**WHITE PAPER**
9 February, 2021

# Finnish bioeconomy on the global product market in 2035


Edited by:
Antti Arasto[1], Antti Asikainen[2] and Anu Kaukovirta[2]
[1]VTT Technical Research Centre of Finland Ltd
[2]Natural Resources Institute Finland (Luke)

# Preface

The Finnish Bioeconomy Strategy has ambitious goals to increase the economic wellbeing and the number of workplaces in Finland. Technological solutions, the policy environment, and world markets have evolved dramatically since 2014. New emerging products, processes and services provided by bioeconomy sectors are coming onto markets with rapidly changing needs and consumer behaviour. Concerns about climate change, biodiversity loss, social aspects and global pandemics challenge the bio-based sector to provide new solutions for more resource-efficient and sustainable operations. Simultaneously, green growth and recovery from the economic shock caused by COVID-19 pandemic urges investments and the enhancement of production and consumption systems. In addition, circularity requirements for materials and even for energy call for new solutions.

The objective of this paper is to describe bioeconomy products and services that are being developed in Finland today and in the near future serving global markets. The objective is also to serve as a background document for the update of the Finnish Bioeconomy strategy in 2020–2021. The paper describes different emerging value-added products which are relevant to the Finnish bioeconomy cluster and discusses trends related to the relevant product markets. It is a snapshot of emerging but tangible visions, underlying the decision-making related to the bioeconomy in 2020.

The paper is written by Luke's and VTT's experts and is based on their decades of expertise and visions of the field of bioeconomy.

# Contents

# Executive summary

### Resource efficiency, investments and focus on added value

- Since launch of the first Finnish Bioeconomy strategy in 2014 the economic output of the bioeconomy has increased particularly in the forest and construction sectors resulting from larger production volumes. In the future, however, more emphasis should be put on value-adding investments and production.

- Initially, the economic output and social welfare created by bioeconomy were emphasized. Today, also the concern about the changing climate and loss of biodiversity challenge bioeconomy, its raw material sourcing and product life cycles.

- Biomass is an abundant yet constrained resource. Investing in new, resource-efficient processes holds significant potential in increasing both the overall production and the value of the existing resource use.

### Insights and snapshots of future products

- A larger share of the forest based value chain could be in Finland when customer-tailored solutions are designed and produced prior to transportation. Packaging solutions, textiles, wood construction and lignin based value added products could be emphasised as examples.

- Realising the unutilised potential in conventional agriculture to increase production efficiency and at the same time radically cut down the environmental impact and maintain safety brings significant competitive advantage. The potential can be fully capitalised through the more efficient use of data and advanced digital systems in production planning and monitoring.

- Emerging food production technologies such as vertical farming, aquaculture based on water circulation, and cellular agriculture are rapidly developing. In the future, they can offer alternative solutions for food production when harnessed based on solar and other renewable energy production.

- Versatility in the energy system is key to increasing resilience in the energy transition currently taking place. The constrained biomass resources available for the energy sector should be directed to the most valuable uses from the systemic perspective with special focus to industrial uses, and other hard to decarbonise sectors such as long-haul transport including marine and aviation transportation. Also the efficiency of existing biomass-based energy generation can be improved significantly by reducing losses throughout the supply chain.

### Future services and knowhow

- Nature based services are essential part of bioeconomy and offer increasing sources of health and welfare also for urban populations. Nature experiences and new types of services (soft adventure, packaged products, guidance, products for urban users etc.) form basis for growing tourism and business.

- Technology industries offering technology, services and machinery for the bioeconomy is a vital and increasing part of the Finnish bioeconomy and its export. Long traditions and investments in high level education and innovation culture form foundation for successfully renewing technology ecosystems.

# Introduction

The objective of the Bioeconomy Strategy 2014 was to push the Finnish bioeconomy output up to EUR 100 billion by 2025 and to create 100,000 new jobs. The value added to the Finnish bioeconomy totalled EUR 26.0 billion and the economic output amounted to EUR 75.0 billion in 2019 (Figures 1 & 2). The forest sector and wood-based construction are the largest sectors in the bioeconomy. The share of the entire bioeconomy in the national economy is 13% (Figure 1).

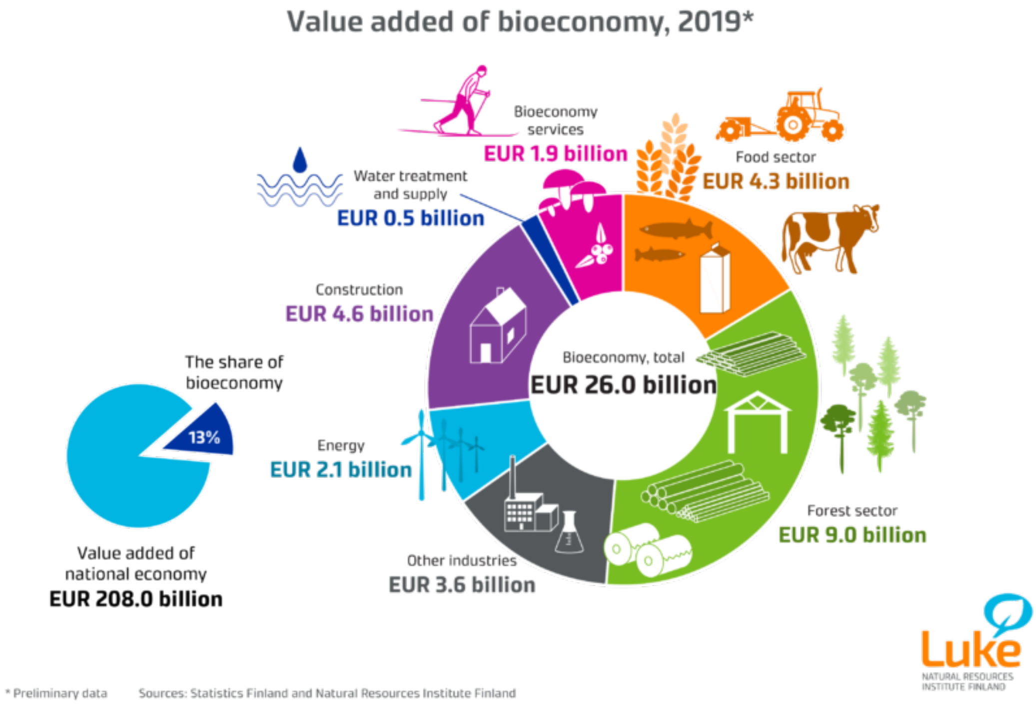



**Figure 1.** Value added by the bioeconomy, 2019.

The bioeconomy output has been increasing and if the current trend would continue, the goal set for the economic output could be achieved by 2025 (Figure 2). However, the COVID-19 pandemic will reduce global economic growth and thus also the export opportunities of the Finnish bioeconomy cluster. Another noteworthy development regarding the Finnish bioeconomy is the increase in labour productivity, resulting in a decrease of the labour input of the bioeconomy since 2014 (Figure 2).

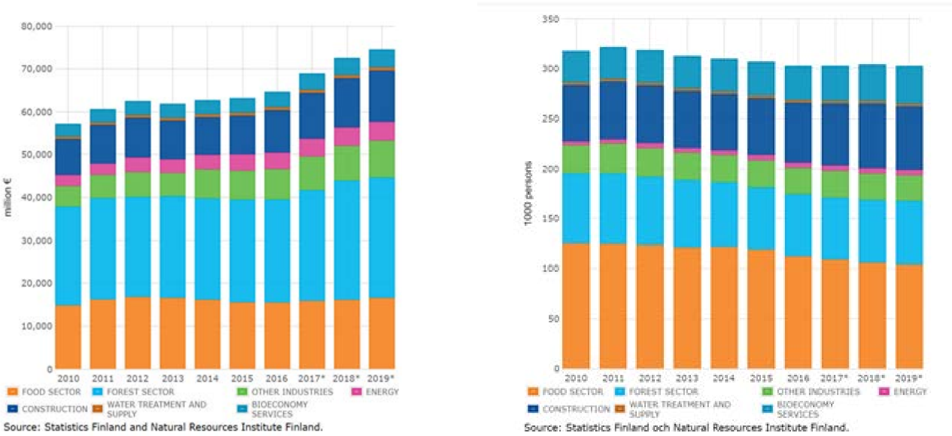



**Figure 2.** The Bioeconomy output, million € per year and the number of people employed in the Finnish bioeconomy, 2010-2019.

This paper describes different bioeconomy product segments relevant for Finland based bioeconomy in perspective of global bioeconomy product markets in future. Fibre products; construction materials and systems; value-added, high-volume products from lignocellulosic side streams; high-volume chemicals; food and food ingredients; animal feed, fertilizer products & growing media; functional ingredients for pharma, cosmetics, and nutraceuticals; bioenergy, biofuels, and energy storage; nature-based well-being services; data and analytics; and technology and service exports are covered and specific products within these segments and their prospects in the future are described. The intention is not to weight or evaluate these products against each other nor to make choices or preferences in the light of different values related to bioeconomy. The objective of this paper is to serve as feed for update for national bioeconomy strategy, where priorities and strategic objectives will eventually be set.

