

A laboratory setting with a pipette and a petri dish. The pipette is white with a pink tip and is positioned above a petri dish containing a yellowish substance. A person wearing blue gloves is holding the petri dish. The background is a blurred laboratory environment with various pieces of equipment.

CEI

# Swedish Forest-based Sector Research Agenda 4.0

FOR GROWTH IN THE WORLD'S BIOECONOMY





The Swedish Forest-based Sector Research Agenda compiles the research and development priorities of Sweden's largest export industry: the forest-based sector. A broad group of experts, from the industry as well as the research community, have actively contributed to an agenda that will guide the Swedish sector's endeavours for years to come.



# The Swedish forest-based sector must double investment in research

The Swedish forest industry has been creating efficient value chains for decades, based on sustainable forestry, effective logistics and competitive production facilities. This has made Sweden the third largest exporter of forest-based products in the world. Sustainable housing is being built with Swedish wood in Peking; in New Delhi, juice cartons made of Swedish packaging are being sold, and in Paris, clothing made of Swedish textile pulp is being marketed, to name just a few examples. Rigorous research efforts provide the right conditions for a competitive forest industry. However, current products can be further developed and supplemented with completely new materials that can not only replace the fossil-based products of today but also achieve completely new areas of use.

Today, Sweden is in many ways an international leader in forestry and forest industry research. Of the annual investment in research in silviculture and the forest industry, the forest industry and private foundations account for two thirds and state financing for one third. Investment in research needs to continuously increase in order to strengthen the competitiveness of the Swedish forest industries and for Sweden to manage the

transformation to a fossil-free, biobased society and circular economy. It is believed that the Swedish forest-based sector needs to double future research investment to achieve this.

This English edition of the research agenda aims to connect Swedish national priorities to the international arena. International cooperation is essential as many research areas and innovation priorities are most efficiently pursued jointly, with stakeholders from other countries.

In this context, the Swedish Forest-based Sector Research Agenda will serve as the Swedish national complement to the European Strategic Research Agenda of the Forest-based Sector Technology Platform (FTP).

TORGNY PERSSON  
DIRECTOR OF RESEARCH  
AND INNOVATION  
SWEDISH FOREST INDUSTRIES  
FEDERATION



# Research contributes to the UN's sustainability objectives

There is a global agreement on 17 objectives for sustainable development, through the United Nations Sustainable Development Goals. Environment and development are no longer treated as separate issues; the growing forest and the products that can be made from it will contribute substantially to meeting these global objectives. In the same way, sustainable cultivation of Swedish forests is necessary for a sustainable society. Once society fully adopts the use of renewable raw materials, it will be possible to phase out products that have a negative environmental impact.

Swedish forests are carefully managed. After harvesting full-grown trees, new ones are planted, which means that the forest stock in Sweden is increasing year by year. Research and forest inventory show that there is potential for increased sustainable harvesting.

Products manufactured from materials made from forest raw materials can be recycled and used for new products. The forest industry boasts a high proportion of recycling and is an example for many other industries that are only now starting their conversion. Research shows that a circular and biobased economy not only has a climate perspective but that by taking care of our ecosystem, the forest industry also has a social

and financial responsibility for our future. The renewability and recycling of products generated from forests is part of this responsibility.

Value creation is maximized by forest raw material being used at each stage where it can generate the greatest value, and fibres being used as many times as is feasible before being turned into bioenergy. Both from a climate and environmental perspective, as well as from an economical point of view, this principle is a condition for the efficient use of forests. But more research is required to refine the boundaries and increase understanding of this area.



**9** INDUSTRY, INNOVATION  
AND INFRASTRUCTURE



**11** SUSTAINABLE CITIES  
AND COMMUNITIES



**12** RESPONSIBLE  
CONSUMPTION  
AND PRODUCTION



The forest industry is contributing to all 17 sustainability objectives, to varying degrees. The research areas presented in the research agenda are closely aligned with six of these objectives.

**15** LIFE  
ON LAND



**13** CLIMATE  
ACTION



**10** REDUCED  
INEQUALITIES



**11** SUSTAINABLE CITIES  
AND COMMUNITIES



**12** RESPONSIBLE  
CONSUMPTION  
AND PRODUCTION



**13** CLIMATE  
ACTION



**14** LIFE BELOW  
WATER



**15** LIFE  
ON LAND



**16** PEACE, JUSTICE  
AND STRONG  
INSTITUTIONS



**17** PARTNERSHIPS  
FOR THE WORLD



Wood is a renewable raw material that is part of the continual cycle of life starting with photosynthesis. Growing forests take up carbon dioxide and bind carbon into wood components which are industrially refined to create a variety of different products. Innovation means that ever-more raw materials are being sustainably utilized and new products are seeing the light of day. Material is then reused or recycled and once the wood fibres are finally exhausted, they can be utilized as bioenergy together with other residual products from the forest industry, for heating, electricity or as propellants. Carbon dioxide is formed during incineration but taken up again by growing newly planted trees – and the cycle of life starts again.





# Sweden's bioeconomy can triple in size by 2050...

...and research is an essential component. The forest industry has a vision where the Swedish forest-based sector drives sustainable growth in the global bioeconomy. In a bioeconomy, industry uses renewable raw materials from forests, the earth and the sea instead of fossil fuels and fossil-based materials.

A competitive forest industry is reducing climate impact and optimizing the value of ecosystem services, whilst contributing to the economy and to society.

The bioeconomy today constitutes 10 per cent of the added value of Swedish business and approximately 16 per cent of Swedish export goods. Close to two thirds of exports linked to the bioeconomy are made up of products coming from forests: pulp, paper, cardboard and sawn timber.

According to a report from the Stockholm Environment Institute (SEI), the share of Swedish GDP represented by the bioeconomy will triple by 2050. This presupposes an increase in biomass production, competitive conditions for busi-

nesses, efforts being made in research and development, and access to expertise at all levels.

## A circular economy

A biobased economy goes hand-in-hand with a circular economy. Active forest management and the use of forest raw materials are part of the continual cycle of life. Growing forests take up carbon dioxide and store carbon in wood components and when one mature tree is harvested, at least two new ones are planted. Wood fibre is used to make products that can be recycled many times before finally being used as bioenergy. Carbon dioxide is formed during incineration and is taken up again by growing trees.



# The forest industry in Sweden's new industrial landscape

The Swedish forest is important for welfare, jobs and growth in Sweden. In the fossil-free, sustainable bioeconomy, which is becoming ever stronger, products from Swedish forests play a central role. In order to grow and develop, the Swedish forest industry requires competitive conditions and calls for strong support from research and innovation.

The Swedish forest industry is of significant regional and global importance. Income from forestry and jobs within the forest industries are, for many people, a prerequisite for living and working in rural areas. Half of the Swedish forest land is owned by 350,000 private individuals. As felling is not compulsory, it is solely the owner who decides how the land is to be used. It is therefore important that the forest owner is sufficiently motivated to produce the raw material.

## The Swedish forest industry is expanding

The term forest industry encapsulates companies that use forest material as the raw material for

their products and services. These companies are producers of pulp, paper, cardboard, packaging and biofuel, as well as wood for construction, interiors, furniture, packaging and composite materials.

Swedish pulp and paper mills are in an expansive phase. Major changes are taking place and companies are investing in new production facilities and new products, although pulp, paper, cardboard and structural timber will remain the main products for many years to come. Meanwhile, research is opening up new possibilities, such as for textiles and new materials.

Swedish sawmills have modern facilities for efficient and customer-adapted manufacturing. >



This cycle helmet made from wood has been produced to show that cellulose can be used as a shock-absorbing material. This foam-like material could be used, for example, as insulation in cars and packaging.

Cross-laminated timber comprises at least three layers of glued board or plank. This makes it an extremely strong and light construction material, with a high bearing capacity. Cross-laminated timber is used, among other things, for timber frames in modern multi-storey wooden buildings.



