples of the product portfolio of a biorefinery include organic acids produced in biogas processes that are used in the production of bioplastics and liquid fuels (Rasi et al., 2022; Bartek et al., 2021); liquefied biomethane used as the starting material of fuels and chemicals (FarmGas-PS2 project: https://www.youtube.com/watch?v=7uZFQQqeal4); bulk chemicals converted from plant sugars that are used as starting materials and reagents in fine chemical production; wood vinegar produced from hemicellulose with torrefaction used as a plant protection products or in applications that aim to control acidity (Keskinen et al., 2018); biomass that has been pre-processed with torrefaction for use as a raw material for biochar (Rasa et al., 2021); and organic fertilisers that are used as sources of carbon and nutrients in forestry and agriculture (Heikkinen et al., 2019; Keskinen et al., 2021; Sarvi et al., 2021).

The technologies used in the biorefineries of example 2A are envisioned to reach maturity in the 2030s. The flexibility of technologies has increased, linking them has been optimised, the processing of the different intermediate products into products with high added value is highly advanced, and their demand in the markets is trending strongly upwards.

In the 2030s, the first industry-scale pilot refineries have been constructed in different regions, and the global demand for different biorefinery products is starting to attract the local upgrading industry aiming for export. In the 2050s, the challenges caused by the moderate production volume have been overcome with high added value products and efficient logistics solutions. The campaign-style processing of the refinery enables both continued employment and the profit from value-added products to be maximised, as well as the overall sustainability and carbon negativity that span the monitoring period.

Figure 2B shows a vision based on fractionation, thermal processes and pilot experiments in which a variety of primary products and by-products is produced and processed with a biomass utilisation rate that is as high as possible. Figure 2B shows that biomass processing can become profitable in the long term. Economic thinking and opportunities are based on the optimal combination of various process options. Overprocessing material results in a weaker yield, increases processing costs and lowers overall profitability. Increasing the perceived value of biomass also increases the value of products and creates political pressure to steer society to the sustainable use of biomass with legislation. The increased perceived value also increases prices and enables the cascading use of raw materials with new processes.

Novel technologies and their combinations enable more resource-wise processing of raw materials (Rasi et al., 2019) because they take into account the quality of side streams and enable their better further processing. Biomass is only used for energy production in the form of heat-producing reactions included in the processing. The components of biomass are used as close to their original state as possible. Fractions with commercial value are separated from biomass component by component with a good yield and without unnecessary process stages. It is important that the processing progresses stage by stage, and that each stage makes the next easier. The end products are not only pure fractions, but yields are given special attention, and efforts are made to create combination products that can replace many of the raw materials currently used. Biobased raw materials are not merely used to replace fossil-based low-value products, because there is not enough biomass to do that. Instead, the produced products are recyclable, store carbon for a long time, and make versatile use of the natural characteristics of biomass.

Different conversion and beneficiation techniques are key when new processes are planned. The number of chemical compounds for different uses has increased, and less useful compounds are used for products that allow the properties of each compound to be fully exploited. This results in better products that are more recyclable and stable than the original biomass in their properties and usefulness. The efficient use of side streams to produce char, biogas and fertilisers ensures their usefulness for the overall economy.

Circular bioeconomy solutions combining energy and food production will also use the regional key organic side streams in 2050 (Figure 3). For example, ecosystems can be built to include electricity or district heating based on a region's forestry side streams and food production such as recycling aquaculture system for fish farming or plant or growth rooms. In addition, the ecosystem has processes that use waste and side streams such as biogas production or insect farms. Ecosystems also take into account water, heat, electricity and organic side stream circulation within the system.

Figure 3. Different units of industrial symbiosis, internal resource flows, inputs, and outputs all affect each other and produce financial benefits, but the costs and profitability vary depending on the current availability of raw materials and energy and their prices (Lokka et al., 2021).

The aim of the circular economy ecosystem is that all production lines benefit financially from being part of the circular economy system. The dependencies between units and their balancing on each hour of the year will be a challenge (Lokka et al., 2021). The production costs of the different units in the symbiosis also vary, depending on the availability and price of raw materials and energy. Fast changes in the global situation such as changes to the prices of energy and fertilisers have a significant impact on the profitability of symbioses such as the one in this example but also on whether these symbioses are built around energy or food production. Not having to pay electricity distribution fees, and in some cases, making use of surplus electricity, creates further financial benefits. In addition, benefits are obtained by reducing the climate effects of individual product lines by using side fractions as products and using renewable energy for the processes.

Bioeconomy and circular economy operators form regional value networks in the sustainable cascading use of recycled and side stream materials in the 2030s

This vision report highlights regional solutions for the cascading use of biomass that can differ greatly, depending on both the raw material streams and the uses of the products (Figure 2A). In the sparsely populated northern regions, the challenge for future visions for the cascading use of biomass will be the changing raw materials whose continued availability is uncertain, as well as the lack of sea and rail transport opportunities. In this case, the vision for the cascading use of biomass differs from the envisioned adaptive technology cluster, which focuses on a small area. In the vision for the northern region for 2030, the bioeconomy and circular economy operators will form regional value networks for the sustainable cascading use of recycled and side stream materials (Figure 4). Finland's national Arctic circular economy has been promoted by bringing together the different bioeconomy and circular economy operators and by forming regional value chains based on the circular economy that start at the sources of the side streams and end at green construction or cover solutions for mining tailings, for example.