# Global trends impacting local production

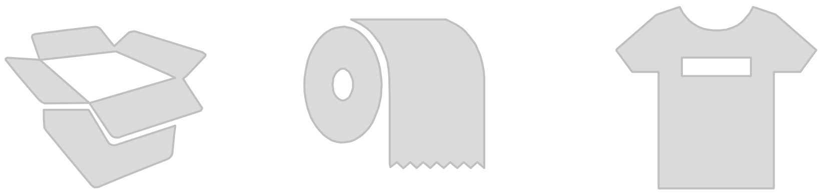
Global trends have evolved dramatically since the formulation of the first bioeconomy strategy in 2014. The awakening awareness and concern about the changing climate and its impact on the global ecosystem and livelihoods have also created pressures on the bioeconomy. On the other hand, the EU's revised bioeconomy strategy[1] has also recognised the potential and importance of the bio-based sector for the EU's sustainable economy. At the same time, the land use, land-use change, and forestry (LULUCF) regulations together with the biodiversity strategy should set criteria and indicators for the bioeconomy in general and for its raw material sourcing, in particular providing measures for making the bioeconomy even more sustainable. These developments challenge the raw material sourcing of the agro and forest sectors. More emphasis has to be put on efficient and resilient bioproduction in the changing climate, e.g. using genetics and breeding technologies and regenerative cultivation and silvicultural practices.

Based on UN forecasts, by 2050 population growth will have slowed down +0.1% and reached 9.8 billion, with higher performing life and extended working careers on average. People will live dominantly in megacities, where public transportation and data community solutions will reshape the built environment. In addition to population growth and anticipatory indications of an initial decoupling of energy use and economic growth, the increase in living standards will undermine the development of product markets with a greater focus on health and wellbeing in wealthy economies. The increasing pace of climate change and its impacts have increased concerns about resilience and biodiversity on a global as well as local level. This trend has been further strengthened by the COVID-19 pandemic in 2020. All this introduces new standards for consumption, reuse and sharing. These factors will lead to carbon neutrality and recyclability, creating value throughout the production chain with an increasing focus on ethics in cross boarder value networks. On the process level, the more efficient use of resources will be an asset in the global context. Traceability and data solutions are opening new possibilities for sustainability follow-up, product safety, and transparency emerging also in single use and short lifecycle product segments. Emerging data opportunities also bring consumer needs closer to production with increasing needs for agility and the ability for continuous change.

[1] European Commission, 2018, A sustainable bioeconomy for Europe: Strengthening the connection between economy, society, and the environment: updated bioeconomy strategy

# Fibre products

Fibre products have traditionally been the second stronghold of the Finnish wood-based bioeconomy. Currently the declining demand for paper products seconded with the shift to e-commerce has strengthened the shift away from graphic paper and towards packaging products. This trend will continue with further shifts towards more technical and demanding products with improved functionalities. From the Finnish perspective, adding value to cellulose which is currently exported largely as a bulk product is a major vision of the industry. The value-added products emerging already from the 2035 perspective will be flexible and advanced packaging solutions, textiles, and hygiene products.



**Packaging** materials are used to protect tangible products to reduce the risk of any kinds of losses or damages while shipping or delivering the products. The most common packaging materials are paper, plastic, metals, and glass. The global packaging materials market is primarily driven by increasing growth in the global food and beverage industry. Furthermore, this growth is predicted to immensely affect the demand for packaging materials in the developed as well as the developing economies. The rise in consumption of ready-to-eat foods as well as frozen food products is going to substantially contribute to the growth of the global packaging materials market.

Over the past two decades, the development trends in the use of plastic have continued to grow fast and this has concurred with a large share of fibre packaging materials, dominantly flex pack. Other success stories for plastic have been modified atmosphere packaging (MAP), soda bottles and several single use service packaging. Aluminum cans have competed well, but other metal packages, especially tin cans, are declining. Glass has had the largest drop in volumes, while board has been successful in rigid packaging. Plastic is expected to continue to grow further, especially when recycling issues have been solved. The balance between fibre and plastic packaging materials will depend not only on oil prices but also the regulative position of different regions. Market analyses have shown that we can expect more positive attitudes towards plastics in Asia.

Population growth and urbanisation are increasing trade and simultaneously, the use of packaging. Online trade is further increasing the need for packaging and the recent COVID-19 pandemic has increased the pace of this trend. Recyclable rigid packaging is the traditional use of fibre materials with several applications such as fluted board boxes, which are dominant and have hardly any alternatives for this particular use at all. The high efficiency and recyclability of the material has made these dominant options and market is still expected to grow. Currently around 50% of paperboard packaging market is supplied with fresh fibre.

Novel packaging materials for food will enable an efficient and sustainable value-chain from farm to fork. These solutions based on cellulose and wood fibres are currently emerging in the markets. Combined fibre and plastic packaging materials will provide packaging solutions with highly recyclable materials with a long shelf-life and low loses in the food chain.

**Flexible packaging** is the most complex plastics-related challenge. Recyclable paper materials and novel cellulose films have the potential to reduce the environmental micro-plastic loading related to the use of plastics in packaging. Service packaging is part of the modern lifestyle and demography and its use is fast growing. However, it is facing a new position due to the single use plastic directive, and recyclable and biodegradable solutions will find new challengers from reusable solutions and there will be challenges for fibre product-based, recyclable alternatives.

Plastic films are the most challenging plastic waste stream in this context due to their light structure and the hard to collect nature of the products. They also play a significant role in marine plastic waste-related problems. The potential for packaging papers and novel cellulose films in wraps, pouches and bags is significant, and could replace something in the range of one third of the plastic films that are currently dominantly polyolefin and multi-layered. Regenerated and nanocellulose films will be the next-generation solutions for this. Significant potential can also be seen in films applied in agriculture, including soil cover and pale protective films where moisture repellent papers are a volume product. These concepts will lead to significant potential to reduce the level of micro plastics in fertile soil.

The high price competitiveness of fossil plastics, especially polyethylene and polypropylene, continues because of expanding unconventional raw materials, such as shale gas condensates. Simple mono material films will not be sufficient in the future to be utilised especially for long self-life food packaging. Multi-layered films that combine several layers are facing limitations due to public acceptance related to the plastics challenge. Strong attempts to find alternatives are currently being undertaken and emerging breakthroughs can already be seen. New converted papers with innovative barrier materials will fulfil paper recycling and plastic recovery requirements and may reach up a 40% market share of a highly growing market of over 12 million tonnes annually.

**Rigid packaging**. The main applications for growth in the rigid packaging market are those for liquid packaging and serving. Fibre-based solutions are currently available as liquid packaging board and cup stock board providing a recyclable and environmentally friendly solution.

Fluted board and cardboard are currently dominant options in rigid packaging. This position will continue and also has the potential for further improvement. Petrochemical aromate-based solutions have less opportunities for growth, especially if the use of affordable condensate feedstock is decreasing with a simultaneous increase in the use of bio-feedstock. This will cause issues in the currently dominant polyester and polystyrene usage. Discussion regarding single-use application products and a shift towards reusable packaging solutions may change the rules of the game and enhance the use of other than fibre materials.

**Hygiene products** are welfare products, of which consumption depends on both demographic growth and aging, in addition to the development of national income. This trend can especially be seen in Asia. Alternatives beyond soft and tissue paper, such as more developed nonwoven and absorption materials are finding increasing use in several applications of nonwoven roll goods. This includes hygiene papers and wipes for personal care in addition to many other applications. Major segments of hygienic non-woven fabrics include baby diapers, feminine hygiene napkins and diapers for adult urinary incontinence patients. For technical applications the material cost is dominant. The performance of synthetic fibres, both polyester and polypropylene to a smaller extent become dominant in the faster growing segment of textiles.

In addition to tissue, there are personal hygiene products including napkins, diapers and cosmetic wipe materials, which are dominantly synthetic materials. Polypropylene and polyesters are especially used, and they are replaceable with cellulose of modified fluff and regenerated cellulose. In medical applications, wound care is also a dominant field of application.

Tissue papers are welfare products, and their usage is increasing steadily. The underlying trend of the increasing focus on wellbeing, especially in developing countries, and the demographic changes everywhere will accelerate the utilisation of disposable products in general. To compensate for the increasing environmental burden, compostable alternatives will probably become officially required. The boundary between hygienic products and medical devices will narrow, among other reasons, due to healthcare becoming more of a form of home care.

The **textile** market is growing, and further potential exists both in fashion and technical applications. The availability of cotton and its environmental acceptance is the main driver for sustainable alternatives, predominately in fashion but also in casual apparel as well the home textile segment. In addition to challenges with cotton, another widely-used material, polyester is considered one of major sources of micro plastics. The potential for both, regenerated and fibril cellulose is high also in technical textiles for applications such as filtering, insulation, cleaning and personal protection.

The textile business is generally under pressure to reorient itself. Raw-material availability, profitability and acceptance are creating the potential for sustainable and recyclable alternatives. Fashion and apparel segments continue to show steady growth, while the growth in technical and hygienic textiles is more rapid. More cotton alternatives are coming on to the market and this will slow down the expansion of the use of polyester. Regenerated cellulose fibre is becoming increasingly importance as part of the solution. A so-called cellulose gap has been noticed, referring to the replacement of cotton with man-made cellulosic fibres including viscose and lyocell. This leads to increase in volume in dissolving pulp markets. Due to limited production capacity and the expectations of cotton, polyester will play a dominant role in fashion also a long way into the future.