New functions and areas of use are the focus of research for packaging. Here are a few good examples of packaging where the material is completely made of renewable processed wood, or to a higher degree than before.



Research is being done to increase the extensibility of paper. Extensibility is an important property when replacing materials that are today made from fossil-based raw materials.



Carbon fibres can be produced from lignin from Kraft pulp mills. An increased availability of carbon fibres means that more products can be used from high-performance lightweight materials, such as cars, aeroplanes, satellites, rotor blades in windmills, and bicycles etc.



The forest-based industry represents

**9-12%**

of employment, exports, turnover and added value in Sweden

The annual export value has been

**SEK 125 billion**

for the last few years

Sweden is the

**3rd**

largest exporter of pulp, paper, cardboard and sawn timber in the world



Researchers have succeeded in producing transparent wood by removing the lignin. There is great interest from architects who envisage the possibilities for this strong and translucent material. In addition to being used for windows and interior panels, this material also has interesting potential for use in solar panels.



Protein for fish food can be made from forest raw material. Large-scale production is now possible after successful research efforts. Residual streams from the forest industry are often very nutritious, which makes them excellent for use as fertile soil for various microorganisms.



➤ A large proportion of timber is already being refined today. With an increase in the degree of refinement in sawmills, new composite construction products will be delivered to a growing global market. Being an international leader in research in this area further contributes to Sweden's market advantage.

### Exciting future markets

In order for Swedish production to remain competitive, the development of knowledge, technology and products must be a priority. Increased efficiency and profitability in the forest industry's existing production facilities is a precondition for continued success.

The Swedish forest-based industry is continually developing towards new markets and new goals of efficiency and sustainability. The industry is investing ever more on growth markets in order to increase its market share. Future markets can often be found at the boundaries of different consumer sectors and on the threshold between various technical and scientific disciplines. Significant market changes, such as the transition from printed to digital media, has started a transforma-

tion that will create new opportunities in the digital community. Nanotechnology, the integration between electronics and cellulose, and industrial timber construction are just some examples of growth areas to be developed by the Swedish forest industry.

### Increased competition

The developing countries of yesterday are the growth countries of today; considerable resources are being invested on training, research and development. New markets have been created for the Swedish forest industry, but also for new competitors. When new pulp and paper mills are built in China and Brazil, it is being done with frontier technology. But with the advantage Sweden has in the form of knowledge and developed value chains, new possibilities can be created. Through further refinement of Swedish forest management, the development and streamlining of existing production, and with new products, Sweden can continue to have a competitive forest industry and be a leading force for sustainable development.

# Trees as a raw material



Of all the forest raw materials being harvested in Sweden today, the majority are used to produce sawn timber, paper, cardboard and bioenergy. A minor part is used for textiles, chemicals and composite materials. How this breakdown will look in the future is impossible to predict. Anything that is made from fossil-based materials can be created with forest products. Meanwhile, it is demand and competitiveness that control the speed at which innovations reach the market.



## Wood

- Buildings
- Bridges
- Furniture
- Interiors



## Bioenergy

- Bioenergy/firewood/pellets
- Biogas
- Biofuel







### Paper and cardboard

- Packaging
- Functional paper
- Print paper
- Hygiene products
- Toilet and household paper

### Textiles

- Interiors
- Industrial textiles
- Ready-made clothing

### Composites


- Building materials
- Packaging
- Consumer goods
- Vehicles

### Chemistry

- Chemicals
- Foodstuffs
- Plastics
- Medicines



This shows how forestry and forest industrial research in Sweden's universities, colleges and research institutes is located around the country.



## World-leading research is carried out here

Extensive research related to forests and the forest products industry is being done in Sweden. Within many of these research areas, Sweden is a global leader. Research is being carried out by companies and institutes as well as universities and colleges. As can be seen on the map, research is performed in many locations dotted around the country. There is also a well-developed research collaboration between various players, both nationally and internationally.

One condition for the Swedish bioeconomy to be realized and developed, in competition with fossil fuels and other countries' renewable production, is further development of ongoing research efforts. But there is also a need to create completely new national platforms for innovation, research and demonstration.

# Strong need for research and expertise

Investment in research needs to increase in order to strengthen the competitiveness of the Swedish forest industry and for Sweden to manage the transformation to a fossil-free and biobased society. A need to double investment in research is anticipated.

More investment must be made in forestry and forest products industrial research. Strengthening of the forest industry must be achieved with new publicly financed initiatives and efforts on behalf of the forest industry and institutions, as well as through EU research programmes. By utilizing the Swedish Forest-based Sector Research Agenda, the forest industry is continually pushing for the most imperative research issues to be prioritized. By maintaining a dialogue with the financiers of Swedish research, important issues can be discussed leading to the dissemination of research results and resulting in collaborations, at national level. In the international context, the EU's research programmes should be monitored and applied to.

## Increased efforts in training

No research without training but no high-quality training without research either. By combining research with training, the industry has been able to build the knowledge and skills that the Swedish forest industries need. As with research, building-up skills is a long-term task. Society has the main responsibility for providing education and the responsibility of the industry is to clearly point out what skills are needed and to demand a trained workforce.

Today, Sweden offers many modern training courses but training in the forest industries must be increased. Attitudes need to change and there has to be an understanding that today's forest-related training courses are so much more than traditional forestry, woodworking and chemistry training.

## Crucial international cooperation

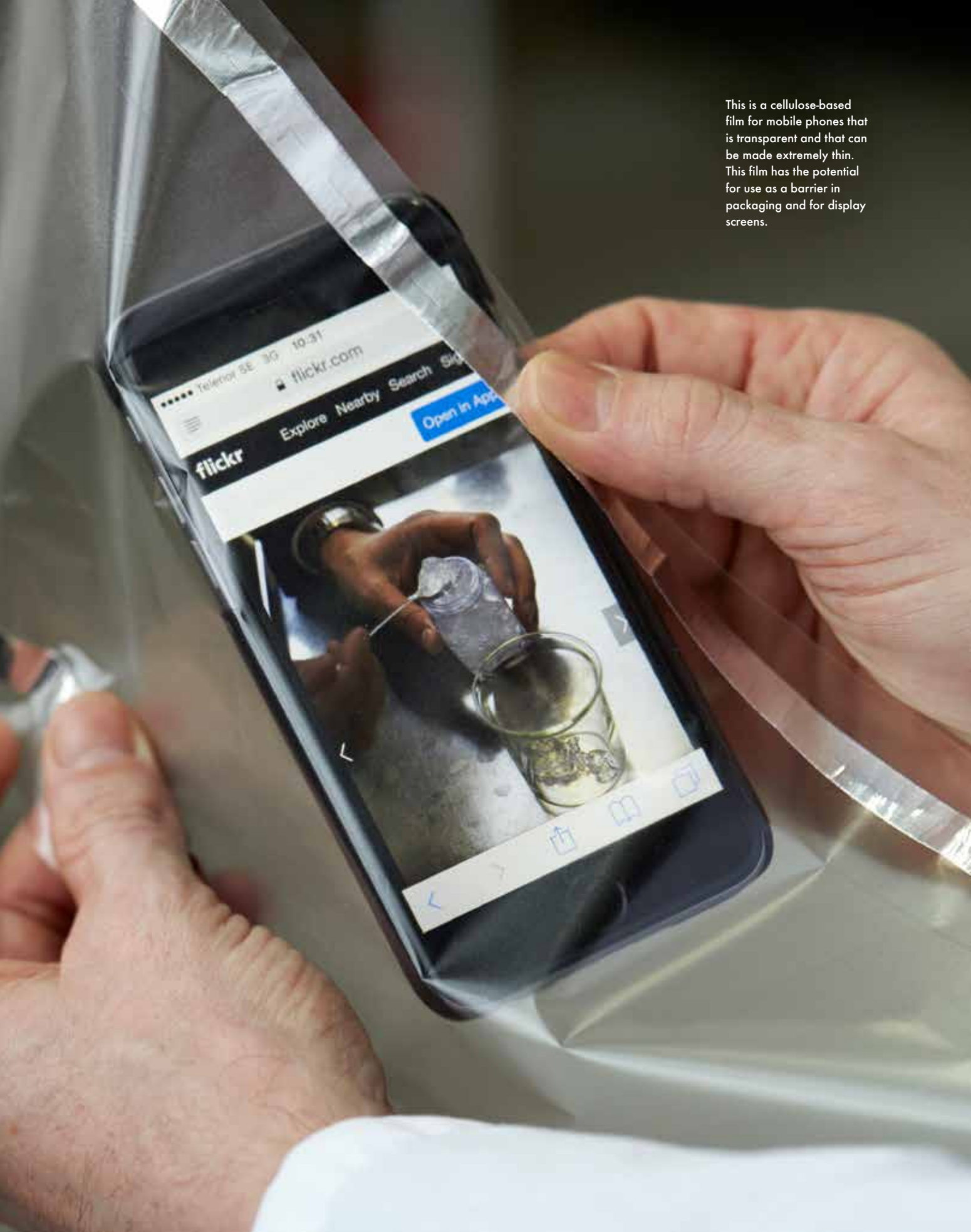
Over the last few decades, research collaboration has increased considerably in Europe, due not least to the EU research framework programme. In order for the Swedish forest industry to achieve the best possible results, national and international collaboration in research is essential.