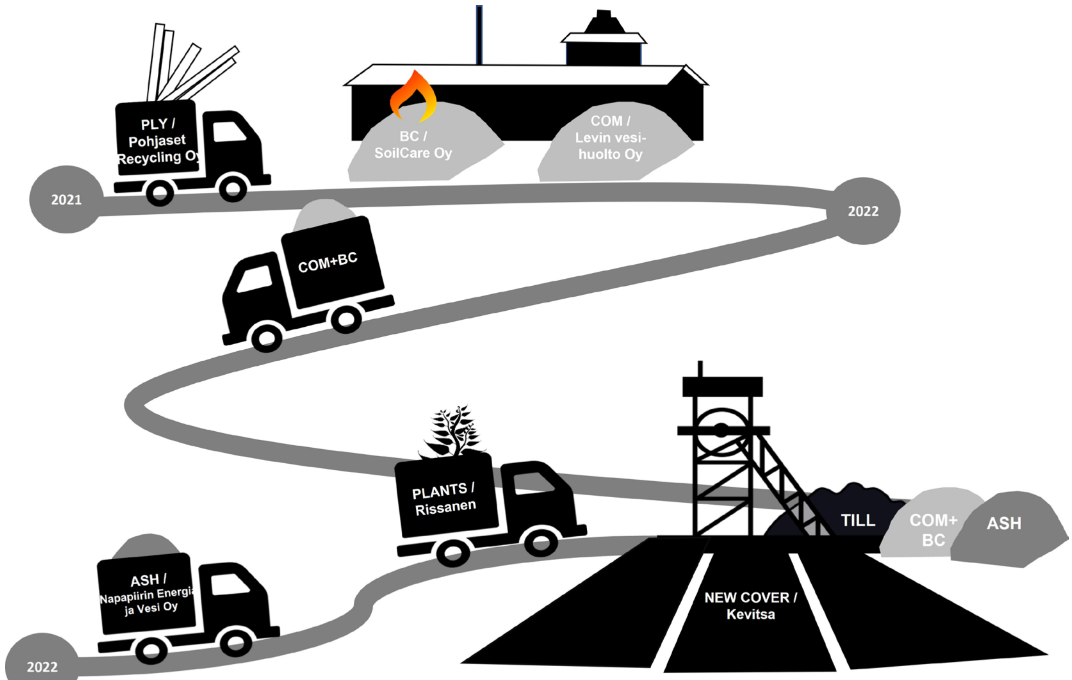


Figure 4. In 2021, in the New Regional Circular-Economy Promoting Co-operation and Bio-Cover Practices in Arctic Mine Tailings project funded by European Regional Development Fund, a value chain was piloted in collaboration with companies that included the piloting of the production of biochar from wood waste, composting of sewage sludge the with wood waste biochar and transporting the processed materials to the Boliden Kevitsa Mining Oy mine's waste rock area to be used as a growing medium (https://www.luke.fi/en/projects/biopeitto2). Image Marja Uusitalo/Luke.

For example, the Lapland region has plenty of side stream materials for the production of wood-based biochar in the form of demolition waste and wood produced in thinning. The region also has other side streams that need to be utilised, such as sewage sludge and ash from energy production that cannot be used as a fertiliser as it is.

In the example in Figure 4, the side stream material producers, treatment and processing facilities (e.g. water supply companies, recycling services, biochar production, composting), and the end users (e.g. green construction, the mining industry) form value chain together. A key aim is to produce growing media to be used in the landscaping of the tailings and waste rock areas of the mining industry that could support cover solutions and landscaping (Hagner et al., 2021; Heiskanen et al., 2022). Implementing cover solutions the size of square kilometres requires value chains that enable strengthening the collaboration between the municipalities, bioeconomy and circular economy operators, and mining industry operators in the Lapland region, as well as increasing business opportunities for the companies in the field. At the same time, the use of side streams and waste fractions will increase, and the sustainability and acceptability of mining operations will improve. Most mining companies benefit from a production chain that produces growing media from the side streams available in the region for use in the covering of tailings and waste rock areas. It is not profitable for mining companies to transport the raw materials over a long distance or manufacture the growing media themselves. Therefore, in the development of value chains, mining companies should investigate whether any local companies would be willing to start producing growing media for the mine's area and to grow plants suitable for its environmental conditions, or whether it would be better for the mining company to invest in a biochar facility, for example. The quality of the biocover to be used in the mine's area must also be optimised to ensure its production is cost-effective and it still meets the covering and remediation requirements of the mine's area.

In Lapland, the long distances are a challenge and thus carbon footprint and financial indicators must be carefully considered when logistics and profitability are planned. A circular economy often involves young companies in the method development stage, which can bring risks related to the availability and quality of the raw materials. In addition, the value chain may comprise companies that differ in size, ownership structure and production volume, and the needs of these different companies must be aligned – for example, the needs of a family business, a municipal waste management company, and an international mining company.

The realisation of this vision has required that areas are carefully and strictly defined because in a large and sparsely populated country, there is a lot of variation in the logistical possibilities and the availability of raw materials. All stages of the value chain must be profitable according to both financial and environmental indicators. The most important measure is to bring together all company networks in the area. The authorities' approval must also be sought for the use of the developed growing medium solutions at the planned location.