**Emerging trends in lignocellulose-based solutions.** Until now, the main drivers for the intensified research and implementation of bio-based products have been sustainability and the aim to reduce the reliance on fossil sources. However, the utilisation of forest-sourced materials, i.e. lignocellulose cannot be justified simply because it is an abundantly available and renewable raw material. Its potential is also derived from the fact that lignocellulosic materials possess features that meet specific application-driven demands that may outperform the existing synthetic counterparts. The fundamental understanding of the inherent features of cellulosic materials have dramatically increased and the findings have propelled completely new applications areas for biomass-sourced materials. Although still in the research phase, cellulose-based materials have already been convincingly utilised as selective membranes for water and solvent purification, as substrates for printed electronics, and in optoelectronic devices, as well as bioactive materials for diagnostics and biosensor purposes.

**Bio-inspired membranes.** Novel cellulose-based materials have clearly shown their potential to act as nano-enhanced purification membranes with the ability to filtrate organic solvents, to capture heavy metal ions and nutrients and to collect nano- and micro-plastic particles. To date, there are no means to recover nano-sized plastic particles for explicit quantification or for qualitative analysis because the existing methods are based on various filtration and elutriation techniques optimised for microplastics on a scale of >50 µm. Moreover, the analogue of responsive membranes from lignocellulose building blocks is currently being demonstrated also for hormone capture from wastewater and for the electrochemical detection of biomolecules. In addition, due to its high hydrophilicity, an inherent feature of the cellulose itself improves the membrane antifouling performance, which is a great benefit over the synthetic membrane materials.

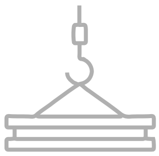
**Next generation photosynthetic cell factories.** Today up to 80% of world's energy and chemical industry demands are covered by fossil sources. Currently the alternative bioproduction pathways such as photosynthetic cell factories, in which the chemical conversion of $CO_2$ to chemicals using solar energy, are suffering from low light-to-product conversion efficiency and excessive water consumption. Recent efforts to revolutionise the cell factory concept by introducing a nanocellulose-based solid-state matrix for efficient carbon capture and the sustainable bioproduction of biofuels, monomers and drug precursors are promising. The evidence exits that the nanocellulose-based matrix boosts the cells' production performance and photosynthetic efficiency. A solid-state photosynthetic cell factory production system will be able to outperform the productivity of existing suspension cultures. An estimated 200-300-fold increase in the volumetric productivity could be achieved in the transition of a cell factory from a suspension process to a solid state process thus making the direct chemicals production industrially feasible.

**Lignocellulose-based (opto)electronic devices.** The latest cutting-edge research attempts have shown that intriguing physical properties of lignocellulosic materials such as their low thermal conductivity, high thermal stability, low electrical conductivity, and peculiar optical properties (light scattering, tunable refractive index, and transparency in a broad wavelength range from IR to UV) could be employed in optoelectronic devices. The approach is different from, e.g., paper-based electronics, in which lignocellulosics are used as a passive substrate in electrical circuits instead of fully exploiting their properties as an integral and active part of the construct. Recently, electronic band gaps of crystalline cellulose allomorphs have been revealed by quantum chemical methods. Furthermore, the optical absorption of cellulose can be tuned from the ultraviolet to the visible range, suggesting their potential use in optical applications. These routes have been so far almost completely unexplored and therefore, the latest attempts of researchers with a background in condensed matter physics, atomistic modelling, and bio-based materials science are pioneering the search for ways to exploit renewable lignocellulosics in entirely new innovations and applications. For example, the intrinsic electronic properties of the cellulose crystal can be foreseen to be employed as components in LEDs, sensors and nanoelectronics, for example. Introducing lignocellulosic components as sustainable, active, and functional materials in new application fields would have a major economic and societal impact in the future when integrated with the existing lignocellulose-based and photonics industries in Finland.

# Construction materials and systems

According to the World Green Building Council, buildings and the built environment are responsible for 39% of global human derived climate effects. On the other hand, construction activities cover half of the exploitation of the natural resources and produce 40% of the waste globally. Therefore, even minor improvements in the sustainability of construction activities would make a major environmental difference. Wood appears to have great potential to contribute to this development, since it is the only renewable construction material available in industrial volumes, and it features many other indisputable sustainability arguments. Recent research results indicate that wooden interior materials have positive psycho-physiological effects on human well-being. Such findings may turn into powerful arguments for the wider use of wood in homes and offices.





Boreal timber itself provides high-level material properties for timber construction as regards the three basic requirements: strength and stiffness, dimension and form stability, and resistance against weather loads. Harmful variations in the technical properties that are typical for natural materials have been largely overcome by applying intensive sorting, in addition to the development of wood engineering and physical and chemical modification methods. **Engineered wood products**, such as glulam, laminated veneer lumber (LVL), and cross-laminated timber (CLT) have up-scaled timber construction from single-family and linked apartment houses to multi-storey residential buildings, schools, offices, and sports halls. The compression strength of wood is extremely high in the parallel-to-the-grain direction. Therefore, LVL and glulam, which consist of members with a longitudinal grain direction have excellent performance in applications that benefit from high compression strength, such as the load bearing vertical structures of high-rise buildings.

The unit weight (ca. 500 kg/m$^3$) of wood is far lower than that of concrete (> 2400 kg/m$^3$) or steel (> 7000 kg/m$^3$). Therefore, wood is less expensive and more energy efficient to transport, handle, and assemble. Its low weight also enables building extra floors on top of old houses without compromising the load bearing capacity of existing structures. The low material weight enables a high degree of dry-condition industrial prefabrication, since light elements can be transported to the building site by trucks according to just-in-time delivery schedules. In an ideal case, a crane could lift several ready-to-live-in volume elements from a truck into their final assembly position within a matter of hours. Wooden volume elements have transformed traditional construction sites into assembly sites, and could potentially reduce the on-site activity time by more than 50 per cent, resulting in considerable financial savings to the developer.

In Finland, timber frames and façades are already the predominant construction principles in single-family and linked houses as well as leisure and second homes. The biggest potential to use more wood lies in multi-storey apartment buildings, but also in a variety of educational and institutional service buildings. While **prefabricated volume elements** are commonly used **in multi-storey buildings** already now, Finland is still short of domestic manufacturers of them, resulting in considerable imports of elements from Estonia and Sweden. In order to fully operationalise the potential socio-economic benefits and business development of increased timber construction, domestic production and the use of domestic products, as well as the development of value networks and stakeholder integration between large companies and SMEs should be strongly supported. Overall, the competitive ability of timber construction compared to other construction methods has improved a great deal already during the 2010s, but there is still need for further development.

In addition to the public sector, the volume of wooden multi-storey apartment building construction is increasing in the private sector. Even greater, still somewhat hidden potential lies in concrete/steel/wood hybrid structures. Wood, wherever technically and economically feasible to use, can positively contribute to the overall environmental footprint of the building, even if considerable volumes of concrete or steel are being used. **Hybrid structures** also enable innovative solutions in terms of structural engineering, architecture, and interior design. Renovation and complementary building of multi-storey concrete and steel houses, either residential or commercial, in parallel to small houses is estimated to be a larger wood user than the building of new houses. The needs and business potential around this activity will grow further, and provide a versatile demand for wood products, components, and elements, for example in facades, balconies, and for extra floors.

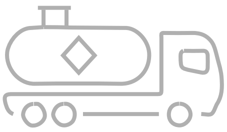
The main industrial logic for turning to wooden structures is the shorter construction times at the site. Additional named benefits for the occupants include increased comfort in acoustics and indoor air quality. Due to their long service-life, the constructions are considered carbon storages, but simultaneously supporting the **concept of flexible and modular buildings with modified function over life cycle**. Composites and additional structures including fixtures and furniture are potential growth areas that require both design and technology development. **Interior businesses** will continue growth and certain major players have clearly stated their support for renewables and especially recyclables. The requirements for reusability will increase the demand for quality in certain segments, while new consumer groups may simultaneously expect even more affordable products. Especially the later may open markets for composites and even specialty board materials.

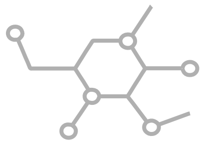
Construction & demolition and new bio-based products represent two of the five priority areas in the EU Action Plan for the Circular Economy. This calls for further improvements of long-term durability, cascaded life cycle management, value-added side stream utilisation, waste management in closed loops, as well as energy and water footprint control in the timber construction value network. The shift from a product-based to a functional economy, in which the functions of things such as residential houses and public buildings are offered to the end-users, requires developed business models, as well as streamlining the regulatory framework.

# Value-added, high-volume products from lignocellulosic side streams

One of the key assets in the bioeconomy is the ability to efficiently utilise raw materials, including side streams for value added products and chemicals. In the future multiproduct biorefineries, where cellulose alone is not the main product, will produce several sustainable alternatives for the current fossil-based building blocks.

Lignin and bark are the largest current industrial side streams in the Finnish forest industry. These forest-based side streams are available at large industrial sites and thus large-scale conversion processes as well as large volume end-use applications can be considered. Annually, ca. 4-5 Mt/a lignin are produced in Finland by the pulping industry. Instead of energy production, up to 1Mt/a of lignin could be recovered for material purposes with current process setups, offering roughly at least EUR 0.5 billion annual income for Finnish pulp mills. An additional lignin side stream originates from bioethanol production. Production processes are currently at the demonstration scale, but the available lignin volume will increase when industrial-scale production starts.





