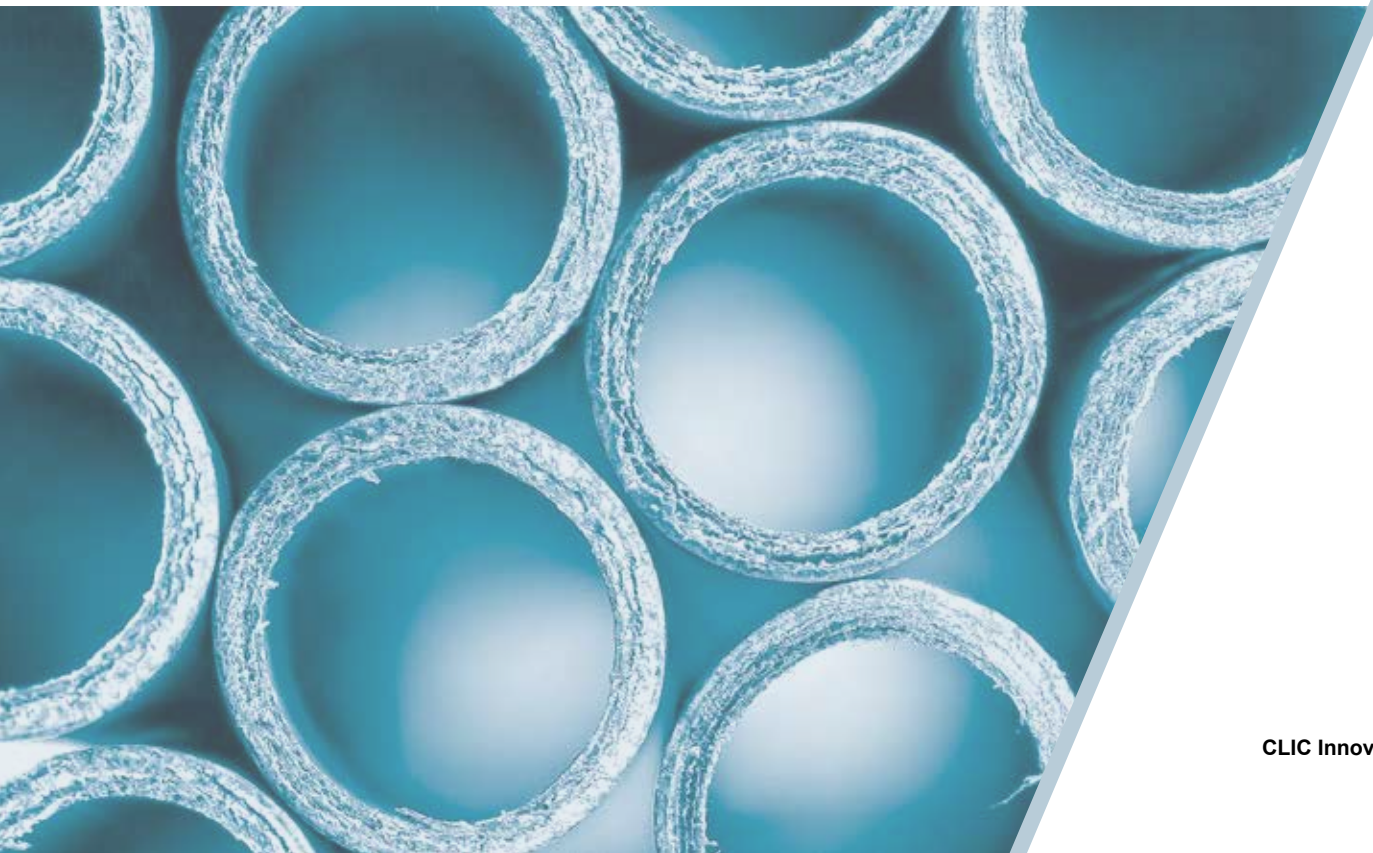
STRATEGIC RESEARCH
AND INNOVATION AGENDA

Forest-Based Circular Bioeconomy
Added value materials and chemicals from wood fibres

CLIC INNOVATION LTD

Contents



Executive summary

This Strategic Research and Innovation Agenda (SRIA) has been developed within the network of CLIC Innovation's owners, comprising a broad group of stakeholders representing business and research. Supporters of this agenda include leading global companies in the forest industry, chemical industry and technology industry, as well as several universities and research institutes.

The purpose of the Strategic Research and Innovation Agenda is to outline the priority areas for joint research and development in wood-fibre-based circular bioeconomy.

Companies in the CLIC network have identified four key application areas where they are market leaders and develop their businesses further. These application areas are the following:

- **High-performance fibres** covers a wide range of technologies and processes which transform raw materials from forest into high-added-value fibres for different end applications
- **Packaging materials** boosts increased use of bio-based raw materials and aims at innovative packaging materials with new properties
- **Biocomposites** aims at enabling biocomposites (especially wood-polymer composites) to become a compelling material alternative in the markets currently dominated by plastics and glass fibre-based composites, by developing new, highly performing natural fibre composites
- **Bio-based chemicals** targets reduced dependency on fossil-based raw materials by developing high-performance, sustainable wood-based biopolymers and biochemicals.