Example 2. A vision of new forms of renewable energy used as part of the regional cascade processing of biomass

Saija Rasi and Markku Vainio

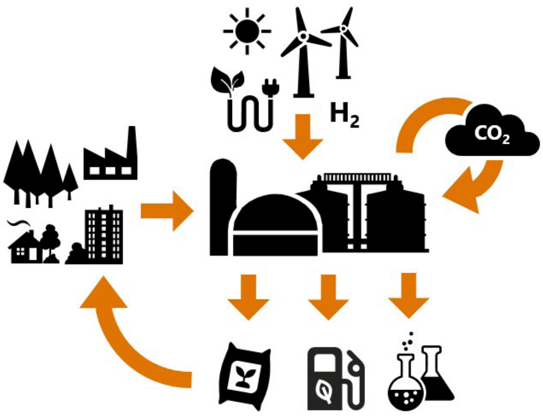


Figure 5. Hydrogen and carbon as part of the cascade processing of waste and side fractions.

The low-carbon targets of the energy sector highlight the role of hydrogen as an energy solution of the future. Hydrogen brings opportunities for the storage of renewable energy, but it is also an important raw material for synthetic fuels and chemicals. In the future, renewable hydrogen will be a sought-after raw material. In 2021, 82 per cent of all hydrogen produced was from fossil energy without carbon sequestration, and nearly all the rest was produced as the by-product of the petrochemicals industry (IEA, 2022). A market for renewable hydrogen is expected to emerge – for example, according to the EU's Hydrogen Strategy (European Commission, 2020), the renewable hydrogen investments made in Europe will be worth EUR 180–450 billion by 2050.

Several hydrogen-based fuels, the raw materials of chemicals and different protein products also require a hydrogen source. In 2023, the costs of carbon dioxide have increased, and its availability has decreased due to the issues in natural gas supply in Europe and because the largest share of carbon dioxide is still produced with fossil fuels. The future hydrogen economy will have several links to biomass processing; we envision that in 2050, genuinely renewable products will be produced with as little fossil fuel as possible required.

In addition to the production of renewable energy (Kakoulaki et al., 2021), green hydrogen will be produced from organic waste and side streams in either thermal processes (e.g. gasification) or biological processes (e.g. dark fermentation; Rasi et al., 2022). In addition to hydrogen, both thermal and biological processes produce carbon as carbon dioxide or carbon monoxide. Organic raw materials cannot cover the increasing demand for hydrogen, but the increasing demand for renewable carbon can significantly increase the value of organic waste and side streams, which would enable even the small hydrogen streams to be used. Using side streams locally would also promote the decentralised production of energy and the circular economy. For example, the strong dependence of the fertiliser industry on hydrogen has already resulted in prices increasing in 2023, so by 2050, new local solutions will emerge that are based on renewable energy and the circular economy.

Before a robust hydrogen infrastructure is built, hydrogen can also be stored as methane either via synthetic or biologic methanation, in which case natural gas infrastructure can also be used as a transitional step (Ijäs, 2022).

Local and decentralised hydrogen production opens opportunities but also brings challenges, as cost-effectiveness has traditionally been based on economies of scale. Research and development are required that the decentralised or local solutions of 2050 are enabled to produce safe, cost-efficient and sustainable products and energy from renewable raw materials (Figure 2A). The role of regions is significant because the shift to a hydrogen-based economy requires collaboration between different sectors.

Example 3. Grass biorefineries produce food, feed, fertilisers, energy and materials in the 2030s

Marketta Rinne

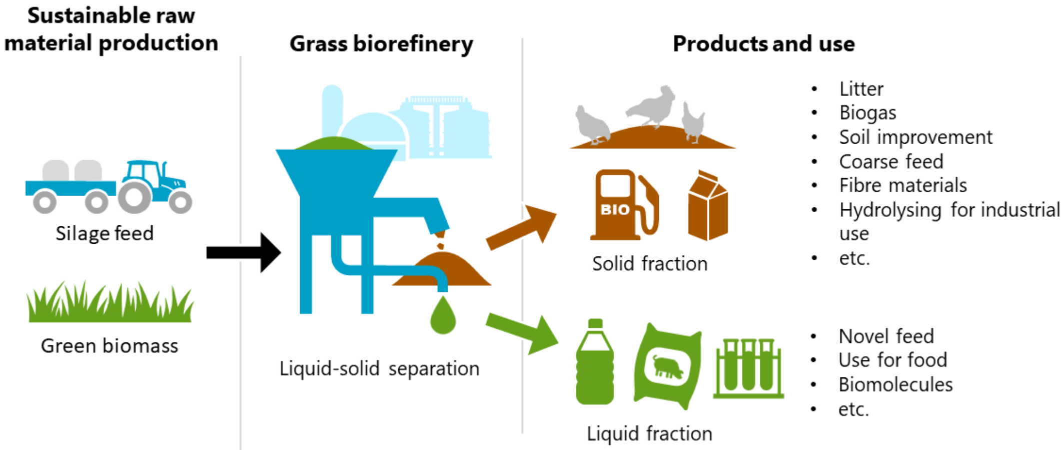


Figure 6. Untapped potential in novel biorefinery concepts.