Forest industries in Finland produce annually ca. 6 million $m^3$ of bark that is mainly used as a fuel for energy production. This raw material could instead be used as a potential source for green chemicals with a higher added value. For instance, softwood bark tannin could contribute to the global tannin market and this is expected to grow. As a polyphenolic compound, tannin has similar end-use possibilities as lignin. In addition, bark also contains several physiologically active components in lower quantities, which could be used as health promoting additives in food or pharma, or as natural pesticides or biocides for agriculture and the chemicals industry. For the recovery of all the value-adding components of bark, research efforts into the development of industrially applicable extraction processes are needed.

In order to enhance the investments of industry in the recovery of polyphenolic lignin and tannin, there must be a well-developed and large enough market for the entry, and this must also match the globally increasing lignin production. Many first generation lignin and tannin products can be found in the construction industry, where there is need to find carbon neutral and safe solutions for the current materials. By 2035, they will be used also in higher value applications, such as in energy storage and harvesting, and in antimicrobial materials preventing the spread of diseases.

**Concrete plasticizers.** Concrete is the most used material in the construction industry, and annually 10-15 Mt of concrete plasticizers are used globally. This is the largest volume end-use application for lignin. Novel oxidised lignin-based plasticizers can produce high-performing products with up to 50-80% lower $CO_2$ emissions compared to current synthetic products. Although this cannot resolve the environmental issues of the cement industry, which produces approximately 10% of the global human-made $CO_2$ emissions, it is a step towards a greener construction industry. In the longer run, more sustainable binders instead of cement could be sought. By 2035, novel lignin-based plasticizers could have a truly significant environmental impact if applied also to alternative future carbon neutral binder materials. Lignin-based dispersants used for concrete plasticization also offer biobased additives for the **painting and coating industry**, where there is an increasing need for safer and more environmentally friendly water-borne products.

**Adhesives, insulation materials, fire retardants, antimicrobial products**. There is increasing demand in the construction and wood working industry to find safe and healthy materials and reduce the use of toxic chemicals that affect both the occupational safety during production and also product safety during the end of life. Lignin is already used to some extent in wood adhesives for plywood and laminates to partly substitute toxic phenol, and at the same time to also reduce the need for formaldehyde, which is toxic. In the future, the substitution levels need to be further increased, and the use of biophenols needs to be extended also to other products, such as insulation materials. In the longer run by 2035, higher-value functional lignin and tannin based products will also be available. Fire retardancy is a prerequisite for many construction materials. Safe and sustainable alternatives to toxic and persistent halogenated fire retardants are urgently needed due to restrictions in legislation. This is a potential future application for lignin and tannins. Additionally, their other functional effects, such as antimicrobial properties, should be utilised in order to produce mold resistant construction materials. In addition, monomeric bark components may find use as natural biocides for a variety of products where synthetic biocides are currently used.

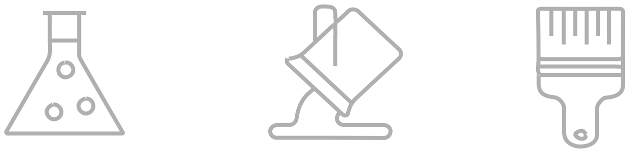
**Water treatment and agriculture**. Especially in applications where the products are directed into natural waters or soil, safety and biodegradability becomes more and more important. Lignin is a natural polymer, and the biological products formed during their degradation are the same humic substances as formed in the decay of biomass in nature, and no micro plastics or safety issues arise. In soil, humic substances can even act as natural soil amendments. Due to its versatile properties, oxidised lignin used for cement and pigment dispersion could offer a biobased alternative also to polyacrylic acid products used e.g. in agriculture as dispersants for pesticides or binders for nutrients, and in water treatment as antiscalants, or for metal recovery. For water and air purification, the biocarbon produced thermally from biomass side streams also offers a sustainable alternative to fossil-based active carbon and presently available biobased carbons that suffer from limited raw material availability.

**Automotive and electrical devices.** The digitalisation and electrification of society will continue to grow, and the supply of many current scarce raw materials used in energy storage and harvesting, such as natural graphite or platinum, will not fulfil the future demand. The increasing demand is heavily driven by the automotive industry's shift from combustion engines to electric vehicles, but even higher growth expectations are in electronics and data communication. In electrical devices, the options for the future rely more on novel technical carbon in accumulators and batteries which will be essential for renewable energy forms and new vehicle solutions. In the future, biocarbon can play a role in the solutions, even towards compostable and disposable batteries. The actual innovations are currently just in the early phases of research. Energy harvesting and energy consumerism together with increased use of electrical vehicles has boosted the accumulator and battery markets and they have more than quadrupled in a decade, and their development continues. The total energy storage market has a major impact on raw materials including not only metals but also carbons. Renewable material innovations in reusable electronics have found a markets in applications such as diagnostics. This market is huge, but access takes major effort.

**Aromatic chemicals**. In addition to its use for material purposes, lignin offers a valuable feedstock for the production of aromatic chemicals, especially phenolics. Aromatic chemicals make up a significant share (40%) of today's building blocks with over 23 million tons in production volume for a wide array of day-to-day products and applications. Approximately 25% of the global production takes place in Europe. The current production stems from fossil-based feedstock which are energy-intensive and have a significant environmental footprint. Moreover, the gradual introduction of shale gas and other light feedstocks in oil refining and cracking operations is resulting in significant production cuts to building blocks heavier than ethylene. For chemical production from lignin, the current industrial side streams are not well suitable. Novel 'Lignin First' biomass fractionation concepts are needed, where lignin is liberated in an intact form or depolymerised into chemicals already during biomass fractionation. The produced mixture of phenolic compounds could be further upgraded either chemically or bio-technically. Through this sort of functionalisation high-value chemicals, such as paracetamol for pharma applications can be produced, whereas at the other end, through the removal of these functionalities pure phenol could be produced.

# High-volume chemicals

Chemicals in their different forms are part of our daily lives. A large proportion of the current fossil-based chemicals can be replaced with renewable alternatives to bring new functionalities to the market, contribute to reducing the dependence on fossil fuels, and for overall feedstock diversification in the chemical sector. Biobased products are derived from forestry side streams, agricultural crops and residues, and municipal organic waste, and can be used to produce platform chemicals, fuels, solvents, polymers, and composites. Biobased chemicals can be divided into several subclasses: drop-in biobased chemicals are structurally identical to their petro-based counterparts with already established commercial productions and markets. The production of smart drop-in biobased compounds offers major benefits compared to the existing petro-based processes and dedicated biobased chemicals are produced through independent bio-based processes, not related to existing petro-based technologies.



**Platform chemicals** are chemical building blocks which can be converted to a wide range of chemicals or materials. The biobased platform chemicals market is still young and is expected to grow rapidly. The use of diverse feedstock creates flexibility in the supply chain and the need to reduce fossil dependence in other down-stream sectors creates a market for biobased building blocks. However, production is expensive and large investments are needed for new production plants. Future opportunities can potentially be found in three value chains: ethylene glycol could be obtained from sugars and could provide an important platform for biobased chemicals and polymers and for anti-freezes, dewatering agents, and heat transfer agents. Another growing platform chemical is 2,5-Furan-dicarboxylic acid (FDCA), which can be used in the production of many polymers like polyamides and polyesters such as polyethylene furanoate (PEF), which is a renewable alternative to PET. FDCA is also the starting material for the production of plasticizers and succinic acid. A third value chain could be built surprisingly on a rather old platform chemical, furfural, which is produced from hemicellulose hydrolysate, which can be obtained as side stream of the cellulose fractionation process from hardwood and straw. Furfural derivatives are value added chemicals with a wide spectrum of applications ranging from adhesives, polymers and textile fibres to solvents and biofuel components. Furfural chemicals can be further classified in two categories: hydrotreated (e.g., furfuryl alcohol and 2-methyltetrahydrofuran) and oxidised (e.g., maleic anhydride and succinic acid).

**Solvents** are a heterogeneous group of chemicals that can be used to dilute, dissolve, or disperse other compounds. Many bio-solvents have functional benefits such as biodegradability. Examples of biobased solvents belonging to the hydrocarbon group beyond already commercial isoalkanes and wood turpentine include plant-oil-based solvents, aromatic hydrocarbons, and glycols. Wood turpentine still dominates the markets in Finland among the biobased solvents. Lignin is the only nature renewable resource which can provide large quantities of aromatic compounds providing the possibility for the transformation of lignin into benzene, toluene, and xylenes (BTX). The bio-solvent market is not expected to grow soon because the industry is dealing with more pressing problems such as VOC emissions. This limits the use of biobased solvents to applications such as paints, coatings, inks, pharmaceuticals, and cosmetics.

**Polymers for plastics** consist of a whole family of polymers with various properties and applications. Packaging is the main application for biobased plastics. Commercial biobased and biodegradable products used for plastics with the largest market share are polylactic acid (PLA), polyhydroxyalkanoate (PHA), poly(butylene succinate) (PBS), and starch. Biobased, nonbiodegradable polymers include bio-poly(ethylene terephthalate) (PET), bio-poly(ethylene) (PE) and bio-polyamide (PA). 2,5-Furan dicarboxylic acid (FDCA) is currently of interest for the production of a new recyclable fully biobased product poly(ethylene furanoate) (PEF). In Finland the production of biopolymers is quite limited at the moment but their role will be significant in polymer processing for packaging. The implementation of a sustainable plastics system requires the design of polymers with both the desired material properties and their recyclability. We will see growth both in biodegradable polymers and recyclable biopolymers, especially in cellulose-based biopolymers. Biobased polymers have new functional benefits and consumer demand is increasing all the time. Additionally, there is pull from large brand owners. Still technical improvements are needed, and bioplastics production and plastic recycling sectors are not yet in harmony.