Good potential for international collaboration exists both for forestry and forest industrial research. With regard to forestry there is the global issue of climate change, whilst on the industry side, international research collaboration is occurring naturally, as more Swedish companies have significant production in other countries and work extensively in foreign markets.

It is also essential that the industry showcases successful initiatives and good examples, based on broad knowledge of and collaborations between industry, academia and the Swedish research community.



This is a cellulose-based film for mobile phones that is transparent and that can be made extremely thin. This film has the potential for use as a barrier in packaging and for display screens.



# Long-term efforts towards clear goals

Research is crucial when it comes to maintaining the competitiveness of the forest industry and to realizing the vision of a biobased society. Through intensified research efforts, the forest industry can be the motor for Sweden's future fossil-based bioeconomy and the basis on which to form new biobased materials and products. The precondition for this is that the industry has long-term objectives. Research takes time and the time from idea to finished product on the market varies from months to decades.

The forest industry and the research community agree that forestry and forest industrial research in Sweden should contribute to:



## Increased growth in sustainably managed forests

Large, sustainably produced and carefully managed forests are the foundation for forest-based industry and a growing bioeconomy. Forests must satisfy many desires and demands. Knowledge which can lead to a sustainable increase in forest production is therefore a basis for the entire industry. It gives land owners a foundation on which to cultivate forests in the long- and short-term. It is also necessary to communicate with the general public and increase their insight and understanding of forestry, forest-related products and ecosystem services.



## Enhanced competitiveness for existing processes and products

The continuous development of existing processes and products is fundamental for any industry to remain competitive. A competitive and profitable forest industry can concentrate on establishing new processes, products, materials and services, and contribute to the development of sustainable forest cultivation. Forestry is continually developing towards new markets and new goals of efficiency and sustainability but needs the strong support of research.





Different forms of biofuel.



### Development of new biobased products

Replacing fossil-based materials and products with renewable, recyclable and degradable ones is the key to sustainable development. In order to achieve the correct properties for various products, research is needed on how materials can be made stronger, safer and more mouldable. Our future markets may be found at the boundaries of different consumer areas and on the threshold between technical and scientific disciplines.



### Increased industrial timber construction

The most commonly used, renewable construction material in the world has a bright future ahead when sustainability is brought to the fore. Wood is a light, yet strong material that enables a high degree of prefabrication. Industrial production allows good control of quality, cost, logistics and working environment. New research and demonstrations of new industrial value chains with collaboration between the wood industry and the building sector are required.

# Research areas

The research areas presented here represent the joint assessment of the Swedish forest industry and the research community, regarding the most pressing research issues. The ambition of the forest industry is to establish sound programmes and projects within these areas. Not everything can be done at once. The preconditions needed to be able to tackle these issues depend on whether financing is available for research and that there are capable researchers to hand.

The research areas are grouped under the following headings: **Strategic areas of research**, **Basic areas of research** and **Comprehensive knowledge development**. There are no strict barriers in this grouping, quite the opposite; there are strong links between them, not only in the traditional value chains but also in the integration with new value chains and between various disciplines.



# Strategic areas of research



## Increased growth in sustainably managed forests ..... 26

- Knowledge of forest ecosystems
- Forest cultivation and forest production
- Forest raw materials and services – availability and properties
- Harvest, refinement and transport



## Enhanced competitiveness for existing processes and products ..... 32

- Production processes – pulp
- Production processes – paper, cardboard and new solutions
- Sawmill processes
- Processes in the joinery and furniture industries
- Hygiene and healthcare products
- Bioenergy and biofuels



## Development of new biobased products ..... 40

- Biorefineries – new concepts
- Packaging
- Intelligent and digitalized paper
- Textile products



## Increased industrial timber construction ..... 46

- Construction processes
- Timber products for building
- Visible wood



## Basic areas of research ..... 50

- Forests for sustainable development
- Understanding and utilizing the raw material
- Material physics of wood and wood-based composites
- Increased understanding of the interaction between cellulose and water
- New moulding processes



## Comprehensive knowledge development ..... 56

- Climate change and life-cycle analyses
- Political processes and means of control
- Consumer behaviour and attitudes
- Energy systems
- Digitalization



Research areas for  
increased growth in  
sustainably managed  
forests



# Knowledge of forest ecosystems

Understanding the function of forest ecosystems, their untapped potential and their limitations, is fundamental.

Intense and sustainable cultivation of forests and forest land requires a good understanding of the function of ecosystems, current potential and limitations, and of climate and other environmental changes. Knowledge of forest ecosystems is also needed as a basis for the development of technology and methods that contribute to the continued growth of forests, to produce valuable timber, biodiversity and other ecosystem services.

Ongoing research on forest production and use of forest land has been carried out over time and has resulted in considerable knowledge being accrued on the preconditions required for various forest ecosystems, to enable the sustainable production of timber, as well as on the risks of damage. The challenge is to develop fundamental know-how, which enables sustainably efficient synergies between a high level of timber production which creates value, yet low risk to the ecosystem, the production of other ecosystem services and consideration for the flora and fauna. Normal Swedish managed forests are regarded by the general public primarily as “nature” areas, unaware of their economic significance as producers of timber. This is an indicator of the fact that the forest ecosystem can produce both timber and recreational “nature” experiences. Most studies have shown that many people in the community lack a relationship with the cultivation of forests and forest land, and often a basic knowledge of forests and forest ecosystems as well. There is little understanding of how much forests contribute to various products that replace fossil-based ones.

## RESEARCH IN BRIEF

- Plant physiology, genetics, soil science, hydrology, ecology, biometrics and ethology
- The influence of climate and environmental change on trees and other species
- Experience with long-term field trials and reference areas
- Sustainable methods for managing forests with special recreational zones close to populated areas
- Results of protection methods for different species through biotope protection and selective harvesting methods

## EXPECTED ACHIEVEMENTS

Know-how exists on how different methods of silviculture influence the ecosystem in relation to reference scenarios. The impact from individual system components and collaborative outcomes are analysed and developed to produce ecological models. This applies to both individual ecosystems and collaboration from a regional perspective. The models are used to predict detailed long-term effects of changes in silviculture, reproductive materials, nutrient relationships, climate and pests. The condition of the ecosystem, biodiversity, production results, environmental consequences and social values are monitored with continuous measurement, control and analysis. Know-how drives technology and methods for precision forestry where the forest ecosystem is managed, cared for and monitored for sustainable use according to the objectives of the forest owner and the community.