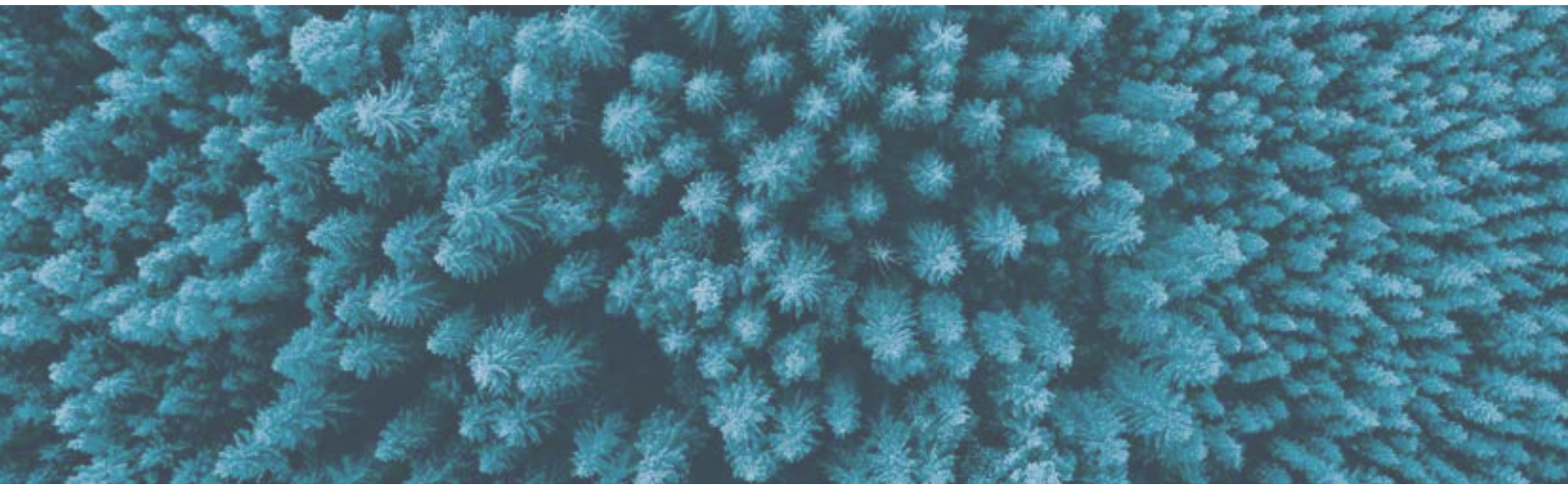
Processing, materials performance and circularity are aspects where joint research will serve a large number of businesses and where collaboration is especially beneficial.

Supply of sustainable raw material is in the core of a successful forest-based circular bioeconomy. The goal is to develop resilient and resource-smart forestry to meet the demands from the growing circular bioeconomy and to simultaneously secure the sustainable multipurpose use of forests.

Digitalisation is seen as an enabler for new solutions and approaches. The regulatory landscape affects the market of existing products and can influence the development of new ones. Hence, monitoring of and influencing the development of regulations are integrated into the research and development work.

As sustainability is one of the core values of CLIC Innovation and its owners, life cycle assessment is seen to be an important continuous task while developing new solutions. In addition, material safety in different applications is kept in mind including application-specific regulatory matters. Moreover, there is a need to consider new business and cooperation models within the value network while new products and new service models are created.

To generate novel solutions and manage complex issues, extensive collaboration between players and sectors is required. Collaboration is also the basis for the development of new wide expertise in forest-based materials and chemicals. Academic and research institutions have a pivotal role in linking such collaborations, but public and private sector players also have key roles.



Foreword

CLIC Innovation is an open innovation cluster with a mission to facilitate creation of breakthrough solutions in three areas: bioeconomy, circular economy and energy. CLIC Innovation aims at speeding up the production and commercialisation of new knowledge by initiating and managing solution-oriented collaborative projects covering the entire field from basic research to demonstrations. As a public-private-partnership, CLIC Innovation uniquely gathers together industrial and academic competencies to achieve its targets.

Building Strategic Research and Innovation Agendas is the primary tool used at CLIC Innovation to set common targets and to define focus areas for a significant number of actors. The first SRIA for bioeconomy was developed at CLIC Innovation in 2018. To keep the SRIA up to date and relevant, its content was recently revised and the document you are now reading was produced.

Circular bioeconomy refers to an economy that relies on renewable natural resources to produce food, energy, products and services and is the renewable segment of the circular economy.

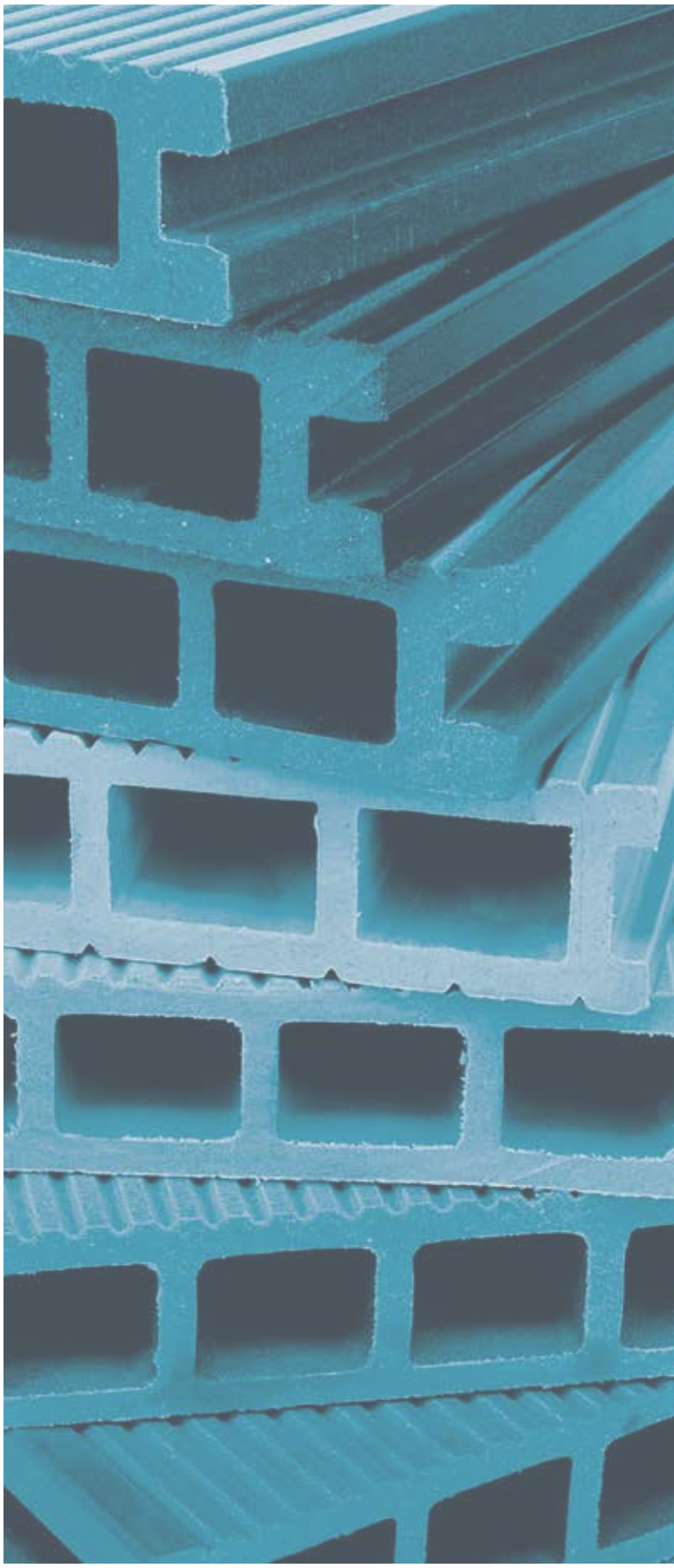
The owners of CLIC Innovation have defined the development of novel added-value materials and chemicals from wood fibres as the main focus for the circular bioeconomy portfolio of CLIC Innovation. The growing global need for sustainable solutions is giving significant rise to new business opportunities, and shareholders of CLIC Innovation have extensive knowledge and leading competence in wood-fibre science and applications, to mention the main reasons behind the focus area.