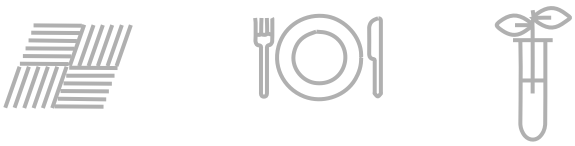
**Surfactants** are usually amphiphilic organic compounds that lower the surface tension or interfacial tension between two liquids, a gas and a liquid, or between a liquid and a solid. Surfactants may act as detergents, wetting agents, emulsifiers, foaming agents, or dispersants. The hydrophilic part is derived from carbohydrate or vegetable oil feedstock and the hydrophobic part typically originates from vegetable oils from oilseed plants and tall oil fatty acids, which are obtained as a by-product of the Kraft process in wood pulp manufacture when pulping mainly coniferous trees. Biobased surfactants typically have better biodegradability and lower toxicity compared to fossil-based surfactants and this is leading to the rising demand for biobased surfactants. The market is also being activated by legislation such as Regulation (EC) No 648/2004 on Detergents. A weakness of this category are the higher production costs which are due to the higher feedstock costs and the need for difficult separation steps. In Finland one major positive aspect for the production of hemicellulose, glycerol and tall oil fatty acid-based biosurfactants is the abundancy of wood-based feedstock and mature technologies for their fractionation.

**Adhesives** are substances applied to one surface or both surfaces of two separate items to bind them together and prevent their separation. Bio-adhesives are commonly created from a polymer or monomer and a solvent. At the moment methacrylates, furfuryl alcohol, epoxy resins and tall oil rosin form the bulk of the biobased adhesive market in the EU, and tall oil rosin production is dominated by Finnish and Swedish production. There is also some domestic production of biobased epoxy resins. The adhesive sector provides great opportunities for renewable adhesives such as lignin-based resins and biobased polyurethanes or non-isocyanate polyurethanes (NIPU) and their components, polycarbonates and polyether polyols, which are made from biomass and $CO_2$ with BECCU-technology. Regulations are stimulating demand and there are an increasing number of biobased applications. On the other hand, there is low interest from customers in biobased adhesives as a part of other products and there are limited possibilities for recycling bio-adhesives.

**Lubricants** are substances, usually organic, used to reduce friction between surfaces in mutual contact, which ultimately reduces the heat generated when the surfaces move. Bio-lubricants are typically derived from vegetable oils such as isoalkanes, and fatty acid methyl esters (FAME) and polyethylene glycol (PEG) esters. Lubricant persistence in the environment largely depends upon the base fluid. Biodegradability and non-toxicity of many renewable lubricants make them a good environmental alternative. Biobased lubricants already have a mature market in total-loss lubricants especially in the Nordic countries. The market growth of other sectors, for example engine lubricants will depend on activation by regulation. Otherwise, the biobased lubricant market is not expected to grow. A weakness of biobased lubricants are the difficulties in obtaining desired properties (oxidation stability, viscosity range and index).

# Food and food ingredients

The global food system is undergoing a major transition to move towards improved resource efficiency, lower GHG emissions, water and land use, and to reduce the negative impact on biodiversity. At the same time the economic viability of primary production needs to be significantly improved. Furthermore, we need to ensure the production of nutritious food for the growing population on the globe. The need to transform the food system towards more sustainable processes opens several opportunities for Finland to strengthen its role in the global food supply. The Finnish food system can have a strong position in the future due to its beneficial climate, water and production hygiene conditions as well as new technology and highly educated primary sector actors. Versatile food production and the export of high quality items can be forecasted to increase by developing the current agricultural and food manufacturing processes based on plant and animal farming. Furthermore, the various emerging solutions, for example, vertical farming and cellular agriculture could open new business fields with global export potential for Finland. Currently the share of the food sector of the Finnish bioeconomy output is about 17%, with good options to grow significantly in the future.



**Dairy and meat products.** Animal farming is one of the food production lines with a high environmental impact. However, when developing more sustainable animal farming, Finland has the capacity to be a key actor in sustainable animal food production in the future. While ruminants are unique in their capacity to digest fibre and convert non-edible resources into high-quality food, grass-based milk and meat production has traditionally been the dominating agriculture sector in Finland. Cattle farms are mainly located in regions with few other alternatives for feasible agricultural production due to the severe climate and hard cultivation conditions for other crops than grass. The sustainability and efficiency of the Finnish system is based on the fact that 85% of the consumed beef comes from the dairy chain.

The main operators in the dairy chain in Finland are aiming towards a carbon neutral dairy chain, which together with the availability of fresh water and suitable agricultural conditions for grassland production will sustain the dairy/meat sector in the future. This is important for food production, the rural economy and the maintenance of ecosystems and biodiversity in Finland, making it also relevant for meeting the increasing global food demand in the future.

In general, the development of innovative production systems (including plant and animal breeding, feeding strategies) that are more efficient in converting non-competitive (not human edible) and local feed resources into high-quality edible foods are assets of Finnish domestic animal production. Breeding and genetics have proven their ability to improve the efficiency of feed input/milk output rapidly. In 30 years the input needed to produce one litre of milk has decreased by 15% and this development is anticipated to continue.

Similar types of breeding strategies can be applied in other animal and plant systems. Furthermore, the high level of animal welfare standards and low use of antibiotics are crucial competitive factors for animal production in Finland. The development of verifiable labels (carbon neutrality, animal welfare, food safety) will be a central part of branding Finnish animal-based products for domestic and export markets.

The global consumption of milk and meat is steady is growing which offers excellent export opportunities for Finnish companies e.g. in Asia and Africa.

Finland has been a forerunner in functional foods, especially in the dairy sector. Today, there is potential also for improving the quality or composition of animal-based products, e.g. by increasing the share of unsaturated or desirable fatty acids through feeding strategies or removing undesirable proteins by genetic selection (so called A2-milk) and thereby enhancing the nutritional value, usability or functionality of the products.

**Cereals and other plant-based food ingredients and products.** Finland has been one of the largest oat exporters in the world already for decades. Most of the oats are exported as grain but during the recent years more and more also as new, innovative oat products. Another traditional, strong export field have been barley malt and malt extracts exploiting the production of high-quality malting barley, barley breeding, and the brewing knowhow of Finnish industries and academia. In recent years, the product development and export of cereal- and berry-based alcoholic drinks has grown rapidly.

The use of plant-based ingredients for food is a rapidly growing field and is booming especially in Finland with high numbers of new product launches. Plant-based protein is an increasingly important research and industry field, and it aims to provide alternatives to meat and dairy products, but it is expected to bring forward other food innovations as well. Plant-based protein and ingredients based on crop farming enable the production of various food ingredients. Diverse crop choices (cereal, oil seeds, legumes), crop rotation, precision farming, cultivation technologies and soil improvement solutions via ingredient production processes up to food manufacturing solutions provide ingredients which are enriched with protein and other beneficial components. The typical use cases for these new ingredients include dairy substitutes (drinks, spoonable products) and meat substitutes (patties, balls, sausages, minced meat etc.).

**Fish and other aquatic products.** Fish and other aquatic products are a strongly growing business area globally. This is attributed to the growing consumption of fish for its nutritional value, and partly also due to the increasing demand for algae and other aquatic products. In Finland, the societal goal is to multiply the use of domestic fish in diets until 2035. For this aim, the domestic aquaculture production and food use of low value species, such as Baltic herring, sprat and roach fish in food will be increased remarkably. Innovations in smart fishing, aquaculture, processing and productisation will enable Finland to meet the growing demand for sustainable aquatic products. Advances in aquatic production technologies and product development from sea, or fresh waters to the fork will be essential to enable the increased use of sustainable fish and algae products in healthy diets.

**Greenhouse production and vertical farming.** In Finland, horticultural plants are produced in greenhouses in 400 hectares and in over 900 companies. The production of ornamentals accounts for 30% of Finland's greenhouse area, while vegetables, salads and fresh herbs comprise the rest. The production of potted vegetables has increased year by year being 100–110 million pots per year. The net profit ratio of the greenhouse cultivation is nearly 1, being the highest among the agricultural sectors in Finland. Finland is nearly self-sufficient in the production of cucumbers (>90% of domestic origin), whereas 60% of fresh tomatoes sold are produced in Finland. Except for occasional batches, potted vegetables are not imported to Finland. According to the Finnish Glasshouse Growers' Association, the biggest obstacle to the export of Finnish greenhouse products is the lack of export channels. Cucumbers would be ready for exporting in terms of price, yield and quality.

Vertical farming is a rising technology for intensive food production in environments where space and the availability of water are limited. In vertical farming crops are grown on stacked layers and illuminated with led lights. These features allow intensive crop production in urban environments near customer markets. Key advantages include the limited use of pesticides, no nutrient emissions, and more efficient use of water. The water is circulated, and nutrients are fed to artificial growth media.

Finland has been and is at the forefront of developing and utilising technological solutions in controlled environment agriculture (CEA) such as vertical farming. The efficient use of supplemental lighting is a key factor and many supplemental lighting techniques and methods for indoor cultivation have been developed here. It has been estimated that greenhouses with optimised lighting can have yield potentials of 20 times higher compared to open field production due to higher yields in controlled conditions and year-round production. Adding to that, plant factories/vertical farming can produce food every day of the year independent of weather conditions or location. Currently, vertical farming produces leafy greens and some vegetables, but it has the potential to produce more protein-rich crops, thus contributing to feeding the world's increasing human population.