In the 2030s, grass biorefineries will provide new opportunities to promote a circular bioeconomy. A grass biorefinery can use grass, which has traditionally been used mainly as cattle feed, to make new products such as proteins, novel feeds suitable for monogastric animals, bioenergy, recycled fertilisers and materials (Keto et al., 2021). Diversifying the use of grass is justified because in Finland's climate, grass produces a dry-matter yield that is twice that of other cereals (Luke, 2022) and it can grow further up in the north than cereals and special crops. Grass is a perennial plant and has many benefits such as sequestering carbon in soil, improving soil structure and nutrient balances, reducing erosion, and having positive effects on biodiversity. Therefore we envision that by 2035, grass has also been added to the crop rotation of areas where cattle are not raised (Tampio et al., 2019). By 2035, the valuation and documentation of ecosystem services have also been developed to prove these benefits.

The composition of grass biomass can be controlled by management decisions, but most often it has around 50 per cent of fibre that is significantly less lignified than wood fibre, i.e. easier to process. In addition to fibre, the main components are protein, sugars, and minerals. If forage legumes are included, swards are self-sufficient in terms of nitrogen supply. In addition, plant protection needs, and the risk of yield losses of grass are low, and as perennial plants, they do not add to the already high workloads of farms in the spring. The diverse use of grass crops can also be considered to contribute to the security of supply, which improves the society's resilience.

In 2035, biorefineries and the required business ecosystems have been built in Finland too, following the example set by the Danish grass biorefineries already in operation. Grass and fractions processed from it are fresh products, so investments have been made to the related logistics, preservation, and process development. The method used to produce silage for cattle, i.e. preserving grass biomass with lactic acid fermentation, is one option for using fresh grass that enables the biorefinery to operate all year round. The innovations and research required to support the technological and financial optimisation of the new processes have progressed by 2035. A grass biorefinery could be made a part of a regional decentralised cascade processing concept presented in Figure 2A or it could be one operative unit in an industrial symbiosis depicted in Figure 3

Example 4. Value chains of paludiculture: environmental benefits and bioproducts

Kristiina Lång and Hanna Kekkonen

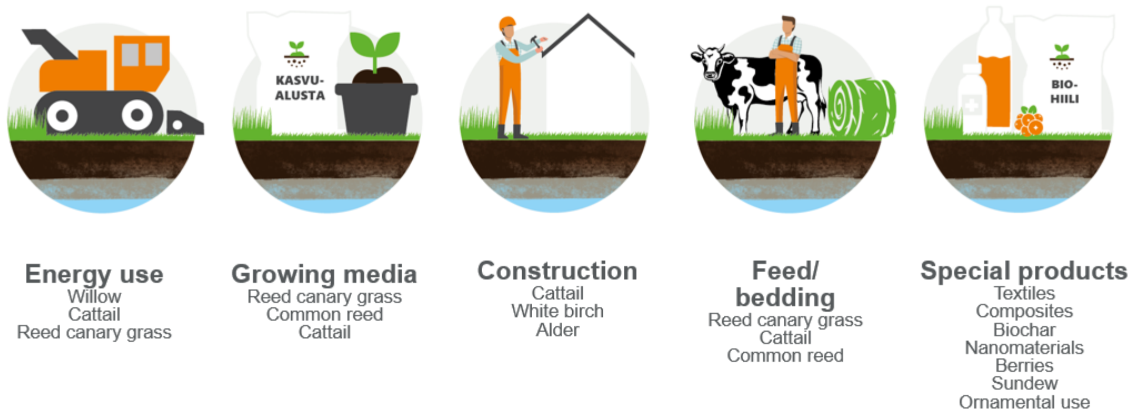


Figure 7. Plants suitable for paludiculture and how they could be used.

Paludiculture is a method for using peat fields or rewetted former peat production sites for the production of biomass (Wichtmann et al., 2016). In paludiculture, the aim is to maintain the groundwater level at 0–20 centimetres below the ground level. This enables reducing the decomposition of peat caused by drainage and reducing the GHG emissions resulting from it (Bianchi et al., 2021). Paludiculture is also suitable for fields where poor drainage has proved challenging for traditional cultivation. A wet environment is suitable for growing e.g reed canary grass, willow, peat moss and cattails (Figure 6). Short rotation forestry could also be used; tree species that thrive in wetter conditions include downy birch and alder.

What if peat fields in 2050 are no longer farmed as effectively drained? Some have been decommissioned; in some fields, the roots of the wetland plants can carry the weight of machines; and in some, the groundwater level is lowered when larger machines are required. The biorefineries in Examples 1 to 3 also use biomass produced with paludiculture. In addition to the already mentioned uses, raw materials produced with paludiculture are used for growing media, by the textile industry (fibre and dyes), for construction materials, and in the food and pharmaceutical industries. There are a few larger operators in Finland that provide harvesting as contracted work and broker different types of biomass to those needing them. Agricultural machinery suitable for wetter conditions have been placed on the market. Consumers are happy to buy paludiculture products, since their environmental benefits are widely advertised.