## REQUIRED RESEARCH

The gathering of comprehensive, in-depth knowledge on subjects such as plant physiology, genetics, soil science, hydrology, ecology, biometrics, climate research and ethology is needed. This will provide answers on how timber production, other ecosystem services, and active nature conservation methods best interact in stands and from a landscape perspective, as well as in a changing environment. Research is also needed on how various trees and other species react to changes in climate and environment, with respect to growth and resistance to extreme weather, disease, wild animals and pests.

Long-term field trials and reference areas with known silviculture regimes including genetic origin of reproduction materials and historical weather data are needed to map and verify research results. Reference areas need to be monitored with continuous measurement, control and analysis of production results, bearing in mind environmental consequences and social values. It is important that data collection is structured and that it is stored and made accessible over a long period of time.

New information services for this type of data need to be developed. Greater know-how is required, and sustainable methods developed, in order to create and maintain forests with special recreational value close to populated areas. Continued analysis of the results of methods for protecting various species, through retention patches, special biotope protection and selective forms of harvesting needs to be carried out, as well as provisions for nature conservation made. It is essential to understand how modified silviculture can create biodiversity in managed forests.



# Forest cultivation and forest production

The bioeconomy requires increased and persistent access to forest biomass. This research area concerns knowledge, technology and methods for sustainable forest cultivation and forest production.

In order for the forest-based bioeconomy to grow, raw material production, as well as existing and new end products, must be developed continuously to maintain competitiveness. Meanwhile, developments must be sustainable. Climate change can increase the risk of damage caused by weather, insects and fungi. Longer vegetation periods may be used to increase production and store more carbon in both growing forests and forest-based products, and thereby reduce the risk of carbon dioxide emissions from fossil-based alternatives.

Swedish forestry today presents a scenario that is grounded on several generations of managing forests and forest land. There is convincing scientific proof that production has largely been both renewable and persistent, and that it is far below the possible sustainable harvest level. Wild animal browsing and insect damage to plants and young forests, however, reduce both growth and quality. The economy, consideration for nature, and the objectives of different forest owners with regard to their forests, also affect the conditions for forest production and the production of other ecosystem services.

## RESEARCH IN BRIEF

- Methods of scarification and technology or mechanized sowing, planting, clearing and regeneration under shelterwood
- Tree breeding and efficient propagation methods
- Long-term field experiments and fixed reference areas for validating various results and climate effects
- Effects on production and quality after clearing, thinning and selection cutting
- Digitalization in order to combine detailed data on forest land with production data and data from harvests

## EXPECTED ACHIEVEMENTS

Existing and new know-how is implemented continuously in a cost-efficient regeneration of forests using environmentally friendly technology and silvicultural practices, including the mechanization of silvicultural processes. Development is based on the knowledge of how forest ecosystems function, on plant physiology, genetical and biotechnical advances as well as efficient pest control. Natural regeneration and selection cutting methods are used as good alternatives, where the objectives of forest owners and regeneration conditions support them.

Digitalization means that vital information from harvested forests can be used to develop higher precision in the choice of measures, forest reproduction material and silvicultural services. The intensity of forest growth varies depending on preconditions and established objectives. The sustainable production of forest raw material has increased considerably. New measurement techniques and monitoring, as well as new information systems make it possible to follow the results of regeneration measures that have been carried out.

## REQUIRED RESEARCH

Research of environmentally friendly and efficient scarification methods and technology for mechanized sowing, planting and clearing is of great importance, as is the know-how and methods of regeneration under shelterwood. Continued, long-term efforts in tree breeding are needed. Also, efficient propagation methods that provide full access to well-adapted reproduction material that increases the possibility of higher and more valuable production are required, as is a readiness to use additional tree species. Long-term field experiments and fixed reference areas are of great value in validating various results and climate effects.

Essential research should also be carried out to develop sustainable systems for increased biomass and value production. This includes the effects on production and quality after clearing, thinning and selection cutting. Digitalization to combine detailed data on forest land with production data on growth and properties of harvested trees is another necessary area of research.

Communication, training and expert advice are central to how reproduction material and silvicultural regimes are best combined.



# Forest raw materials and services – availability and properties

An in-depth knowledge of the existing supply, quantity and properties of various forest raw materials is of crucial importance for the planning of sustainable production and for decisions regarding industry investment.

The proportion of wood obtained from thinning, combined with new possibilities for the economic utilization of small dimensions, contribute to changes in the availability of this type of raw material. Once the trees approach harvesting time, detailed information concerning the size and properties of the trunks is essential for potential industry customers, as is knowledge of the available quantity of forest fuel. The potential for other ecosystem services is also to be considered.

Knowing the amount of forest raw materials available and their properties is central for both producers and industry customers. Better knowledge of standing forests offers a decisive advantage for secure business agreements, planned integration with industry customer manufacturing processes and control of harvests, refinement and transport. It is essential to increase knowledge on the importance of the raw material's variety including possibilities for greater efficiency through harvesting refinement and production control, and to disseminate this. Decision support on possibilities regarding cost, revenues and environmental impact throughout all levels of the value chain, whether impacted directly or indirectly, is important.

All major forest companies have systems for making forest inventories in order to characterize their forest land and forest assets, as well as the prerequisites needed for developing various ecosystem services. Private forest owners may require support to carry out forest inventories and plans for their forest management. A new national standard (Forestand) for data concerning forests and forest utilization has been established and provides a foundation on which information from various properties can be handled with technology and methods that utilize this standard. Digitalization solutions can, for the most part, be based on the integration of existing systems and be linked together with industry systems to give completely new possibilities of analysis and production control through digital value chains, from forest to industry.

## RESEARCH IN BRIEF

- Remote analysis, laser scanning, 3D photography, land-based scanning and sensor techniques
- Information systems for machine-collected data for characterizing standing forest and for communication with industry customers
- Methods for measuring and predicting dimensions and properties, and the traceability of actual yields
- Tools for evaluating and calculating the impact of different uses of forest raw materials
- Traceability from stump to end user

## EXPECTED ACHIEVEMENTS

Sustainable harvesting of forest raw materials is planned on marketable grounds to attain durable solutions to several societal challenges. The properties of forest raw materials can be characterized by looking at all the trees. This makes planning possible with different needs for higher data resolution and time horizons. Precise planning with high-resolution business deals, reliable delivery schedules and a developed analysis of different production and delivery alternatives is possible.

## REQUIRED RESEARCH

The provision for standardized data from remote analysis must be secured and developed. The development of technology for remote data analysis, airborne laser scanning, 3D photography, terrestrial scanning and sensor techniques must continue by resolution and a lower price with the support of broad, general applications.

Research and development efforts are needed for efficient data gathering from forest machines, and measurements of activities such as thinning, cleaning and other measures to assess the effect on growth, availability and properties of forest raw materials. These are also essential as preconditions for ecosystem services and biodiversity. Methods for measuring and calculating dimensions and properties, and the traceability of actual yields, should be used, and can provide new opportunities to effectively characterize and utilize products and processes adapted to raw materials. Today's information systems must be further developed and linked up with industrial customer systems to form digital value chains.

Tools need to be developed to be able to perform scenario analyses of development tracks for the use of forest raw materials and interaction with other ecosystem services and regional perspectives. Methods and tools for flexible valuations of raw materials according to the demands of industry customers need to be developed to support increased accuracy in business agreements, improved flow and transport planning.



# Harvesting, refinement and transport

Harvesting, refinement and transport are key processes in the utilization of forests and the supply of raw materials.

This is where the result of the entire bio-production process, which forms harvestable trees based on the ecosystem conditions, is utilized in the best possible way. Throughout the whole of Sweden, around 75,000,000 tonnes of raw biomass are harvested and refined annually for different customer segments.

Harvesting and transport account for most of the forest emissions of greenhouse gases whilst these, together with the creation of forest roads, represent around 80 per cent of the running costs of a forest. This is an area where it is possible to develop better integration between forest owner, supplier, logistics organization and the customers concerned. Technology and the methods used need to be developed to increase accessibility, without engendering damage to land and water.