The potential for using vertical farming for more sustainable food production is certainly there, but the energy use is still high. Future electricity will come from renewable sources (solar, wind power), making the production more sustainable. In addition, other technological advancements, including improved lighting solutions, will increase the energy efficiency of the production. There are several companies in Finland producing solutions for greenhouses and vertical farms, operating across the world.

**Cellular agriculture-based products.** Cellular agriculture means harnessing microbes and algae as well as animal and plant cells for food production in bioreactors to produce food instead of using animals and fields. These organisms can turn various feedstocks, for example, agricultural side-streams into valuable food materials. Food production using cellular agriculture can be divided in two categories: cellular and acellular products.

**Cellular products** mean that we use the whole cell mass as a food ingredient. Examples of cellular products are single cell protein products such as Quorn (fungal), cultured meat and cultured plant cells. Especially important for the process development is what the cells will use as a feedstock and how sustainable the carbon source used in the fermentation process is. For example, a microbial cell mass can be grown based on $CO_2$. The environmental impact of the product based on $CO_2$ has been estimated to be about 1-10% of the impacts of traditional plant or animal proteins. Microbial-based cell and cultured meat products typically aim to provide alternatives to meat products, but for example, microbial biomass can be used as an ingredient and a protein source for other product types as well. The interest in using plant cells for food stems from the point that the cells produce many of the same valuable molecules as whole plants, including fibre, proteins, and phytochemicals. Plant cell culture technology can enable the production of currently non-sustainably grown plants and fruit such as cocoa and avocadoes.

**Acellular products** mean that cells, for example microbes, are used to produce ingredients that are separated from the cells. Currently, this technology is used to produce food additives such as vitamins and processing aids such as cheese rennet. In the future we will also be able to use cells to produce high quality food proteins, lipids, and other added value components. One specific example that VTT has demonstrated involves the production of chicken ovalbumin using the *Trichoderma reesei* fungus. Based on the preliminary calculations, egg white production using microbes generates 74% less greenhouse gases and uses 90% less land than rearing chickens.

**Insects** have been suggested as an alternate protein source for human diet. New products based e.g. on crickets have been introduced. Their market share has not been increasing as anticipated. Insects, however, can play an important role in the processing of side streams or food industry and farms. They enhance the processing of waste biomass and can convert it into raw materials for animals, fish and e.g. pet feeds. Insects can play an important role in nutrient recycling and refining processes and systems.

The change in food production is just beginning and requires systemic change, but also scaling up technologies, solving regulatory hurdles, as well as engaging consumers with the new food products. In general, Finland is a high-tech country in terms of food production. Already, Finland is a world leader in oat and plant protein-based innovations and increasingly an exporter of these foods. Therefore, we can also pioneer new solutions such as recirculatory aquaculture, vertical farming, cellular agriculture, and innovations in the enhanced use of underutilised raw materials and lead the way in creative disruption in food production.

# Animal feed, fertilizer products & growing media

Plant biomass has multiple uses, one of which is feed for animals, converting the energy and nutrients into high-value-added products, such as milk, meat, and eggs. The manure from livestock operations is circulated into plant nutrition as fertilizer products either directly or after energy recovery or other processing. Nutrients, water and (solar) radiation are photosynthesised into plants in a growth media, such as soil in the fields or specifically prepared growth media e.g. in greenhouses.

**Feed.** The livestock industry has contributed largely to the development of rural areas and biochemical innovations such as the ensiling process of silage leading to the Nobel Prize received by A.I. Virtanen in 1945. In 2019, over 8,000 million kg of grass silage were produced in Finland. The future challenges in feed production are in maintaining the economic competitiveness in the changing climate and in fully exploiting the opportunities of novel technologies. With nutrient use, there are two major challenges: 1) the surplus of nutrients in regions of concentrated animal husbandry and 2) the loss of soil organic matter in crop production areas.

The role of perennial grasses in improving the soil quality and carbon sequestration has recently received much attention. The use of grass-based feeds in ruminant production at the expense of feeds suitable directly for human consumption is likely to increase in the future. Further, green biorefineries utilising grass as a sustainable raw material are also being developed.

Numerous feed materials of highly variable origin and composition are used for livestock. Fibrous forages can only be utilised by ruminants (cattle as the largest consumer but also sheep, goats, and reindeer) and horses while concentrate feeds are used for monogastric animals (pigs, poultry) and farmed fish. Concentrate feeds are also used to supplement forages in ruminant and horse diets.

By-products from the food, beverage and bioenergy industry have a well-established role in circulating the energy and nutrients they contain into the food chain when used as feeds. With increasingly sophisticated biorefinery approaches emerging, there will be novel fractions to be used as feed materials in the future. There is a clear urge to increase the domestic or even on-farm produced feeds due to economic, ecological and food safety risks related to imported feeds. The national feed self-sufficiency is generally very high, but certain special feeds, feed additives and protein supplements are largely imported. The attitude towards soya protein use has been particularly negative among the consumers of livestock products. Domestic alternatives such as rapeseed meal, faba beans and peas can partially replace imported soya protein, but the cultivation of high protein plants in Finland has stagnated. The success of the cultivation of high protein plants in the changing climate continues to be a challenge that urgently needs solutions.

The rapid development of technology continues to shape feed production and use. Novel technologies are being utilised in feed production, processing, analysing, diet formulation and delivering feeds to the animals. New tools such as automatisation, digitalisation, and sensory technologies provide support to farmers e.g. in securing high yields and the efficient use of nutrients in the varying weather conditions of the future. Increasing farm sizes create opportunities to invest in technology. In research, novel technologies related to genomic evaluation in animal breeding, and advances in omic technologies to help understand aspects of feed preservation, the gut microbiome and animal physiology (metabolomics) will contribute to increased efficiency in feed utilisation.

**Fertilizers.** The resource efficient use of various nutrient-rich biomasses, originating from agriculture, industry, and municipalities should always include the exploitation of both organic carbon and nutrients. The reasons for processing such biomasses may include several targets ranging from producing recycled fertilizer products and renewable energy to the mitigation of emissions and carbon sequestration into the soil. For instance, anaerobic digestion (AD) not only produces renewable energy in the form of biogas, but it also enables nutrient recycling via fertilization with digestate or post-processed fertilizer products.

The market for recycled fertilizer products is still underdeveloped and the economic feasibility of their production and use is low. However, the potential is large.

**Growing media.** Continuous urbanisation and the increasing production of leafy greens, soft berries and mushrooms have contributed to an increase in the demand for healthy, nutritious and vegetarian food. These elements also drive food production into protected indoor conditions. Controlled environment agriculture (CEA), takes place in greenhouses and plant factories and within those systems the cultivation relies on the use of growing media.

Globally, approximately 55 million $m^3$/year of growing media is used for the production of fresh vegetables, berries and flowers. This is expected to quadruple by 2050. Currently the three main media substrates used are peat, rockwool, and coconut coir. There is an increasing demand for the industry to find responsibly sourced growing media. From Finland's perspective, wood-based materials, either as virgin materials or as sides streams from the pulp and paper industry, are attractive. The situation can also be seen from the perspective of the need to find a use for "waste" materials that are proving difficult to dispose of or that are available in abundance. Papermill sludge and recycled paper can be seen as examples of the latter case. Other potential materials are available too, e.g. reed canary grass, and especially paludiculture which can combine the reduction of greenhouse gas emissions from drained peatlands through rewetting and biomass production.

New solutions must be compatible with key requirements. They must be responsibly sourced, compostable/recyclable and there must be a steady, economically viable supply. Reducing the industry's reliance on just the few materials that entire growing systems have evolved around needs a lot of research and development. It seems likely that in the future growers will use a greater range of materials as growing media, tailored to the demands of specific crop types and production systems.

# Functional ingredients for pharma, cosmetics, and nutraceuticals

Current and increasing trends in medicine include the prevention and early detection of diseases and customised treatments based on either small specialised molecules or biological medical products. Biological drugs are a rapidly increasing class of pharmaceuticals including antibodies, vaccines and gene therapy products. They comprise more than 50% of the new lead pharmaceuticals and they are typically produced in cultivated living cells in bioreactors or by molecular farming in plants. Recent market and regulatory trends are pushing cosmetics companies to look for natural alternatives to replace synthetic ingredients (e.g., parabens, aluminium-based products), either as drop-in ingredients (the same or very similar ingredients replacing a synthetic source with a natural one) or alternative ingredients that differ from the synthetic ingredient but fulfil the same function. Plants, microbes, algae, and other organisms found in nature synthesise a diverse range of bioactive, low-molecular-weight metabolites described as small molecules or natural products. At the same time, by-products from the food system and forestry comprise a rich source of bioactive compounds. These underutilised resources thus offer enormous industrial potential as pharmaceutical lead compounds or cosmetic ingredients.

**Pharmaceuticals.** New, better, and more precise pharmaceuticals are needed to combat existing and new diseases including future pandemics. Moreover, the development cycle for a new drug is currently far too long and expensive. Therefore, many of the new medicines have failed to be profitable for many pharma companies. The development cycle of new pharmaceuticals can be shortened using non-pharmacological interventions which take advantage of coupling more accurate and precise imaging technologies with precision interventions that utilise robotics, nanotechnology, or tissue engineering. Moreover, biotechnological production systems will be substantially improved through tailor-made host organisms (microbes, yeasts, algae, plant cells or fungi) and bioprocess development. Synthetic biology, strain engineering and automation together with modelling and artificial intelligence will have a huge impact on the whole development cascade.