Example 5. Company partnerships increase the materials efficiency and profitability of side fractions from food production

Marja Lehto, Minna Kahala, Susanne Heiska, Eila Järvenpää, Sari Mäkinen, Jaakko Hiidenhovi and Titta Kotilainen

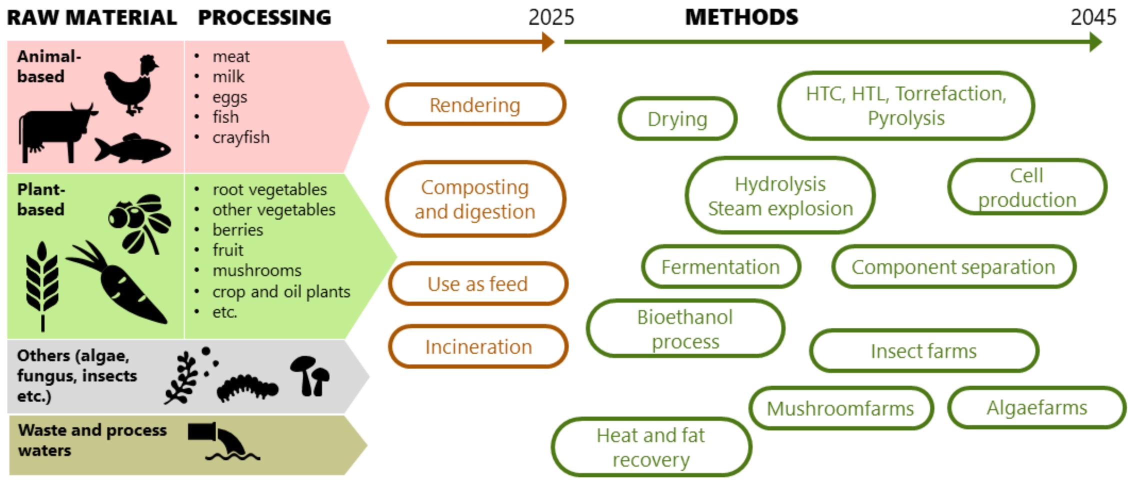


Figure 8. The processing of by-products produced in food companies will be part of the main production process in the future. Industrial ecosystems and technologies developed at different times will increase materials efficiency and profitability. Digitalisation will enable new value chains and distribution channels. Research supports the comprehensive change of the society's decision making and planning as well as the attitudes of companies, households and consumers.

What if the raw materials produced and used in agriculture and by the food industry in 2050 are used in full (Figure 2A) and all material suitable for human consumption in terms of nutrients is used to produce food? A significant amount of proteins and fibre can be produced from side streams; these are vital for nutrition and food security. Fast developing process technologies enable turning valuable side stream components into food products and for use in feed, cosmetics and technology, for example. The sustainability of products is highly important both for consumers and the society. In addition to domestic sales, products are exported. The use of animal-based by-products in feed for food producing animals is increasing, which improves Finland's feed protein self-sufficiency and security of supply. Product analytics and developing processes can be used to change EU legislation to allow the use of by-products as feed more extensively. The side streams produced from the raw material used by the Finnish fish industry in its further processing are processed into components with high added value such as protein, collagen and gelatine products and soluble minerals (Figure 8). In addition to food products, the components are used in biomaterials, health-promoting dietary supplements and cosmetics. The conditions for profitable production are created by combining the side streams of several companies (Figure 2A).

For example, cellular agriculture is used to produce raw materials and food by growing microbes and animal and plant cells under controlled conditions in bioreactors. In 2050, compounds such as sugars, nitrogen compounds and minerals are used as nutrients for producing cells. These come from the main and side streams of primary production and wood-based by-products. Cell factories are used to make meat- or fish-like products or nutrients such as protein, fat, vitamins and flavourings. Genetically modified organisms (GMOs) are commonly used for cellular agriculture products. What if the use of GMOs in food production is no longer banned in 2050? Legislative changes and new competence in implementing new methods are required to achieve this by 2050 if we start in 2022.

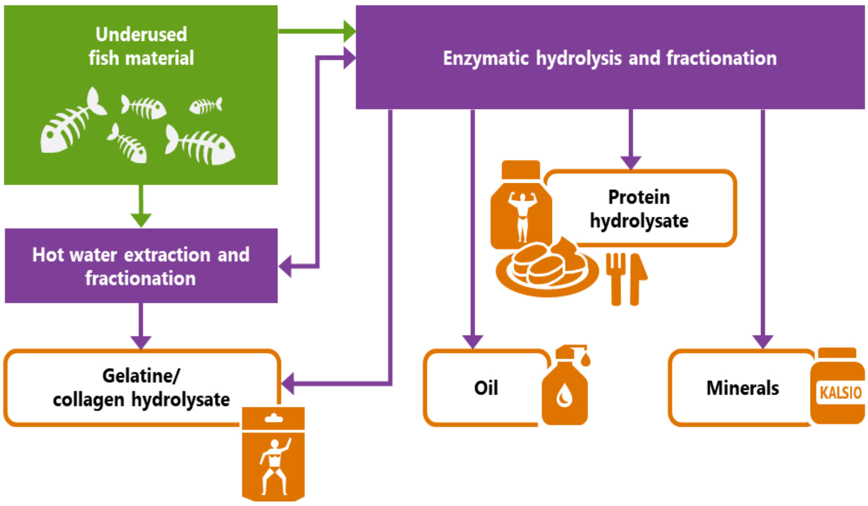
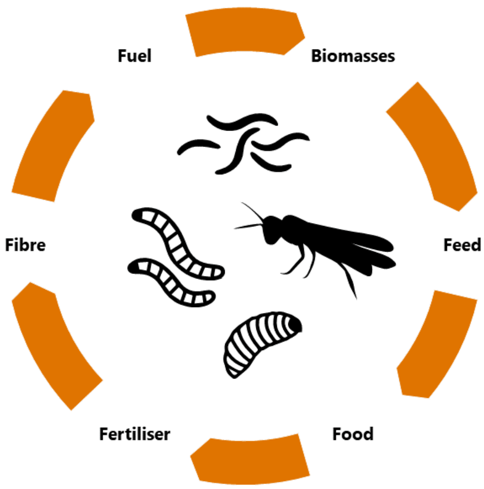


Figure 9. Examples of cascade processing methods for making new products from fish side streams (Hiidenhovi et al., 2021).