Raw material acquisition and timber flows have primarily been built on large-scale and uniform systems with a focus on high efficiency, high productivity and well-organized transport. Thematic map support has started to be used for planning and carrying out harvests, with environmentally friendly transport across forest terrain. Development has been towards fewer and larger industry units but regional coverage is still significant for the forest industry. Timber and woodchip transport using trucks, from the forest to industry or terminal, represents about 20 per cent of the entire heavy goods vehicle traffic in Sweden. Both efficient vehicle technology and logistics solutions are therefore essential areas for research and development.

## RESEARCH IN BRIEF

- Integration of harvesting, preparation and efficient handling of the various parts of a tree, transport flows and subsequent industry processes
- High-yield and environmentally friendly operating systems for harvesting, terrestrial and further transport
- Measurement and calculation technology for automation and increased-value exploitation, digital mapping layers and driver support
- Digitalization and standardization of concepts and data flows
- Efficient forms of collaboration amongst small forest owners

## EXPECTED ACHIEVEMENTS

Harvesting, refinement and transport have been streamlined with respect to economic, environmental and social considerations. Improved knowledge of individual tree properties is used to prepare and refine these properties depending on customer requirements, available manufacturing processes, as well as revenue/cost analyses and a comprehensive environmental evaluation. Better planning, clear and precise agreements with the customer, and harvesting machines with improved measurement and calculation techniques, offer increased precision in forest production control. Information on product properties and traceability is retained through the whole production and information systems chain, making it possible to link measurement results from industry customer systems together with data from the forest.

Productivity has increased with regard to forest machinery while both fuel consumption and rutting from ground contact has been reduced considerably. Control systems and technology for trucks, terminals, trains and other methods of transport have been developed in a more efficient way. Modern driver support and traffic safety systems make it possible to increase load capacity and reduce costs, fuel consumption and emissions. Autonomous and semi-automated systems also contribute to increased productivity whilst addressing environmental concerns, in several areas.

## REQUIRED RESEARCH

The supply of sustainable raw materials requires research and development of technology and methods used for creating value as well as efficient and environmentally friendly harvesting. Research in system development and the analysis of how harvesting, processing and efficient handling of the various parts of a tree, transport flows and subsequent industry processes can be integrated most efficiently, is therefore an urgent area for consideration. Initiation and analysis of new high-yield yet environmentally friendly operating systems for harvesting, terrestrial and further transport with regard to a sustainable working environment is a high priority. Research and development of autonomous vehicles and semi-automated processes and control systems is another area with high potential.

Technology for measurement and calculation regarding automation and increased-value exploitation, as well as decision support such as digital mapping layers and driver support, are important areas to be developed. The far-reaching possibilities of digitalization require continued standardization of concepts and data flows to achieve effective and unbroken communication, both through and between different value chains and actors but also for supporting silviculture operations aimed at subsequent forest generations.

Efficient forms of collaboration amongst small forest owners and impact analyses of various proposals for new regulations are other important areas of research to be addressed.





Research areas to  
strengthen competitive-  
ness in existing  
processes and  
products





## Production processes – pulp

The production process for pulp is a significant link in the forest industry's manufacture of traditional paper and cardboard.

This area covers processes where harvest and development of pulp is central, where cellulose can be extracted from pulp and further refined for modified and new product purposes. The industry needs to develop and refine pulp and fibre qualities to create long-term possibilities for increased functionality and profitability of existing cellulose, paper and cardboard products as well as in new applications.

Today's efficient processes already lay the foundations for developing processes with an improved utilization of raw materials, less environmental impact, more efficient chemical handling and energy efficiency. Increased flexibility as well as new processes produce fibre that is adapted to new products. Processes to create new cellulose qualities are opening up to new product segments and a broader product portfolio.

The bioeconomy will place greater demands on efficiency in processes and product development in order to create greater profitability in the future. At the same time, it is important to continually strengthen existing applications in order to generate the financial preconditions for new process concepts for the products of tomorrow.

Forest-based pulp mills have continuously increased their resource efficiency. Increased use of bark, chips and sawdust for producing energy and the use of other side streams in the processes, as well as a reduction in specific water and energy use in production, for example, has significantly increased resource efficiency. Several production site extensions and rebuilds have been made in the pulp industry for the production of cellulose for new purposes, such as textiles for example. There are pilot facilities for the production of both microfibrillated and microcrystalline cellulose.

### EXPECTED ACHIEVEMENTS

A fundamental shift has taken place in pulp industry processes to offer a broader spectrum of cellulose fibres. Research on processes has generated an increase in efficiency thanks to smaller losses in the production process, more resource-efficient products and reduced energy consumption. This has opened up the possibility for a broader use of residual streams and thereby an increased yield in forest raw materials. The industry leads on an international scale with regard to knowledge in environmental technology linked to processes, energy issues and water management.

### REQUIRED RESEARCH

A fundamental area of research is the development of cellulose through an understanding of its interaction with water and supermolecular structure. The development of new pulp and fibre qualities as well as the modification of cellulose are the basis for the development of new fibre-based products. This also includes the need for the development of process stages and integrated process solutions for new products. To further reduce environmental impact but also increase cost efficiency, processes for more efficient chemical recovery must be developed.

Research is needed for increased understanding and knowledge of the interaction with other materials in order to design processes that give the desired fibre properties. The interaction of matrixes between cellulose and other organic materials in different applications is a possible area for such research.

System analyses and technical-economic analyses for the assessment of process functionalities and economic profitability, as well as increased understanding of the possibilities of digitalization as a support for future processes, must be developed. Research areas to strengthen competitiveness in existing processes and products must be maintained.

### RESEARCH IN BRIEF

- New fibre qualities for the development of existing fibre-based products
- Fibre/wood interaction in matrixes with other materials
- Process stages and integrated process solutions
- Processes for more efficient chemical handling



# Production processes

## – paper, cardboard and new solutions

This area includes production processes for existing products such as paper, cardboard, liner, fluting and tissue, which all come under the paper concept.

It also includes new possibilities for using existing process infrastructures to manufacture new products.

The starting point for this area is functionality, such as improved stiffness with reduced material volume in products, as well as process efficiency and sustainability. This means increased knowledge of processes that allow reduced material use, lower water consumption, lower energy consumption, possibilities for mixing various raw biomaterials and developments that allow the manufacture of new products in existing or modified processes.

Significant societal challenges in energy and the environment can be met by developing paper processes as well as paper properties. A large part of the industry is exposed to competition, and so creating the conditions needed for continued profitability through process development is therefore a key issue, since raw material prices are expected to rise.

Today, the industry already supplies resource-efficient products due to the fact that smaller losses in the production process, reduced raw material consumption and reduced energy consumption have been in focus for a long time. Development has been characterized by incremental improvements but new opportunities based on modified cellulose and nanocellulose are now being tested on an industrial scale. New customer demands, that continually arise, can be met by developing the production process so that new and optimized material properties can be obtained.

### RESEARCH IN BRIEF

- Modelling, analysis and characterization of the raw material, paper and processes
- System studies of renewed process concepts combined with technical and economic studies for the assessment of industrialization
- Acceptable alternatives to water in paper manufacture
- Information and sensor technologies together with online measurement technology
- Systems for intelligent digitalization

### EXPECTED ACHIEVEMENTS

Modified cellulose and nanocellulose are used on a large scale to increase the functionality of products. The industry has developed process alternatives for existing products with radically reduced water and energy consumption. Consumer needs that are met with enhanced material quality and sophisticated product design are being focused on. A radically improved and broader functionality of paper has opened up new markets. A complete product concept based on existing processes has been drawn up and reached the market: textile-like paper, shapeable paper and communicating paper.