It is expected that pharma business models will be reshaped in the coming years. Already at the moment many pharmaceuticals are approved to treat multiple chronic conditions or cancers, for example. Oncologics is the top therapeutic class of drug sales globally, followed by antidiabetics. However, the sales of drugs for autoimmune diseases and diabetes have experienced some of the largest growth in spending in recent years. In the future, more focus will be put on prevention and early detection instead of healing disease. Non-pharmaceutical interventions, including those focusing on behaviour modification (diet, exercise etc.), will be used to reduce or eliminate the demand for medications. Medication will be more personalised driven by artificial intelligence (AI) and other personal data-based solutions.

Over 1600 new drugs have been approved for clinical use between 1981 and 2019. 47% of them had biological origins. They are either biological macromolecules, vaccines, unaltered natural products, or natural product derivatives, often sourced from plants and microorganisms. The share of biotechnologically produced drugs will increase, and therefore the bioeconomy will play a crucial role in drug discovery.

**Cosmetics.** The growing use of cosmetics has increased the demand for scientifically validated bioactive ingredients, reflecting a trend towards greater consumer awareness and a growing interest in functional cosmetic formulations. Consumers are demanding more sustainable products with approved claims and transparency of the ingredients. This has encouraged companies to seek innovations and to demonstrate the evidence-based functionality of their products. Growth in the cosmetics industry has also embraced the demand for green products, i.e. cosmetics containing environmentally beneficial and naturally sourced ingredients. In the last five years a 175% increase in vegan branded cosmetics has occurred including also packaging materials. Here biotechnology can have an impact on the discovery of active ingredients and providing smart biotech-based, sustainable production systems.

Bioactive natural ingredients are likely to boost this market in response to demands from health-conscious consumers seeking to avoid exposure to harsh chemicals and to embrace sustainable production methods. Natural ingredients currently make up 25–30% of the total market, but this is predicted to double in coming years with particularly strong demand among consumers in China and India. To place this in context, the market for cosmetic ingredients is much smaller than the end-user market for cosmetics. Growth in natural and organic ingredients is part of a larger movement towards bio-based materials and chemicals, again driven by consumer preferences. Personal care and cosmetic ingredients face highly competitive price pressures, leading to the need for mergers with or the acquisition of competitors to achieve cost leadership by expanding technological innovation and diversification strategies.

**Nutraceuticals and wellness products:** Consumers are increasingly interested in tailored, personalised products to optimise health, physical and mental performance. At an industrial level, prebiotics, probiotics, antioxidants and PUFAs are the most produced and consumed dietary supplements. Vitamins are considered vital for the proper functioning of the human body and they also help in wound healing and prevention of various diseases. Additionally, a larger vegetarian population is increasing the need for vegan dietary supplements to support their nutritional needs.

The other important drivers for consumer choices are the environmental and social sustainability of the products. Underutilised resources such as algae and side streams from the food system, forestry and fish sector comprise a vast resource for producing sustainable, functional ingredients for health promoting foods, food supplements and nutraceuticals, e.g. for tackling metabolic disorders such as obesity and diabetes and increasing physical and mental well-being. Development and upscaling of processes and unit operations is essential to optimise the recovery of bioactive compounds (e.g., carotenoids, terpenoids, phenolic compounds and bioactive peptides) from these inexpensive renewable resources and industrial side streams. These bioactive-rich extracts can be used for high value-added applications and will help the circularity of industries nationwide. Cascade approaches aiming at extracting major portions (e.g., proteins, lipids, and polysaccharides) and minor compounds (e.g., colouring agents, polyphenols) deserve special attention for increased resource-efficiency and profitability on an industrial scale.

# Bioenergy, biofuels, and energy storage

The global energy supply system is currently in transition from one that relies on fossil inputs, with oil as the ultimate benchmark, to a system relying on non-polluting and non-depleting inputs that are dominantly abundant and intermittent. Optimising the stability and cost-effectiveness of the transition to a future system requires seamless integration and control of various energy inputs. The role of energy supply management is therefore expected to increase in the future to ensure that customers will continue to receive the desired quality of energy at the required time.

**Wood-based bioenergy** will be a vital part of the Finnish energy system in 2035. In 2019, the total energy consumption amounted to 378 terawatt-hours (TWh). Energy consumption decreased by one per cent from the previous year. The most important energy source were wood fuels with a 28% share of the total energy consumption. The use of wood for energy has increased from 111 TWh (2010) to 141 TWh (2019).

Although bioenergy is a mature technology and its efficiency has improved, there is still vast potential to improve the net yield of energy from biomass. For instance, recent studies show that dry matter losses in the supply system and storage can be reduced markedly. The efficiency of refining and energy conversion processes are improving in the forest industry and also in dedicated energy production. It is also evident that more wood is being made available for products and less will be used in energy conversion. Because the volume of bioenergy is huge, rather small efficiency improvements can increase the net energy outputs by many TWh. Therefore, the efficiency of bioenergy generation and use as a separate process and as a part of the entire energy system needs to be an area of focus by 2035.

**Balancing of power and heat grids.** In countries where wind and solar are expected to play a dominant role in the energy transition, the integration of these intermittent energy sources with the power grid places significant pressure on the grid operators concerning how to balance the grid. Furthermore, the renewable electricity from wind or solar is often provided at times when the demand is low, and the electricity has to be stored (e.g. in H2) or wasted. There is a huge market need to create solutions for industrial-scale, cost-effective electricity storage capacity; and biomass could play a role. Bioenergy is currently the major source of renewable energy in the world, while wind, solar and geothermal are the fast-growing alternatives. At best, the role of bioenergy can be highly complementary with wind and solar in the energy sector. Wind and solar electricity production will increase more rapidly compared to other renewable sources. However, bioenergy will continue to provide the bulk of heating and transport fuels for decades to come. Bioenergy, in its various forms, will eventually contribute to balancing the electricity grid, including bioenergy as one form of stored solar energy storage.

**Bioenergy enabling transition and debottlenecking hard to decarbonise sectors.** The role of bioenergy and biomass is changing, with the underlying fact that globally bioenergy is by far the largest source of renewable energy. The electricity sector is decarbonising faster than other sectors due to the multitude of cost-efficient options. For heat production, long haul transport and industrial applications, which are hungry for hydrocarbons and high temperature heat, the situation is not so easy. There biomass and biomass residues will play a significant role, first as energy carriers suitable for drop-in use. In practice this means bio-coke, biogas, and liquid biofuels especially for long-haul transport. These energy carriers can already now be produced in large quantities and can be utilised in the existing infrastructure. Secondly, combined with clean renewable electricity, biomass can offer a sustainable source of carbon for drop-in energy carriers in those hard to decarbonise sectors.

**An enabler for negative emission concepts.** Biomass use, more specifically combining the use of biomass resulting in a $CO_2$ stream together with CCS (carbon capture and storage) offers the potential for a technological solution removing $CO_2$ from the atmosphere on a lifecycle basis. The advantage with Bio-CCS or BECCS, is that $CO_2$ can be removed at the same time as producing energy or products and thus also creating positive revenue streams for the concept. As most of the IPCC scenarios incorporate at least some if not significant amounts of carbon dioxide removal depending on the level of overshoot, the need for these ready-to-be-deployed technologies will be emerging before 2040. The first applications of this technology are expected to be seen before 2030, especially in relation to biogenic fractions of waste.

# Nature-based well-being services

Nature amenities or cultural ecosystem services as they can also be defined provide a wide range of services. The added value of these Finnish bioeconomy services totals EUR 1.9 billion annually. Here we focus on the three most important categories of cultural ecosystem services: nature-based tourism and recreation, green and blue care services and housing and work-related services both indoors and outdoors.

**The nature-based tourism and recreation** (NBT) service sector has been rapidly growing. It covers both self-guided recreational use of nature, producing public health benefits, in addition to purchasing products and services of small and medium sized entrepreneurs. Population growth and urbanisation will lead to an overall increase in demand for and participation in nature-based tourism and outdoor recreation (NBT). Unprecedented growth may lead to the overuse of natural attractions negatively affecting nature resources, and to crowding leading to reduction in the quality of nature-based experiences in specific locations. Growth is anticipated to take place both in protected areas and also in commercial forests that are easily accessible for people. This will increase the need for new infrastructure and other recreation services on-site. Moreover, the increased use will reinforce the need to for improved planning for recreation and tourism in land-use and forest planning. This will strengthen the demand for economic incentives for private landowners to provide and sustain attractive environments for recreation and tourism in various locations. In state forests and municipal forests in Finland this development will lead to social and political pressure to better balance timber production and climate mitigation targets with producing more amenities for public health and well-being.