This Strategic Research and Innovation Agenda outlines the priority areas for joint research and development in wood-fibre-based circular bioeconomy. The following application areas are in the heart of the SRIA due to their industrial relevance:

1. High-performance fibres
2. Packaging materials
3. Biocomposites
4. Bio-based chemicals

Joint research is especially needed in the crosscutting topics of material processing, material and product performance as well as enhancing circularity.

We are committed to work together and are actively inviting other stakeholders to join and participate in the activities that originate from this SRIA.



Addressing global challenges

Europe aims to become the world's first climate-neutral continent by 2050. It has set ambitious targets to fight against climate change and to transform the Union into a resource-efficient and competitive economy. To guide the way to a sustainable economy, the European Green Deal roadmap was created. The tackling of climate change and transformation of European economy claims actions from all the industrial sectors. (European Commission, 2019)

Global long-term development requires a controlled transition from the current, unsustainable fossil-based economy to a sustainable, circular bio-based economy. An important basis for the transformation is the UN Global Goals for Sustainable Development which are pointing towards a bio-based economy based on resource efficient processes, renewable raw materials and principles of circularity (United Nations). The 2018 update of the European Bioeconomy Strategy aims at accelerating the deployment of a sustainable European bioeconomy so as to maximise its contribution towards the UN Sustainable Development Goals. The Strategy Update focuses on strengthening and scaling up the bioeconomy sector and deploying local bioeconomies in Europe. (European Commission, 2018)

The turnover of the total bioeconomy, including food and beverages and the primary sectors, i.e., agriculture and forestry, amounts €2.3 trillion in the EU-28. Roughly half of this turnover is accounted for by the food and beverage sectors, and almost a quarter of the turnover is created by the primary sectors. The other quarter is created by the so-called bio-based industries, such as chemicals and plastics, pharmaceuticals, forest industries, textiles, biofuels and bioenergy. (Piotrowski et al., 2019)

The forest-based sector has an important role in European economy. It accounts for around 7% of the EU's manufacturing GDP and employs over 3.5 million people boosting also local business development and growth of small and medium-sized companies (FTP, 2013), (CEPI, 2020). The total employment in the European bioeconomy in 2016 was about 18.6 million persons with primary biomass production (agriculture, forestry and fishery) as the biggest contributor (55%). (Piotrowski et al., 2019)

Figure 1. UN Sustainable Development Goals (United Nations)

Forests and the related industries are the cornerstone of the European bioeconomy. Sustainably managed forests work as carbon sinks, and bio-based materials and products produced from wood decrease our dependence on fossil resources contributing to both mitigating climate change and solving the Plastics Challenge. Moreover, biodegradability in some applications can strongly contribute to restoring ecosystems and biodiversity.

Climate neutrality and circular economy require actions from all the sectors. Forest sector has applied circularity in its processes for a long time and is strongly boosting circularity in the whole value network by applying recycling principles, material efficiency, and cascade use of materials. The foundation for the entire sector lays in sustainable forest management and sourcing which enable biodiversity in forests but also resource-efficient use of the valuable raw materials.

Realisation of the possibilities of the circular bioeconomy requires strategies, research, innovations, and investments as well as cross-sectoral collaboration to enable systemic changes. What we need is a wide set of actions to enhance the capacity to turn the innovations into products and services sustainably and economically. The development of forest-based materials, products and services is fundamental to such a conversion.