### REQUIRED RESEARCH

A priority for research is to increase knowledge of the properties of input pulp and the subsequent processes to enable higher product quality and the increased functionality of paper. Important tools being developed are those of modelling, analysis and characterization of the raw material, paper and processes. This is needed as the basis for new unit processes.

System studies for the development of process concepts combined with technical and economic studies for the assessment of industrialization potential is an important area of research. The development of new industrially acceptable alternatives to water in the manufacture of paper is another area of importance. Research of unit processes is also needed for increased flexibility, through the use of advanced information and sensor technology together with online measurement technology.

Developed systems of digitalization are also essential and are regarded as a way to change the process by reducing the complexity and simplifying the unit processes. This also enables modelling by increasing the possibility of smoothing out fluctuations in the process.



# Sawmill processes

Sawmills are part of a process industry with advanced measuring technology and complicated logistics. Swedish sawmills are becoming fewer in number but those that are left are increasing their production.

They are often located in rural areas and typically serve as the largest employer of a given locality. To face competition from foreign companies, both the technology as well as communication and business models must be of the highest order. Two thirds of today's production is exported without further refinement.

Timber drying is a key process in the woodworking value chain from a quality perspective. The drying process is to be further developed to ensure that properties are carefully monitored and controlled during drying, so that the desired properties of the end product can be customized. This can be achieved with an understanding of the interaction between processes and materials with well-defined properties.

The precondition for an increase in timber construction includes sawmills consistently delivering components that are easy to integrate into the construction process without any additional measures. Through increased digitalization of the processes, improved precision in specifying and measuring timber properties and process parameters, plus better customer order control, the efficiency of the entire value chain can be improved.

Sawdust is today regarded as a by-product; the material value is more than halved when the fixed wood volume is converted into sawdust. Through further processing of products, both its value and raw material utilization increase, while carbon is captured in products for the duration of their life.

Today, Sweden is considered to be a leading player in sawmill processing for products found on the international market, whilst the productivity of the Swedish sawmill industry is world class. Processes have been developed and have become more efficient with regard to precision, energy consumption, yield of raw material and availability. There is, however, still great potential for improvement. Sweden has lost ground however at international level, in areas such as the development of machinery.

## EXPECTED ACHIEVEMENTS

Productivity has improved considerably. Stock turnover has doubled whilst process efficiency and raw material efficiency have also increased. Research and development of drying control and drying schedules have made great advances, as far as the knowledge and understanding of the interaction between process and wood is concerned. There are improved chances of a radical reduction in dryer-related damage. New technologies for splitting have been developed and refined. Swedish sawmills are world leaders in productivity and several sawmills have customer order-based production throughout the plant.

## REQUIRED RESEARCH

To reach established goals, technical development must be improved and streamlined. Principally, this concerns splitting technology, drying technology, measuring technology and new methods of sorting based on customer orders. Research efforts to study the added value of by-products from sawmills are of great importance for increased raw material utilization and the future bioeconomy. Furthermore, it is imperative that support systems are established for pilot trials and the development of prototypes where new processes for splitting and drying, for example, can be tested under realistic conditions.

How sawmills will be able to deliver components for construction is another significant area of research.

Communication and business models for controlling flows of information, both upstream and downstream in the value chain, must be developed. Here, digitalization of the information flow both inside and beyond the sawmill will increase to provide important and useful process and product information.

Autonomous forklifts and automatic storage through improved internal logistics will replace today's traditional handling, but this also requires considerable research efforts.

### RESEARCH IN BRIEF

- Splitting technology, drying technology and measurement technology
- Sorting based on customer orders
- Increase in value of by-products
- Communication and business models, especially through digitalization
- Internal logistics at the sawmill



# Processes in the joinery and furniture industries

This area covers processes for visible wood products and those that are used in everyday life.

It includes processing and production of wooden products in various forms, everything from simple moulded products, to composite furniture and interiors.

Wooden products play an important role in the shift from fossil-based materials to biobased materials and must be developed to fulfil the user's need for long-term sustainable solutions. The joinery and furniture industries produce yield depending on the degree of refinement, and create employment throughout the country, especially in rural areas.

In some areas, the Swedish joinery and furniture industries are well developed, with advanced production methods that are highly automated. Other regions have developed more slowly and today have a low degree of automation, with outdated machinery and lesser development. This means that competitiveness varies greatly in this area. The shift overseas of machine manufacturing has become a trend, leading to knowledge being lost at national level and resulting in competitors increasing their expertise in this competence.

## RESEARCH IN BRIEF

- New technology for 3D measuring
- Densification and other surface modifications
- Chemical and thermal modification for new functionalities
- Wood processing, bonding and surface treatment
- Communication and business models, especially through digitalization

## EXPECTED ACHIEVEMENTS

With the increased use of wood, the joinery and furniture industries have replaced fossil-based materials and found a new range of uses. The basis for this comes from Swedish forest raw materials. Collaboration with international players within the entire wood mechanical industry is considerable. Automation has been carried out extensively and the digitalization of the industry has come a long way in its development. Customer adaptation is integrated into production.

## REQUIRED RESEARCH

Technology development must be intensified to attain established goals. Research should be directed to the study of wood properties so that better automation can be developed, or in the case of certain properties, the need for automation can be removed. Understanding of the added value is important so that the customer base can be retained and profitability increased.

One important area that will revolutionize the industry is 3D measuring, especially when it comes to the renovation of buildings and interiors. Development is still in its infancy but will be important for new automated production technology.

Examples of innovative processes include densification of the wood surface so that pine and spruce become just as hard as oak, surface modification for improved fire resistance, increased dirt repellence, colour determination and transformation of texture and structure. Chemical modification to radically change the properties of wood, thermal treatment for both reduced moisture movement and the possibility of controlling the colour of the wood surface, as well as its thermal diffusion, are further examples. The wood processing, bonding and surface treatment areas need to be further developed.

Furthermore, communication and business models in the value chain should be developed to follow flows of information, both upstream and downstream. The digitalization of the flow of information can be used as a sales argument that gives customer value to the information itself. Issues concerning organization and leadership linked to product development, innovation, etc., are in demand with the aim of optimizing the value chain, from sales, planning, production and storage, up to delivery.



## Hygiene and healthcare products

This area is based on household and toilet papers as well as other hygiene-oriented articles such as nappies and incontinence products. The process-oriented development of material is mainly in the paper process.

From this base, more products adapted for purpose in healthcare are further developed with several new potential applications.

Single-use in healthcare is a hotly debated issue and with this there are possibilities for biobased materials within a range of product areas such as bedclothes, and textiles and aprons used in surgery. Safety, health and sustainability issues come into focus in healthcare and these issues are significant points of origin for biobased solutions. All these areas require considerable efforts in research and development.

Healthcare costs in Sweden, as elsewhere, are increasing, meaning that the elderly and sick are being cared for more and more at home. This increases the need for home and immediate family care, and therefore the demand for biobased home-care products is also increasing. In many parts of the world, the availability of traditional fibres is limited, whilst an increase in living standards means a higher demand for hygiene products. These are significant drivers of development, and good hygiene levels in developing countries can be met with new low-resource and creative biobased solutions.

The pulp and paper industry today is well established in this area. Tissue paper is used in most environments and often as different single-use applications in healthcare. Tissue paper products have been improved considerably in terms of their water-sorption capacity.

### EXPECTED ACHIEVEMENTS

The pulp and paper industry has considerably increased its market share of biobased materials for new hygiene and healthcare products. More integrated solutions in fibre products mean a widening of its range of uses and can be included as a part of the diagnostic work carried out in healthcare. The knowledge developed around the functionalities of cellulose and modified cellulose has created the conditions for even more integration of products in the treatment of patients.


### REQUIRED RESEARCH

One important area for development within this domain is the research being done primarily in the field of cellulose, but also in other parts of the raw material. This development creates the right conditions for the development of paper processes in order to increase and broaden the functionality of existing hygiene products. Research and development of biobased single-use products in healthcare, both from a technical perspective as well as a holistic perspective of the healthcare process, is very important.