Regarding the productisation of forest amenities and increasing the value of assets there is an increased demand for product customisation and understanding differentiated markets. In order to realize the growing market potential and considerable growth in international demand, the need for the diversification of high-quality services is eminent. This translates into the creation of new types of services (soft adventure, packaged products, guidance, products for urban users etc.). One of the key tools to developing a nature-based service sector is through digital services. i.e. developing electronically shared and digitally augmented nature experiences as well as virtual nature experiences at home in built-up environments with poor access to nature environments. More generally, digital services are important in renewal of NBT and outdoor recreation sector, also ranging from improved marketing and access to tourism and recreation services, but also from learning, accessibility, and safety perspectives. NBT is strongly impacted by climate change; in particular, winter tourism and snow-based activities will be challenged by the changing environmental conditions. This will strengthen the attractiveness of the northernmost part of Finland for tourism. However, technological advancement in the transport industry may reduce the costs and improve the accessibility of nature-based destinations worldwide. In the future increased environmental awareness together with climate change may reduce the acceptability of flying and increase acceptability of travelling by rail. Moreover, regional development and urbanisation in Finland may increase and shift the demand for recreation and NBT more to southern Finland, where nature is easily accessible for both domestic and international visitors.

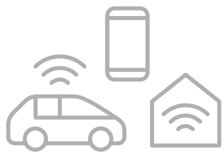
**Green and blue care** are increasingly receiving attention as means to support human health and well-being. These services use natural environments and nature-based activities in a conscious and goal-oriented way to enhance rehabilitation and social inclusion, for example. In recent years business models including training and quality marks for these services have been created by a number of research and development projects in Finland and Europe. Green and blue care services are relatively novel service types, although some approaches such as horticultural therapy and social pedagogical horse activities have been known for a long time. Nature-based services are increasingly recognised as a means for care, rehabilitation, and social inclusion responding to increased demand due to various social and health problems among different client groups. There are already service providers in these sectors and different means of obtaining and financing these services. More research is needed to reveal the impacts of nature on human well-being (including the role of microbes), and their value for individual and public health to mainstream these services in social and health care. Due to the aging and growth of social and health problems in our society, the finance of these services remains insecure.

**Housing and work-related services** refer to services provided by green infrastructure in housing and work-related environments**.** The current lifestyle trend that supports "being closer to nature" and overall appreciation of health and (physical, mental, and social) well-being will continue and strengthen. Engagement in sports and being physically active in nature will increase in all population segments. This may be seen in an increase in nature related activities in everyday life inside and outside homes, gardens, playgrounds, and workplaces. It will have implications for the planning of housing, housing areas, public institutions (schools, day care, retirement homes) and green infrastructure. Furthermore, this will lead to important implications in terms of finding sustainable and circular solutions based on biomaterials in housing as well as planning and developing a green environment. The use of electronically shared and digitally augmented nature experiences as well as virtual nature experiences at home or in public institutions (such as retirement homes) will increase in built-up environments with poor access to nature environments.

Overall, the demand for nature as a part of human well-being will become stronger, while the quality of the environment in many parts of the world will get worse due to overpopulation leading and the overuse of some recreation and touristic areas. Finland as a sparsely populated country is considered to have pristine nature and pure silence, providing new business opportunities in NBT and other nature-based services. From the global perspective, improving sustainability will be an important factor in improving the competitiveness of these services in Finland. In this work the secured availability of pure, high quality, and authentic nature environments, as well as safety, and low-carbon solutions will also play important roles. Along with the increased demand for natural resources and technologies and social and the cultural diversity of the service users, new ethical dilemmas as well as questions of ownership and inclusion/exclusion may emerge. The importance of environmental education not only as a potential employer, but also in enhancing broader societal awareness of the amenity benefits of nature will be an important cornerstone in the long-term development of the sustainable bioeconomy in Finland.

# Data and analytics

Digitalisation is one key enabler of the bioeconomy transformation. It will contributes to two key steps in the long-term development of the bioeconomy up to 2035: 1) RD&D of future technologies, and 2) operations of the bioeconomy value chains. These contributions come in different forms of efficiently using (big) data analysis techniques, continuously developing computing power, artificial intelligence (AI) and digital twins, and the new service models around Internet of Things (IoT), cloud services and XaaS. The key products within the bioeconomy are data and its utilisation.



Data sharing between value chain actors is expected to be more widely accepted. Data will become an integral part of bioproducts: transparency and traceability will be important product features for customers and thus the need to carry data with the material will be cascaded to the production chain. On the other hand, recycling and measurement of the biobased share of products necessitates the addition of data attributes to them. Open data will play a big part, especially in the development of new products and processes.

For these reasons, data will be a significant future product for all value chain players. Research organisations will create dedicated datasets for industry to be used as has been the case always, but also, they will have more flexibility to create business by combining datasets into databases. Process equipment and system providers will be able provide engineering data with their equipment or system to engineering companies and their end customers to be used in process design, operations optimisation, and asset management. Material and final product producers will be able to add value to their products through data-based features of the products, e.g. related to environmental performance. Consumers will further pass on the product data with the product when it is recycled. Around this data, reliable and trustworthy data management and storage services, software and hardware are needed, creating business opportunities for current actors in the field or to new companies.

**Digital twins**, based purely on crude data, on physics, or on combination of them, will be commonly used in industry in 2035. They will created during process development and will live with the production plants throughout the plant's lifetime. These digital twins participate in the data generation and measurement systems. They will also support the decision making at strategic, tactical, and operational levels during the life cycle.

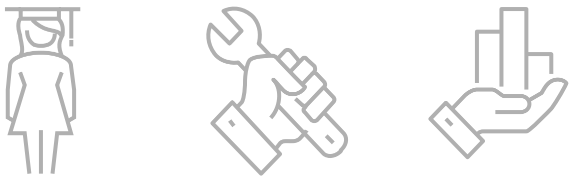
The potential estimated for integrated control systems to improve industrial energy efficiency in existing production systems will be fully utilised, and the advanced decision support and control systems that have been proven to give efficiency gains will be implemented more broadly in bioeconomy production processes. This will make the bioeconomy very energy efficient.

**The as-a-service (aaS)** model will be a common operating model at different levels of data analysis and decision support for the bioeconomy. For example, laboratory data and information storage and management will be mainly handled by external service providers operating with a service model or, advanced process controls (both in the cloud and at the edge) will be required to be remotely configurable and updated/taught leading to the possibility for an aaS model or, digital twins that are hosted on a web-portal and accessed by anyone with rights through a web-browser.

The key asset Finland has in data analysis and its conversion into information is the country's long history in the P&P industry and the development of biomass utilising technology. The understanding gained over the years of the feedstocks and the processes and the conversion of this knowledge is a crucial aspect in developing competitive analysis products.

# Technology and service exports

The process of deploying new technologies, concepts and production methods and practices develops competences and capabilities in parallel to investing in new production facilities. The investment in new process or method requires the production equipment itself but all kinds of auxiliary services such as consulting, engineering, project management, R&D, and manufacturing of machinery etc. Further use and widespread safe operation of these new concepts also requires education and training. All these are also export products in addition to the products and goods from the process industry itself. The technology industry, forestry and chemical industry together represent 60% of the revenues of Finnish service exports.



The Finnish mechanical engineering industry, manufacturing processes, and equipment for forestry, pulp and paper mill unit operations, harvesters, chippers etc. have also traditionally been global players in this field that in recent decades have also increased their service and aftersales activities. Additionally, consulting and engineering companies have been recognised players in this field and are able to export the knowledge, concepts, and practices as well as the insight related to best practices which have been industrially proven in Finland. These immaterial exports can also be export of concepts and production practices, where Finnish operators design, assemble and set up a production unit, e.g. a piggery with good practices or forest raw material harvesting value chain, train their users and can finally be an essential part of the operation and maintenance of the unit. This is applicable also to RDD&I services and IPR in all related steps of the innovation value chain including providing relevant education.

# Contributors

**VTT Technical Research Centre of Finland**

Antti Arasto
Ali Harlin
Janne Hulkko
Eemeli Hytönen
Tiina Liitiä
Emilia Nordlund
Kirsi-Marja Oksman-Caldentey
Timo Pulli
Tekla Tammelin
Tarja Tamminen

**Editors**

Antti Arasto
VTT Technical Research Centre of Finland
antti.arasto@vtt.fi

Antti Asikainen
Natural Resources Institute Finland (Luke)
antti.asikainen@luke.fi

Anu Kaukovirta
Natural Resources Institute Finland (Luke)
anu.kaukovirta@luke.fi

**Natural Resources Institute Finland (Luke)**

Antti Asikainen
Sanna Finni
Henrik Heräjärvi
Anu Kaukovirta
Titta Kotilainen
Sari Mäkinen
Marketta Rinne
Liisa Tyrväinen
Katariina Soini

# About VTT & LUKE

**VTT Technical Research Centre of Finland Ltd** is a visionary research, development, and innovation partner. It is one of Europe's leading research institutions. Our task is to advance the utilisation and commercialisation of research and technology in commerce and society. Through scientific and technological means, we turn large global challenges into sustainable growth for businesses and society. Our research is guided by the company's lighthouse themes: climate action, resource sufficiency, good life, safety and security and industrial renewal.

**Natural Resources Institute of Finland (Luke)'s r**esearchers and specialists provide new solutions towards the sustainable development of the Finnish bioeconomy and the promotion of new biobased businesses. Together with our partners we will build a society based on bioeconomy.

The sustainable use of natural resources calls for advances in know-how and new business models, as well as close collaboration. We bring together experts in natural resources and sustainable food production. This makes us one of the most multidisciplinary research institutes in our industry worldwide.

Luke also carries out statutory government work. We monitor natural resources, certify plant production, inspect control agents, store genetic resources, produce data on greenhouse gases, support natural resource policies and produce Finland's official food and natural resource statistics.