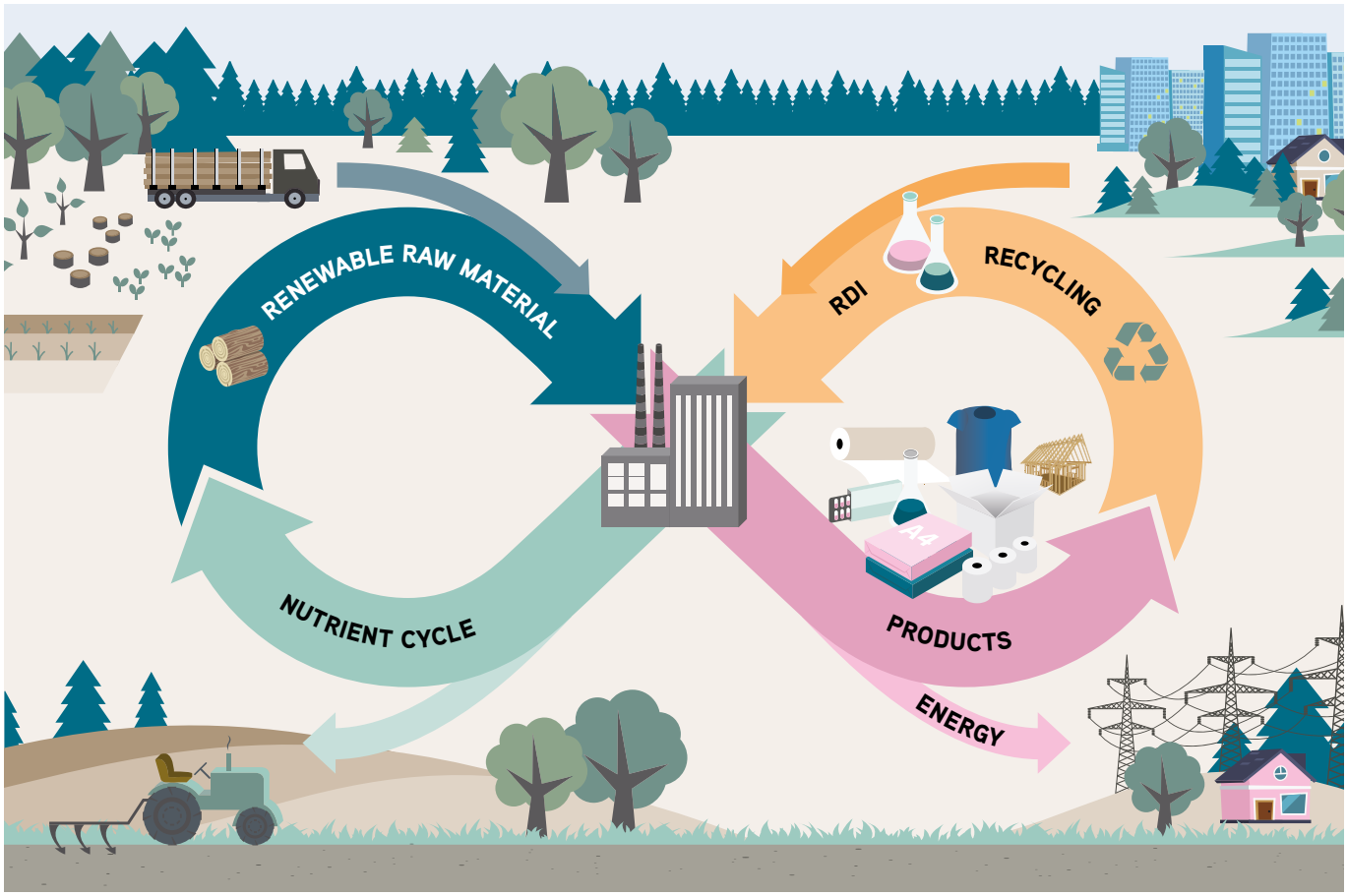


Figure 2. Circular bioeconomy approach of the forest-based sector (further modified from the original figure of Finnish Forest Industries Federation).

Vision

Added-value wood fibre is the preferred, sustainable choice in the growing global market of materials and chemicals.

In the future, many products will be efficiently manufactured from materials or chemicals that are based on renewable, sustainably managed forest resources. These biomaterials and biochemicals also have a range of new functions that we are completely unaware of today. The functions and product attractiveness are so compelling that they have become the first choice of consumers. Resource-efficient and sustainable manufacturing processes of the novel materials, chemicals and products have been implemented. To maximise the capacity of the materials to store carbon, the long lifetime is kept as an important design aspect, and reuse and recycling principles are integrated into the development to prolong the carbon cycles. Developed business models have resulted in extensive cooperation throughout the value network.

The net value and export revenue created by the Finnish wood-based fibre value network have increased significantly. New high-value products with long lifetime are widely spread on the market. By 2030, Finland will be the global innovation and knowledge hub for wood fibre-based innovations.

Welcome to a future, in which the forest-based sector is leading the way towards a circular bioeconomy!

Focus areas for research and innovation

The global challenges are systemic and entail solutions which are beyond the resources of any single organisation. Companies in the CLIC network have identified four key application areas where they belong to the market leaders and develop their businesses further. The application areas are: high-performance fibres, packaging materials, biocomposites and bio-based chemicals. Processing, material performance and circularity are aspects where joint research will serve a large number of businesses and where collaboration is especially beneficial.

The sustainable use of forest resources is the core of a successful forest-based circular bioeconomy. Managing forests sustainably means to manage and use the forests in such a way that future generations will benefit from forests in economic, social and environmental terms. The diversity of forest nature creates the basis for the growth of forests and is thus a prerequisite for the economic use of forests. Multipurpose forest planning aims to balance the complex and sometimes conflicting sets of demands on forests, for the benefit of all.

Digitalisation is seen as an enabler for new solutions and approaches. The regulatory landscape affects the market of existing products and can influence the development of new ones. Hence, monitoring of and influencing the development of regulations are integrated into the development work. As sustainability is one of the core values, life cycle assessment is seen to be an important continuous task while developing new solutions and also material safety in different applications is kept in mind, including application-specific regulatory matters. Also, there is a need to consider new business and cooperation models within the value network while new products and new service models are created.

Holistic sustainability aspects – such as environmental, economical, cultural and social sustainability and scalability – must be taken into account from the very beginning of the development of novel fibres, fibre materials and fibre-based structures as well as their production processes. Material development supported by ecodesign is aiming at long lifetime, reuse and circulation of materials and products.

To generate novel solutions and to manage complex issues, extensive collaboration between players and sectors is required. Collaboration is also the basis for the development of wide expertise in forest-based materials and chemicals. Academic and research institutions have a pivotal role in linking such collaborations, but public and private sector players also have key roles.

This Strategic Research and Innovation Agenda has been developed within the network of CLIC Innovation's owners, comprising a broad group of stakeholders representing business and research. Supporters of this agenda include leading companies in the forest industry, chemical industry, technology industry, as well as universities and research institutes. In the next chapters, we will present a more detailed view of the chosen four application areas: high-performance fibres, packaging materials, biocomposites, and bio-based chemicals. The objectives of the joint research are defined and market opportunities explored. Most importantly, focus areas for research and innovation are described to point out the future actions needed.