The need for research on the use of advanced biobased solutions, for example the use of biobased material for controlled release, smart intake control and prostheses, is essential. Of importance also is close cooperation with users and healthcare workers who can convey which properties are required for such products for use in the healthcare industry.

#### RESEARCH IN BRIEF

- Increased and expanded functionality in existing hygiene products
- Biobased single-use products in healthcare
- Advanced biobased solutions such as controlled release and smart intake control



## Bioenergy and biofuels

This area comprises the extraction of energy, partly from tops and branches and partly from side streams generated in sawmills and pulp mills.

End products can be pellets, gas, process and district heating, electrical energy, biofuel, etc. This does not include developments concerning the use of biomaterials for energy applications, for example, such as batteries or solar panels.

The bioeconomy demands and presents several alternatives to current fossil-based products. The establishment of new, competitive, energy- and material-efficient biobased value chains for energy and fuels is therefore essential for the development of a successful European bioeconomy. The development and acceptance of new products is often a risk when it comes to technology, prices, markets and policies. One way for biobased energy and fuel products to gain ground is technology development, as new products must also have a high energy output so that biobased raw materials can be used as efficiently as possible and therefore be most advantageous where climate issues are concerned.

On a larger scale, there are facilities for the extraction of biodiesel from tall oil, for example, or as ethanol or methanol demonstrators. Projects for the development of other biobased energy solutions are ongoing.



### EXPECTED ACHIEVEMENTS

Research and development in this area has provided the industry with the necessary knowledge to steer decisions on the optimum characteristics for future biorefineries. New biobased energy and fuel products contribute greatly to the forest-based industry, confirming its place as a central player for and enabler of a biobased and sustainable society. The forest industry collaborates in research and industrial networks with new stakeholders and business areas that have not previously existed.



### REQUIRED RESEARCH

Research and development in logistical systems is needed to be able to take branches and tops out of the forest in a profitable way for processing, as well as in other processes of extraction and reprocessing. Furthermore, fundamental technology in this area needs to be developed, in order to utilize side streams and make direct use of the biomaterial. This applies, for example, in processes for pyrolysis, production of biogas from sludge, combustion, and further refining and processing of fuel.

Research carried out to develop small-scale processes that can produce increased profitability from the forest and generate local employment can be very valuable.

Analysis methods need to be developed. This involves characterization not only of biobased raw materials and reprocessed energy and fuel products, but also models as a tool to analyse energy products in relation to user demands. In order to implement and test research findings and new knowledge, demonstration and pilot facilities are essential for an increased industrialization of this area.

### RESEARCH IN BRIEF

- Processes to utilize side streams and the direct use of biomaterial
- Small-scale processes
- Analysis methods for the characterization of biomaterial and reprocessed energy and fuel products
- Models and tools for the analysis of energy products in relation to user demands
- Demonstration and pilot facilities to test full-scale activity



The world's first fibre-based bottle for carbonated drinks is under development. The bottle is cast in 3D and is completely biodegradable.



Research areas  
to develop new  
biobased products







## Biorefineries – new concepts

Biorefineries offer refinement or transformation processes for reprocessing of biomass into a useable product and provide the foundation for new future products with regards materials, chemicals and energy or as a replacement for the fossil-based alternatives used today.

Synergies and collaboration within the forest-based sector and with processes used for other biobased raw materials provide added advantages and efficiency, which contribute to increased sustainability, renewal and value growth. Through the integration of various raw material streams from forestry and agriculture with an already established infrastructure, lower costs for new products are possible. The raw material can also originate from residual products from the forest, such as branches and tree tops, as well as woodchips, sawdust and bark from sawmills and pulp mills.

Research focuses on new processes, where the components of the raw material are separated. It can also lead to new process concepts based on other raw material streams in biorefineries.

A central objective of the European Union is to reduce Europe's dependence on non-renewable resources for materials, chemicals and energy. Part of the solution is the creation of new value chains based on biomass from forests and side streams from existing processes. Biorefineries are an important part of further development for the industry and for broadening the range of products.

The first new-style biorefineries are now being built in connection with existing pulp mills and new concepts for integrating the production of biofuels in existing factories are being tested at pilot scale.

Opportunities to develop brand new products will be created in the new biorefinery. Examples that are already under development today include fish food and material for prosthetic body parts, among others.

### EXPECTED ACHIEVEMENTS

New biorefinery concepts have strengthened the competitiveness of the forest-based sector and laid the foundation for new value chains. The industry has taken a significant step towards its ambition of doubling value growth by the year 2030 with new, profitable products. There is also a number of newly developed products that replace existing fossil-based raw materials and which show new and improved characteristics. The range of raw materials processed in biorefineries, driven by the forest industry, has been extended to include new raw materials and recycled materials. Collaboration with energy and chemical companies and users of new materials and composites has been developed.

### REQUIRED RESEARCH

The conditions needed for biorefinery are based on research concerning separation technology for forest raw materials and other biobased raw materials, focusing on system-oriented process development. The development of efficient unit processes is also needed, in collaboration with chemical and biotechnology companies.

Furthermore, the development of forming/moulding methods is essential to enable stakeholders in various refining chains to develop new products and generate profitable growth for value products. It is imperative to develop knowledge as well as creating technical and economic models for evaluating how processes can interact with existing structures, generating profitability and increased value. Greater energy efficiency and the development of more efficient systems for energy generation and energy use are essential to release side streams for new products. In order for research results to be validated, large-scale pilot tests are essential. Pilots will also provide a basis on which to evaluate new processes and the industrial and technical potential of the resulting products.

### RESEARCH IN BRIEF

- Technology for the separation of various biobased raw materials
- Efficient unit processes
- System analysis including technical and economic analyses of the functionality and profitability of processes
- Energy generation and energy use
- Large-scale pilot tests as well as test and demonstration facilities



# Packaging

This area covers packaging that is fully biobased and degradable.

Functionality and enhanced characteristics are the focus of this area, covering the entire value chain from material manufacture to consumption and reuse or recycling. It includes a wide spectrum of products, ranging from consumer and food packaging to transport packaging. By volume, this area is important not only for the paper and cardboard industry but also for sawmills. Nineteen per cent of Swedish wood production ends up in packaging, of which pallets form the most part. Well-developed returns systems link wooden packaging successfully to the circular economy.

Trade is increasing and requires efficient, sustainable and smart packaging systems. Packaging is being considered more often as an enabler in the development of value flows, where the reduction of losses in the value chain act as a major driving force. Consumers regard fibre-based packaging as more ecologically sustainable, even so the market share of competing fossil-based packaging is increasing faster than fibre and wood-based packaging.

The packaging market is in continual expansion, mainly depending on greatly increased population growth and urbanization. Packaging materials and components based on a new generation of biobased polymers are at pilot stage and are only found on the market to a small degree. Combinations of wood and fibre products have great potential for development.

## RESEARCH IN BRIEF

- Packaging solutions that are completely biobased and reusable as well as degradable after use
- Concepts for materials that are based on the development of the paper process
- Process automation in mechanical wood manufacture
- New technical concepts such as formable fibre-based materials, biobased barriers, new surface treatment techniques and smart functions
- Digitalization development coupled with packaging solutions

## EXPECTED ACHIEVEMENTS

Biobased packaging solutions, based on forest raw materials, have reversed the trend and are increasing their share of the packaging market. Technical developments have resulted in stiffer lightweight cardboard, formable biobased packaging, new material combinations with wood, fibre and cellulose, and packaging solutions with increased "intelligence". The advantages of fibre-based materials are put to use in developing smart, safe and degradable packaging. New packaging concepts that combine wood and fibre have been developed for oversized and heavy products.

Packaging is a multidisciplinary area and a comprehensive overview is applied to the entire value chain. Consumer demands and needs are an important starting point for developing new and enhanced packaging solutions, as is the fact that consumers value and understand the circular nature of biobased packaging.