What if **the use of feathers** produced in chicken processing extends to cross-sectoral cascading use by 2035? Feathers are light, porous and water repellent and consist mainly of keratin, a fibrous protein. Feathers can be used to produce feed, fertilisers, soil improvers and biogas, and in 2035, they can be separated and cleaned. This means they can be used as is, crushed, ground into powder, or processed (e.g. hydrolysis or steam explosion) into products such as insulation, acoustic panels, packaging material, different agriculture applications (litter, growing media), composites, geopolymers, adhesives or flame retardants (Lehto et al., 2023). Feathers are category 3 animal by-products and the EU Animal By-Products Regulation must be complied with in their use.



Generally, plant and animal by-products spoil fast and their water content is high. Transporting wet material to the location where it will be used is challenging and expensive. The further use or transport of side fractions (Winquist et al., 2022) must be done quickly and as close to their source as possible. Preservation methods extend the shelf life of by-products and enable collecting a larger amount of the by-product before it is transported or processed further (Lehto et al., 2020).

Figure 10. Insect bioconversion can be used to produce fertilisers, growth enhancers and feed, for example.

Insects efficiently convert different types of biomass to more valuable products as well as purify waste and make it more hygienic (Figure 9). In 2050, we envision that in the EU, clean plant-based side streams, milk and eggs, previously prohibited side streams, biowaste and manure – which are species appropriate nutrition for insects – are used in insect farming. The safety of their use in farming insects that will be used for food has been studied and the research results have enabled their use by 2050. Mass produced in cascade processing, biogas residues, fungal culture media etc. will be used as insect feed as well. Insects fed with biomass unsuitable for use as food and fat side streams from these insects are used in biogas production.

Chitin obtained from insects can be used by the food industry and the pharmaceutical industry. Insect chitin can be used to replace unsustainable chitin production, and demand for it will grow as an alternative for fish chitin as it has no off-flavours (fish chitin typically has unwanted flavours). The insect manure or frass produced as a side stream of insect farming is used as a fertiliser and a soil improver (after it is processed in accordance with the Animal By-Products Regulation). By optimising insect production methods, frass can be used to make special fertilisers that activate the plants' natural defence reactions, which reduces the need to use plant protection agents and improves the plants' ability to use mineral fertilisers.

What if protein and fat processed from insects is used in the EU in the feed of pigs, poultry, aquaculture animals and pets in 2050? Organic certification of insects will most likely be possible in the near future. There is research indicating that insect feed has positive effects on animal wellbeing and health. Production costs of insect protein have decreased as a result of developed technology, and prices have dropped to a level that can compete with other sources of protein. The insect feed sector has grown – especially in Europe – now that we know more about insects as production animals; the ratio of carbohydrates and protein and amino acid composition are important for insect feed as well.

In 2050, processed insect products are marketed as super food products to different groups of consumers (Heiska et al., 2020).

Table 1. Drivers and obstacles for the use of food production side streams and example methods and drivers and obstacles for their implementation.

Using the by-products and production methods of the food industry Drivers and obstacles