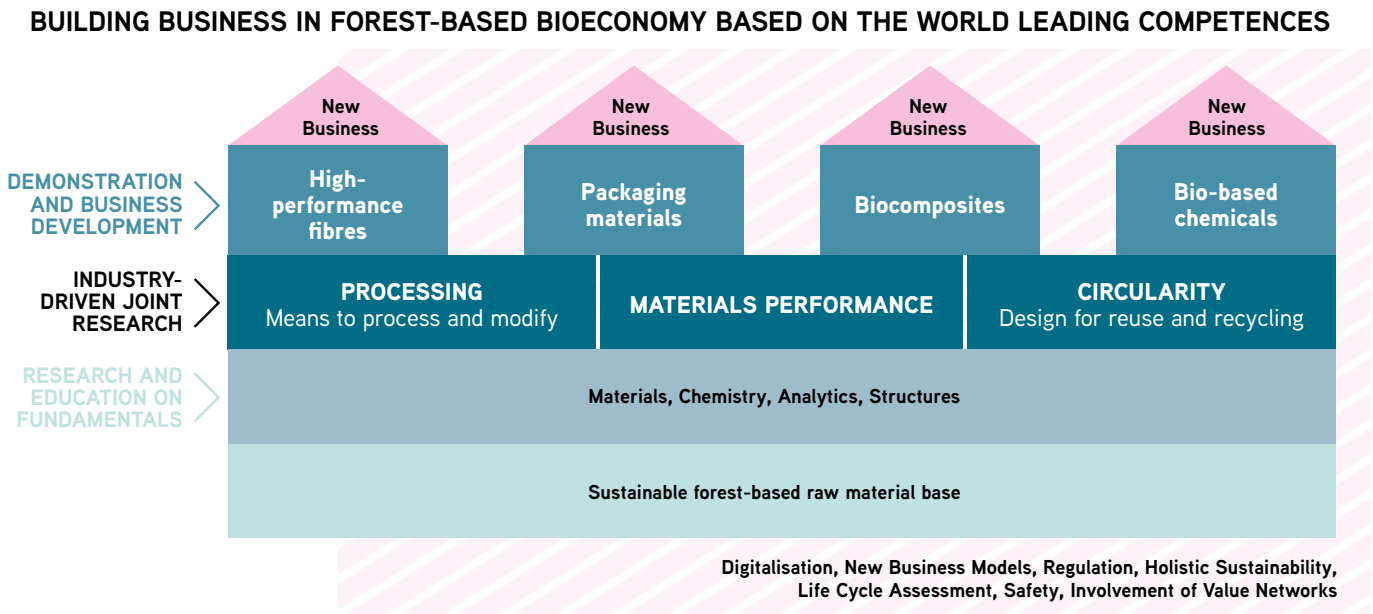


Figure 3. Spearheads and basis of the Strategic Research and Innovation Agenda of the Forest-Based Circular Bioeconomy at CLIC Innovation.

HIGH-PERFORMANCE FIBRES

Objective

The objective is to develop functionality and performance of wood-based fibres and fibre-based materials to enable their sustainable use in novel value chains or to significantly boost their use in current value chains. Development of wood fractionation technologies to support performance-fibre development to enable the added-value use of all wood components is also aimed at.

The theme “Performance fibres” covers a wide range of technologies and processes which transform raw materials from forest into high-added-value fibres such as high-performance kraft-pulp-based fibres for different end applications, novel sustainable nonwoven and woven textile grade fibres, reinforcement fibres, or new barrier and/or fibre materials for packaging applications.

In order to fully utilise the potential of the wood-based raw materials, new process innovations and wood fibre-based materials need to be developed for a broad spectrum of end-use applications. Technically, economically and environmentally feasible processes and materials are aimed at. In addition, principles of circularity must be followed, meaning that all fractions of the incoming biomass are valorised and that reuse and recirculation aspects are included in the material design.

Market opportunities

An increasing number of global brand owners have announced their efforts for changing raw material base towards bio-based or recycled materials. The existing fibre materials as such are well suited to a part of the increased demand. A substantial potential lies, however, in the development of performance of current fibres and fibre materials for both current and novel value chains.

The production of paper and board was 92.2 million tonnes and market pulp 14.4 million tonnes in 2018 (CEPI, 2019). Investments are undertaken to widen the application areas for wood fibres e.g. to textile fibre production. Textile and clothing industry is shifting towards sustainable and circular raw materials and production as well as to high added-value products opening new business for wood-based fibres. As will be described in the chapter on Biocomposites, market opportunities for wood-based fibres in composites are also growing fast.

Production of plastics reached almost 360 million tonnes globally and 62 million tonnes in Europe in 2018 (PlasticsEurope, 2019). Global bioplastics production capacity is set to increase from around 2.11 million tonnes in 2019 to approximately 2.43 million tonnes in 2024. Bioplastics are used in an increasing number of markets, from packaging, catering products, consumer electronics, automotive, agriculture/horticulture, and toys to textiles and a number of other segments. The primary market for bioplastics remains packaging with more than 53% of the total market in 2019, but the diversification of applications for biopolymers is seen due to e.g. emergence of innovative materials and increasing demand for sustainable solutions. (European Bioplastics, 2020) Raw material for these uses can come from renewable raw material or residues or sidestreams of the forest industry processes.

Focus areas for research and innovation

Wood fibres have unique properties due to their natural composite structure. When separated in pulping, the resulting cellulose fibres can be used for many products. Pulp fibres do not, however, meet all the requirements of material processability and/or performance that are defined today through the fossil-based fibres or polymers. Thus, broadening of the property space of the wood-based cellulose fibres is needed.

The properties of the fibres can be modified through fractionation, modification and purification processes. Therefore, advanced fractionation, separation and purification methods resulting in high-performing fibres and enabling the added-value use of all the wood components should be searched for. Furthermore, research to improve the fibre properties in pulping and bleaching processes and to increase the process specificity and efficiency is needed.

Innovative means for broadening the functionality and performance of fibres and fibre-based materials can promote the use of wood-based fibres in current and new end uses. Novel fossil-free chemistry, physical methods and biotechnology and their combinations could be considered as examples of tools for fibre and fibre material property enhancement. Novel structural fibre-based materials with extraordinary properties could be developed based on e.g. structure-function understanding. The potential of material modelling and various digital tools should be fully exploited in the development.

THE R&D TOPICS IN FOCUS INCLUDE

Processing

- Advances in specificity and efficiency of unit processes in fractionation, separation, purification and post-processing of wood-based cellulose fibres and processing of side-streams
- Development of new process modelling and measurement technologies
- Development of novel sustainable, simple, and scalable process concepts with good performance
- Advances in processing chemistry including tailored separation and fractionation matrices

Functionality and performance

- New application areas for materials from fibres and other wood components
- Material performance in end-use applications
- Novel fibre-based structures to enable new functionalities
- Hybrid material structures including improved compatibility with non-cellulosic materials
- Fibre modification in novel solvents
- Use of advanced digital tools in fibre property development

Circularity

- Design for reuse and recycling of novel materials, their combinations and structures to meet the needs of specific end uses
- Recycling of the novel materials and their combinations
- Recirculation and valorisation of processing side-streams in a mill environment or in value-chains
- Increase in the circularity of current fibre products

PACKAGING MATERIALS

Objective

The objective is to increase the sustainability of packaging materials and thus decrease the environmental burden caused by the growing use of packaging e.g. in eCommerce. In order to ensure high performance, increased sustainability across the value network and high degree of circularity, a holistic but in-depth understanding of the sustainability of fibre-based packaging is needed.

Increased use of bio-based raw materials is targeted while innovative packaging materials with new functionalities are aimed at. Potential of complex structures and hybrid materials is explored. Safety and acceptability issues are kept in mind when developing new solutions. To enable cascade use of the products and materials, circularity is taken as a key aspect already early on in the development. Reliable production including the conversion or post-processing of materials is targeted focusing especially on packaging related applications.

Market opportunities

The total value of the global packaging market in 2016 was USD 850 billion from which paperboard represents 36% and flexible paper 6%. The share of plastics, rigid and flexible, was 34%, thus being the second-most used material used for packaging. However, over the recent years, plastics have been enjoying faster growth compared to paperboard or paper in packaging. Latest analyses show the market size for packaging to be USD 917 billion in 2019. The growth is estimated to be around 2.8%, reaching USD 1.05 trillion in 2024. (Smithers, 2019)

Global megatrends such as GDP and population growth and urbanisation suggest that the need for packaging material will continue to grow. This is further supported by factors such as eCommerce, demand for packaged food and environmental awareness. Retail eCommerce sales in 2019 was USD 3535 billion and the estimations predict the sales to be more than USD 6500 billion in 2023 (Statista, 2020). The market size of the global food packaging was estimated to be USD 303.26 billion in 2019 with an annual growth of 5.2% until 2027 (Grand View Research, 2020).

Packaging is the main market sector for plastics use. The demand for new alternatives for plastics which is supported by regulatory affairs has recently created new opportunities for fibre-based packaging materials. Easy recyclability, existing collection infrastructure and in many cases also biodegradability makes fibre-based materials an attractive alternative.

Focus areas for research and innovation

Materials research and development is the most important enabler for addressing the current challenges and opportunities. There are several functionalities which need attention when aiming at substitution of plastics in packaging applications. Barriers for food packaging is the most important development area.

Although the recycling rate of fibre-based packaging is excellent today – for paper and board in the EU-28 around 85% (Packaging Europe, 2019), it is important to ensure recycling without too much down-cycling or loosing the fibre properties in the future as well. Cascade use is the key as the spectrum of bio-based products and applications broadens. New functionalities for fibre-based packaging are created by layers or other structures which may pose a challenge in terms of recyclability and biodegradability. Therefore, design for recycling is important. Additionally, for the future circular economy of the packaging materials, we must also aim to improve the entire recycling system, sidestream usages and related processes.

In the research and development of packaging materials, attention must be paid to addressing the expected future developments in regulation and consumer awareness. Product safety standards are tightening and some limitations to raw material basis might arise, both requiring efforts from the research community.

THE R&D TOPICS IN FOCUS INCLUDE

Processing

- Novel processes to produce fibre-based packaging solutions including novel performance fibre approaches
- Processes for creation of new functional components and features in fibre-based packaging
- Resource efficiency through sustainable chemistry
- Material modelling to continue the advancement of material efficiency
- Development of processability, post-processing and convertability of the novel packaging materials including pilot and production-scale machinery
- New raw material alternatives e.g. through utilisation of carbon capture and storage (CCU) technologies for CO2 neutral production or side streams
- Development of automation via intelligent systems including techniques for on-line process and product analytics and robotics
- Development and ramp-up of new business and process concepts to enable production and use of novel fibre-based packaging concepts

Functionality and performance

- New types of cellulose-based packaging materials including bio-based emulsion barriers
- Use of novel renewable, recyclable and preferably biodegradable raw materials including cellulose and its derivatives in films and coatings for packages
- Functionalities in packages such as moisture tolerance, grease barrier properties, elongation, and shrinkage
- Interactions between material components as well as development of novel hybrid materials and structures enabling new or developed functionalities
- Compliance with packaging regulation, including safety and customer and market acceptance

Circularity

- Materials and combinations of materials designed for recycling including both hybrid and layered materials
- Evaluation of mono-materials implications on circularity
- Recycling processes, compliance with the current recycling and circular economy design principles of fibre-based packaging, especially addressing the needs of eCommerce
- Identification of innovative ways to re-use fibre-based packaging
- New end-uses for recycled materials
- Analysis, development and demonstration of solutions for the whole life cycle of packages
- Measurements and evaluation principles for environmental performance e.g. biodegradability, compostability, environmental compatibility, and product safety

BIOCOMPOSITES

Objective

The main objective is to enable biocomposites (natural fibre composites, especially wood-polymer composites) to become a compelling material alternative in the markets currently dominated by plastics and glass fibre-based composites. This is achieved by developing new, highly performing natural fibre composites to fulfil market needs. Circularity is supported by integrating ecodesign aspects into the development. To reduce the environmental footprint of biocomposites, the use of materials from side streams or wastes as part of biocomposites is aimed at. Furthermore, the development of completely new application fields for biocomposites and new innovative new business models are on the agenda of industry.

Market opportunities

As legislation and changing consumer behaviour drive increasing demand for bio-based solutions to replace plastics, the opportunities for natural fibre composites will also increase. Global market for natural fibre composites is expected to reach USD 10.89 billion by 2024 with a growth rate of around 11%. North America is still the leading market, which is not expected to change within the coming years (Grand View Research, 2018). According to nova-Institute, the biocomposite (including wood and natural fibre composites) production in Europe reached 410.000 tonnes in 2017. In Europe the market has been estimated to grow around 3% annually, with highest growth rates (30%) in applications such as technical applications, furniture and consumer goods which are mainly injection moulded. (nova-Institute, 2017) This means that a higher level of market penetration is to be expected in the future for natural fibre composites.