	BY-PRODUCTS			METHODS			
	Animal-based by-products	**Plant side fractions**	**Wastewater**	**Insect farming**	**Mushroom farming**	**Algae farming**	**Cell production, agriculture**
Applications	Food products, feed, health products, cosmetics, technical products, soil improvers, energy	Food products, feed, health products, cosmetics, technical products, soil improvers, energy	Soil improvers, energy	Insects for food and feed production, by-products for soil improver production, technical use, cosmetics	Mushrooms for food, feed and biomaterial production, used growing media for soil improver production	Algae used for various valuable products, for cosmetics, pharmaceuticals, food and feed production, energy	Food, feed
Processing	Hydrolysis, fermentation, steam explosion, component separation Composting, digestion, pyrolysis, biodiesel process Drying	Drying, fermentation, component separation composting, digestion, pyrolysis, bioethanol process	Anaerobic and aerobic, MBR, RO, micro/ultra/nano filtration, DAF, electrochemical treatment, etc. heat exchanger	Composting, digestion, biodiesel production	Separation of mushroom by-products, growing media production	Grown hydroponically or in a bioreactor, harvesting and processing of the algae biomass Algae sequester nutrients from waterbodies.	Gene techniques, biotechniques, automation and process techniques, microbe cultivation, calculation, modelling.
Drivers for use	Optimisation of production, environmental considerations, replacing imported feed and fertilisers, source of renewable energy,	Optimisation of production, environmental considerations, replacing imported feed and fertilisers, source of renewable energy, interest in renewable/recyclable materials	Nutrient, fat and heat use. Purified water returned to circulation as process, flushing, cooling water	Production is not location-restricted, environmental considerations. Decomposition of harmful substances and mass hygienisation. Food industry side fractions are used as feed for insects.	Plant side fractions, mash, etc. used for growing media. Production is not location-restricted	Use of wastewater heat, nutrients and carbon dioxide – fish farming, greenhouses	Production is not location-restricted. Environmental considerations. Food production side fractions used as nutrition for cells
Obstacles to use	Legislation, logistics, shelf life, demand for vegan products, volume, cost-effectiveness	Shelf life, logistics, volume, production being season-dependent, quality, cost-effectiveness	Legislation	Legislation (animal-based by-products, food and feed use)	Food legislation	Need for light and heat – restricts growing outdoors all year round. Legislation	GMO and food etc. legislation, competence, costs. Energy consumption.
Examples	Fish side streams, blood products and internal organs as food products, pet food, biodiesel from animal fat, spare parts for humans, gelatine, collagen, minerals	Cereal mash, use of apple and berry press cakes in food production, fibre fractions, colour and flavouring substances, feed for ruminants, insect feed, bioethanol	Biodiesel	Protein products, frass fertiliser, plastic decomposition. Manure and waste treatment. Fat and chitin for special animal feed.	Biopolymer packaging, antibiotics	Algal biomass for fish feed. Products e.g. lipids, biogas, biodiesel, fertilisers, biopolymer packaging	Meat- or fish-like products or ingredients – proteins, fat, vitamins, flavourings, etc.

3. Conclusion — On the framework conditions for cascade processing and cascading use

Environmental impact assessments supporting decision making in the development of regional biomass cascading use

Ilkka Leinonen and Merja Saarinen

The application of a product-specific environmental life cycle cost assessment (E-LCA) is necessary to ensure that the implementation of the cascade vision can result in environmental benefits in addition to financial benefits and, in particular, help achieve national and international climate targets. Multi-product production systems and the circular economy create challenges for this assessment. The starting point of the assessment must be the comparability of alternative production systems, which means that multiple products with differing uses must be examined. Products produced in a circular economy include raw materials that are created as by-products or waste in other production chains, alongside the primary or main products of those chains. In other words, circular economy products are created in multi-product production systems. In in assessing the life cycle environmental impacts of multi-product production system products, the process of allocating the emissions and environmental impacts is key, because it can have a large effect on the result of the assessment. There are several allocation methods and different methods are suitable for different situations. The allocation method must always be chosen based on the target and scope of the assessment and justified carefully and clearly.

According to the international standard on life cycle assessment, allocation must be avoided whenever possible. It can be carried out either by dividing the process under assessment to subprocesses and then assessing the different inputs and outputs separately or by extending the production system to cover the functions of the parallel products as well. If allocation must be done, it can primarily be based on the physical relationship (e.g. mass or energy content) of the products or functions of the multi-product production system being assessed or, secondarily, on their other relationships, e.g. a financial assessment.

In practice, in the allocation carried out during E-LCAs, a financial assessment is carried out (e.g. estimated price), because it is easier and deemed to reflect the production incentive. In this case, the largest share of the environmental impacts is allocated to the product with the highest value for its producer. In circular economy solutions, the financial significance of side streams changes, which increases variation and uncertainty in the results of the environmental impact assessment.

The environmental impacts of the circular economy are often produced by a system that is larger than a single product, or even by a completely new industrial ecosystem. In these systems, the production processes of the different products are closely linked and dependent on each other. Often the decisive factors are the overall impacts of the entire system and not the impacts of any individual product produced in the system. Due to this, extending the production system to include all products in that system can often be a justified choice for the method. In comparative studies, the reference production system must therefore include functions corresponding to all the products produced in the multi-product production system under assessment. Often the selection of corresponding products is not simple, so it is important to examine different alternatives and justify all choices carefully.

In addition to assessing environmental impact, life cycle assessments can be used to examine financial impact, in which the total life cycle costs can be considered from the perspectives of both production and consumption. In addition, the cost of the product to the society, i.e. its externalities, can be examined and their possible long-term financial impact on the production can be assessed. In the future, a chapter of its own will be the assessment of the social impacts of the circular economy and reliably making their assessment as part of the assessment of environmental and financial impact.

In particular, the life cycle assessment based on extending the production system provides diverse and well-grounded information that can be used in several stages of decision making. What if, the LCA methods of the 2030s have developed in such a way that the reliable and efficient assessment of the financial and environmental sustainability of biomass cascade processing is business as usual for companies?

The shift to a circular economy must be supported with diverse social change and research

Päivi Abernethy, Matleena Kniivilä, Pasi Rikkonen and Jutta Kauppi

Using side streams and the related shift to a circular economy are not merely technological questions. Instead, their implementation requires diverse social change at the level of policy-making and covering the attitudes of individuals as well as renewing product design and production processes. The shift to a circular bioeconomy requires a novel comprehensive approach in which social and ecologic sustainability are considered throughout the production chain. At each step of the production, from primary production to waste management, several social factors affect the popularity of the developed products, their sustainability and the financial viability of the production. Social change at the level of individuals and companies is affected by values, information, capacity, decision-making mechanisms, the social environment and the overall steering system created by the society, among other factors. In order to promote an effective circular bioeconomy, it is therefore critically important that in the technological development of biomass main and side streams, knowledge in natural sciences and technology are combined with the realities of productivity and policy steering determined by the financial framework conditions. To promote the circular economy, research is needed that helps understand the needs, the information, and the decision-making criteria of primary producers, companies, decision makers and other stakeholders such as consumers.