Currently the most-used application area for natural fibre composites is the construction industry followed by the automotive industry. Other sectors like sporting equipment and consumer goods are also gaining interest. Wood fibre composites dominate the market covering more than 50% of the total natural fibre composite market (Grand View Research, 2018). Wood fibre composite granulates for injection moulding are produced and offered by global players and are becoming more attractive for companies searching for more sustainable alternatives to plastics. The development of applications and production methods will lead to wood fibre composites being increasingly used for applications beyond the traditional ones like decking or automotive parts.

New market opportunities will be influenced by the ability of the industry and infrastructure to meet demands for replacing plastics with more environmentally friendly options, material-first approach to process development, recycling processes including collection, identification and sorting, and reprocessing of recycled material.

Focus areas for research and innovation

Focus areas in research of natural fibre composites, here especially meaning wood-polymer composites, are to develop new natural fibre composites with properties that match the market needs and to ensure that circularity of natural fibre composites is realised.

Wood fibres have properties and attributes that make them interesting as reinforcing elements in thermoplastics from both technical and commercial perspectives. Low density, good specific stiffness, low abrasive nature combined with low cost, renewability, biodegradability, availability, and potential for modifications are some of the advantages. Some challenges remain in manufacturing of wood fibre composites e.g. compatibility of fibre and plastic matrix for the reinforcement effect and water absorbency of fibres at the cut surface.

In addition to material specific development needs, the key in meeting the demands for composite performance lies in the processability and compatibility of the materials combined in a natural fibre composite. Development of specific processes both for the pretreatment of the materials as well as for the final production step would benefit the whole natural fibre composite industry.

One of the key perceived value propositions for natural fibre composite is based on their environmental benefits, including reaching a required performance level with a lighter structure and/or with lower environmental footprint. The end-of-life use of natural fibre composite depends on the base polymer. Natural fibre composites can be recycled to be used as a filler in the same end use or reprocessed into new products for other end uses depending on the fibre volume of the composite.

It is of utmost importance to quantify the environmental advantages of natural fibre composites in given applications and benchmark against competing solutions. Correspondingly, it is important to find the most suitable business and use cases for natural fibre composites and explore the potential and/or need for new business models.

THE R&D TOPICS IN FOCUS INCLUDE

Processing

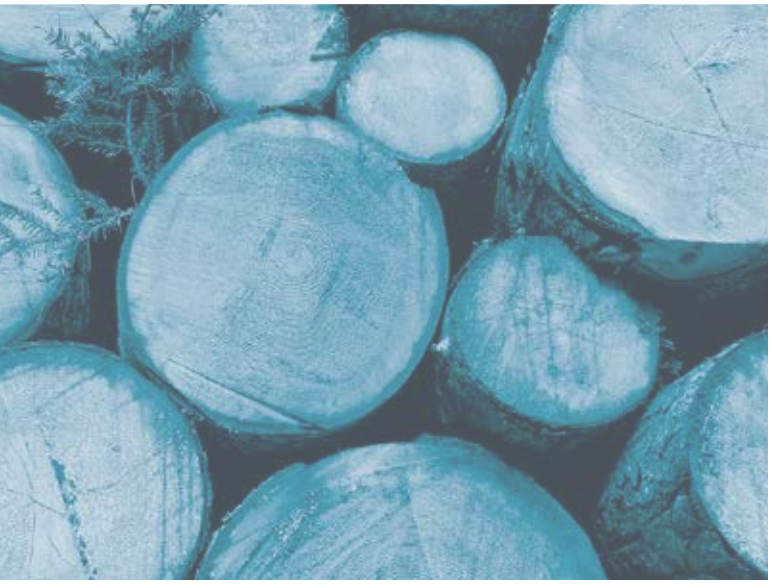
- Development of new fibre and polymer materials and their combinations
- Development of novel modification methods
- Tailored and optimal processing of materials and material combinations including development of measurements, modelling and equipment.

Functionality and performance

- Increasing the functionality of natural fibre composites
- Development of design and planning tools to match the properties of natural fibre composites with its end use requirements
- Development of bio-based coupling agents (compatibiliser)

Circularity

- Development of recycling routes for natural fibre composites
- Recycled materials and recovered bio-based compounds as raw material for natural fibre composites
- Ecodesign, including design for re-use and recirculation
- Development of standardisation for better circulation of materials
- Biodegradability and safety of virgin and recycled biocomposites



BIO-BASED CHEMICALS

Objective

Reduced dependence on fossil-based raw materials is targeted with high performance, sustainable wood-based biopolymers and biochemicals. In order to use wood-based polymers as high-value chemicals, there is a need to explore the full potential of cellulose, hemicellulose, lignin or related process side streams. Fundamental knowledge and techno-economical understanding need to be generated on feasible extraction processes, sustainable chemistries and end-product properties and performance. New end-use applications for wood-based biopolymers and biochemicals are explored.

Market opportunities

World chemicals turnover was valued at €3.347 billion in 2018 with the global sales growth by 2.5% from €3.266 billion in 2017 to €3.347 billion in 2018. The EU chemical industry ranks second in total sales after China with the share of 16.9%. (CEFIC, 2020)

Recent political, socio-economical, technical and regulatory changes drive the preference of chemical manufacturers towards more sustainable and renewable raw materials. Worldwide sales of renewable chemicals represented 9% of the €2.3 trillion in chemical sales in 2012. By 2020 bio-based products are expected to make up 11% of the global chemical market (BIO, 2016).

However, the challenge is to find bio-based alternatives that are available in industrially relevant scale, equal or even better in performance compared to fossil-based chemicals, recyclable and cost effective.

Focus areas for research and innovation

Polymeric component and structures of wood have unique characteristics and specific purpose as such but when extracted from wood they can be used to offer alternatives for fossil-based chemistries. Use of valuable components from side streams further broadens the sources of raw material.

Polymeric structures can e.g. affect the rheology of fluids, give strength and structure to materials, act as adsorbents or reduce friction between interfaces. One limiting factor for the use of wood polymers is their poor solubility in water which can be either a benefit or a challenge. In addition to solubility, many properties need to be improved further by modification and derivatisation of the polymeric structure to obtain a desired functionality. Derivatisation could increase the charge, hydrophobicity or physical properties of the polymers or polymeric structures e.g. thermoformability, film forming, elongation and strength. Combination of soluble cellulose derivatives/particles with bio-based polymers and synthetic polyelectrolytes in the form of complex structures could offer new properties for many areas.

One major challenge in the utilisation of wood-based polymers is a feasible extraction method which would maintain the polymeric structure as intact and as long as possible. On the other hand, it would be beneficial as well if the extraction as such could create new properties to the structures. Many technologies have proven to work in a laboratory scale but there are still many things to examine in the scale-up of the processes both from the feasibility and technical point of views.

THE R&D TOPICS IN FOCUS INCLUDE

Processing

- Development of scalable extraction processes and structure preserving extraction and fractionation
- Catalytic production
- Novel environmentally sound chemistry e.g. ionic liquids and deep eutectic solvents
- Simultaneous extraction and derivatisation systems
- Opportunities of industrial biotechnology and related methods in the fibre value chain
- Increase of yield, material and energy efficiencies of production processes with on-line information connected to optimal control methods
- Thermochemical processing
- Analytical and modelling tools supporting toxicological evaluation and characterisation

Functionality and performance

- Development of new or improved properties like positive or negative charge, hydrophobicity, water absorptivity, high molecular weight, elongation and thermoformability, or filmforming
- Development of supportive tools e.g. modelling the performance and structure of end products
- Development of new end uses for bio-based chemicals/materials

Circularity

- Feasibility of process chemicals e.g. for recycling and solutions enabling improved recyclability
- Value for waste and side streams in wood processing or usage of them as a feedstock to new value chains
- Compatibility with existing infrastructure
- Development of new infrastructures for processing or recycling of the novel materials
- Adoption of design for circularity
- Compliance with regulations

SUPPLY OF SUSTAINABLE RAW MATERIALS

Objective

The objective is to develop resilient and resource-smart forestry to meet the demands of the growing circular bioeconomy while securing the sustainable multipurpose use of the forests.

The raw material base

The European Union accounts for approximately 5% of the world's forests and the forested area continues to grow. The EU-27 have around 179 million hectares of forests and other wooded land which corresponds to almost 45% of its land area. (Eurostat, 2020)

However, even in Europe, the forest ecosystems are threatened by the rapidly progressing climate change and biodiversity loss. The sustainable use of forest resources is the core of a successful forest-based bioeconomy. It offers a holistic approach to the management and use of forest resources enabling economic, environmental and social benefits for the future generations and balancing possible competing needs. The diversity of forest nature creates the basis for the growth of forests and is thus a prerequisite for the economic use of forests.

In Europe more than 30 million hectares of forests have been protected with the main objective to conserve biodiversity or landscape which corresponds to 12% of the forest area in Europe. More than 50% of the strictly protected forests of EU are located in Finland. (Forest Europe, 2015).

According to recent nature inventories, decline in the biodiversity of forest habitats and species is continuing. However, based on the studies of the impact of improved forestry practices on forest biodiversity, the already known and used nature conservation measures in commercial forests are working in the right direction and have a positive impact on biodiversity. Still, especially for the endangered and demanding forest species, new measures have to be developed. The results show, however, that it is possible to significantly increase the scale of existing nature management measures, increase forest protection and at the same time produce wood for the needs of the forest industry. (Luke, 2019)

Focus areas for research and innovation

New methods and techniques are needed to increase the profitability of wood production and supply chains while minimising the negative impacts of extraction on the environment, biodiversity, productivity, regeneration capacity and vitality. Multi-functionality is set to be a key driver in forest management, emphasising the safeguarding of ecological sustainability as well as promotion of diverse use of forests, landscape management and water protection.

The demand for wood is estimated to increase markedly in the near future, due to the growing bioeconomy. Better understanding on raw material

properties and their quality control throughout industrial value chains, from wood production to industrial processes, is essential for higher added-value commercial products. Additionally, climate change forces to broaden the selection of commercially utilised tree species. New know-how is needed to direct tree breeding for further improvements in quality of industrial feedstocks and climate change resilience in the longer term.

THE R&D TOPICS IN FOCUS INCLUDE

- Breeding and gene preservation for resilience and productivity for the future bioeconomy
- Management concepts for productive, resilient and climate smart forestry
- Inventory, planning and forest operations for diverse land use and wood sourcing
- Development of the sustainable and resource-smart management of forests
- Comprehensive use and diversified basis of raw materials
- New and/or efficient supply chains in circular bioeconomy and novel operational models among the actors
- Environmental impact assessment methods (e.g. LCA) and measures to minimise negative environmental impacts of forest operations
- Tracability tools in value chain to end products

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Finnish areas of strength in forest-based circular bioeconomy

The forest sector is one of the cornerstones of Finnish economy and wood is a strategic renewable resource in Finland. Industries based on the sustainable use of wood are a substantial source of revenue for both the national and regional economies. Finland has world-class know-how in developing innovative biobased products and technologies. Currently, the industrial exploitation of wood-based biomass is in transformation, creating compelling new business opportunities and possibilities. Modern Finnish pulp mills are versatile biorefinery hubs that offer attractive ecosystems and investment opportunities for developing new products and technologies.

Key Finnish areas of strengths include

- Extensive experience and excellent know-how in sustainable forest management
- Excellent forest resource information produced by national forest inventories based on unique time series over decades
- Established collaboration models in RDI between academia and industry covering the whole sector from forest to fractionation and novel products from biomass
- World-leading education and research organisations in forest-based industry
- Frontrunner companies and strong knowledge of forest based industry
- Numerous new commercialised businesses based on renewable raw material and circular business models
- Expertise in wood pulp fibre structure, properties, separation and modification
- Expertise in paper and packaging value chain and recyclability
- Excellent piloting opportunities for new fibre based processes and products

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