As discussed, the society has a key role in enabling the green transition. In terms of government steering (financial, regulative, quantitative and information steering), it is important for new industries and innovations that there is sufficient information steering in their development stage, i.e. different demonstrations, pilots and development platforms that RDI operators promote in collaboration with the business sector. Regulative and quantitative steering is usually retrospective, and incentives of financial steering are mostly associated with venture and pilot funding rather than long-term development investment aids. However, it should be noted that the society's existing aids and tax reliefs linked to traditional business activities affect how well the new opportunities in the use of higher-level cascading can be taken advantage of. The grassroots obstacles and drivers must therefore be examined case by case as part of the new circular bioeconomy product and innovation processes. This means the shift away from the established system is bound to take time.

Interdisciplinary research processes that involve innovating solutions, creating debate, and combining information from different areas of expertise are important mechanisms both in applied science and in advancing social change. It will be easier to innovate solutions for biomass production and processing processes, if researchers understand and better consider the practical challenges and regional expertise of primary producers, For example, the shift to a circular bioeconomy can be promoted in practice by biogas research that – in addition to technological solutions – helps solve the financial and capacity challenges related to farm size by actively including the agricultural entrepreneurs, local companies and decision makers in the entire research process. When companies and researchers develop new innovative products in collaboration with land owners and other stakeholders, solutions are created that take into account the practical challenges and local strengths more efficiently. Interdisciplinarity helps with understanding social challenges more comprehensively, creating a shared understanding, and improving the knowledge base used in decision making.

In its different policies and strategies, the EU has stressed that there is a need to start using side streams in the production of products that are as highly processed as possible. In addition, it has been stressed that the green transition should not increase inequality in the society. Generally, it can be concluded that RDI measures supporting a just social change and their implementation in practice are such that they include stakeholder representatives actively throughout the process, including determining the RDI questions. This enables the better consideration of the expertise of different stakeholders in terms of their needs and the challenges they face – whether they are related to the overall practical professional competence of primary producers and their regional expertise, production requirements or market understanding of companies, or administrative information needs of policymakers.

Nationally this vision report and the measures based on it are closely linked to supporting the growth targets of regional ecosystems and the circular bioeconomy value chains of the RDI and business sectors. In practice, regions have defined their targets that support vitality in regional specialisation strategies, through internationalisation, and in the ecosystem agreements concluded separately by the biggest cities in key regions. Local collaboration networks for innovation activities that are close-knit and used effectively strengthen the competitiveness of Finland's circular bioeconomy.

On the international market, 'circular bioeconomy' has many definitions. Due to this, these visions should be updated regularly, but also because the markets change at a fast pace, green investments are targeted at different regions, and EU legislation is developed. However, it is expected that ecosystems of value chain operators, the strength of partnerships, awareness, and reliability are among the factors affecting the globally significant solutions leading to a circular bioeconomy revolution in the future.

The future is built today and our decisions affect the lives of and opportunities available to the future generations. What if the circular bioeconomy in 2050 is a mainstream economy and we have moved on from the linear economy to a circular bioeconomy with the help of the visions presented in this paper? We are already on the right path, but what kind of a roadmap do we need? This vision paper provides some tools for that as well.

Thank you!

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Glossary

Wet pyrolysis	A conversion technique suitable for organic biomass with a high water content (cf. 'pyrolysis'). The technique can be used to convert biomass into liquid or solid products with water and heat.
Fermentation	Fermentation is a process in which microbes break down organic compounds and produce different metabolic products such as alcohols and acids. It can also be used as a preservation method.
Extrusion	In extrusion products like polymer plastic are heated and pushed through a die to create products of different shapes.
HTC (Hydrothermal Carbonization)	See 'wet pyrolysis'. Processing technique suitable for the production of solid, energy-dense products such as biochar.
HTL (Hydrothermal Liquefaction)	See 'wet pyrolysis'. Processing technique suitable for the production of liquid, energy-dense products such as bio-based oil.
Hydrolysis	Chemical reaction in which a compound breaks down to its starting materials after water is added.
Steam explosion	Wet biomass is heated and pressurised in a sealed vessel. The pressure is dropped quickly, which increases the volume of the steam, which in turn causes the steam to 'explode'. This results in some of the biomass fibres breaking down.
Pyrolysis (slow, fast and flash)	A conversion technique suitable for dry organic biomass. In the conversion process, dry biomass is converted to liquid, gas or solid products by using high temperatures. The production volume and the suitability of the technique for different uses depends on the process speed of the type of pyrolysis used. Pyrolysis processes can be divided into three categories – slow, fast and flash – based on the speed at which the material is heated.
Torrefaction	A conversion technique suitable for dry organic biomass. In the conversion process, dry biomass is converted to liquid, gas or solid products by increasing the temperature. The production volume and the suitability of the technique for different uses significantly depends on the raw material used. The method is suitable for producing value-added products from lignocellulose-based biomass and for use as a raw material pre-processing method for different types of pyrolysis (see 'pyrolysis')

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