## REQUIRED RESEARCH

The next generation of packaging solutions is, in part, a future development of the paper process. One important condition for the next generation of biobased packaging is fundamental research concerning the understanding of cellulose. Research, development and demonstration of packaging materials and packaging solutions that are completely biobased and degradable are acquiring an ever-greater importance. All aspects of sustainability are in focus.

The development of concepts for materials that lead to broader and increased functionality is an important area of research. Even in the case of wood, with particular focus on modification and new surface treatment techniques, this is an important development area, as is the digitalization and robotization of mechanical wood manufacture in the form of process automation.

An understanding of the advantages provided by fibre-based materials needs to improve and be turned into competitive packaging solutions. Specifically, this involves the development of new technical concepts such as formable fibre-based materials, biobased barriers with multifunctional features and new built-in smart functions. The latter, in particular, requires close research collaboration with the food and pharmaceutical industries.



## Intelligent and connected paper

This area includes the development of paper characteristics towards broader functionality and greater potential for combinations, thereby expanding its reach to include the intersection between printed products and e-media.

Solar energy and energy carriers could also benefit from large paper areas produced in paper mills as solar energy collectors or batteries, for example.

There is a strong need for research in order to understand the possibilities of biobased raw materials in the world of media. Functionality and connectivity need to increase.

Competition from e-media has stiffened with access to the Internet, social media, e-books and e-magazines, which has led to a reduction in demand for printing paper. Even if traditional paper production is still an important base, development towards other areas is essential. System solutions, such as integrating printed media and e-media, may prove to contain both increased functionality for the consumer and an improved environmental profile.

The status of this area within established industrial sectors is characterized by incremental development focussing on improved printability and achieving lower grammages of printing paper. This area is strongly associated with the development taking place in paper production. There is also development at research level and, in this case, it is where biobased raw materials and paper are used in combination with the digitalized world and with energy systems.

### EXPECTED ACHIEVEMENTS

Paper has become a carrier of electronics and is combined with electronic products. Development has taken the industry from traditionally printed products to new and more knowledge-intensive solutions through increased functionality in paper and combinations with electronic products, as well as links to the digital world. The use of paper as an energy carrier has been tested in pilots and demonstration projects and has shown great potential.

### REQUIRED RESEARCH

The development of printed products is closely linked to the development of packaging and both are dependent on a continued increase of expertise on surfaces and possible ways of making surfaces more functional. This is fundamental to this area, which concerns optics and the interaction between material components. The industry also needs development of materials that includes organically conductive polymers, semiconductors and functional printing inks as a part of, for example, flexible, portable, paper-based writing surfaces.

Furthermore, research of battery systems and other developments for storing energy in paper are needed to create functional e-paper products.

Research on separation, degradation and reuse of hybrid products is important. Research around infrastructure in information systems, to clarify the possibilities and obstructions to biomaterials, combined with technicaleconomic studies is also of considerable significance.

### RESEARCH IN BRIEF

- Ways of rendering surfaces more intelligent, including the use of optics and interaction between material components
- Development of materials for organically conductive polymers, semiconductors and functional printing inks
- Energy storage in paper
- Recycling of hybrid products and technologies for separation and reuse



## Textile products

The area of textile products covers all types of textiles, whether for private consumption, public places or technical textiles.

Textile choices are often directly related to the individual consumer, so issues concerning quality, feel and design are important factors. Technical textiles are those that are not created primarily for aesthetic reasons or for use as clothing; instead, the focus is on function, such as flexibility, permeability or strength. Technical textiles have increased in importance within the construction, automotive, agricultural and medical fields.

Research focuses on issues regarding the separation of various components in raw materials, the solubility of cellulose and the development of new sustainable textile-fibre processes in various chemical systems. Research and development is taking place in parallel to allow for the manufacture of dissolving pulp with a high reactivity to chemicals, so that cellulose can be dissolved and regenerated in more sustainable processes.

Cellulose-based textile fibres from wood are becoming all the more important as the world population and prosperity increase. This field is a volume segment and important to the industry. At present, it is a question of covering the need for growth. Cotton production, which is the dominant cellulose fibre used for textiles, is difficult to expand, as the cultivation of cotton is already competing with food production today. In time, cellulose may also replace fossil-based synthetic textile fibres in certain applications. Synthetic fibres such as polyester are clearly dominant alternatives today.

The most common way of manufacturing textile fibres from wood-based cellulose is via the viscose process based on dissolving pulp. There are alternative commercial processes for the manufacture of cellulose fibres but at the moment only in small volumes. Dissolving pulp is manufactured today from both hardwood and softwood, and with either a sulphite or prehydrolysed Kraft process. There have been several conversions from paper pulp to dissolving pulp factories over recent years. Recycled textile fibre is another source that is on the increase, to produce new textiles.

### RESEARCH IN BRIEF

- Cellulose that is custom-made to directly fit into a new textile-fibre process
- Process techniques and chemical systems with a focus on sustainability
- Less ecological burden throughout the entire value chain
- Systems perspective in the entire value chain up to the finished textile

### EXPECTED ACHIEVEMENTS

Considerable research has led to cellulose qualities being adapted to sustainable textile production and to textiles with a high acceptance level for consumers being manufactured; new sustainable production processes have been developed. The Swedish forest industry has a major market share in pulp and fibres for textiles for clothing, home textiles and technical textiles.

### REQUIRED RESEARCH

The most important issue to develop is custom-made cellulose that can directly fit into a new textile-fibre process. A process technology needs to be developed so that the new processes are sustainable. An understanding of the value chains for textile fibres from a systems perspective, and with the consumer in mind, must be developed.

Development must be closely linked to the demand side. The demand for technical textiles is steered by the need in a number of other sectors, which is why development should include research collaboration with these sectors. An understanding of the ecological burden throughout the entire value chain is of fundamental importance.

The global need for textile fibres is increasing – consumption is expected to triple by the year 2050. BioInnovation is investigating if and when sustainable biobased textile production can again be established in Sweden, through their ENTIS project.





Research areas  
for increased  
industrial timber  
construction



## Construction processes

Products that are intended for the building sector are to a large extent generated in the forest-based industry cluster, both for new build as well as renovation.

Ongoing research shows that construction and renovation with wood is economical, sustainable and under the right conditions can be even more profitable, through new ways of managing the building process, manufacturing and logistics.

The establishment of new value chains and building processes is important for the development of a successful European bioeconomy. The development and adoption of new processes is often a risk when it comes to technology, prices, markets and policies. For a new breakthrough in biobased construction, an efficient collaboration between actors in the value chain is needed, together with their combined efforts to develop the processes.

Today there are suppliers of wood-based building systems, now a growing market, which make large structures and multi-dwelling properties. Development is driven by solid-wood construction companies that make premanufactured multi-dwelling blocks using a highly industrialized building process. This type of process is currently under development, with automation taking place in both the production and in information management, resulting in completely new processes. In traditional construction, development is taking place in the large contracting companies as they move towards timber construction, while medium-sized construction companies are also growing and becoming important for timber construction. Internationally, Sweden has a strong position in timber construction, although competition is increasing.

### RESEARCH IN BRIEF

- New industrial value chains with augmented reality (AR) and building information modelling (BIM)
- Automation for increased use of BIM
- Manufacturing methods adapted to biobased materials
- Construction physics in conjunction with increased energy requirements and new building processes
- Calculation models adapted to complex and heterogenous bio-components

### EXPECTED ACHIEVEMENTS

The forest industry is a major supplier to the construction industry. Consumer demand for biobased accommodation is one of the cornerstones of development in this sector, that is otherwise teeming with new corporate activities that create employment and enrich the rural economy. Completely new construction processes have been developed that fully utilize the functionality and quality of wood products, which are incorporated throughout the entire construction process. The efficiency of wood materials has increased through combinations with other materials. A multitude of solutions can be found on the market. Building systems based on wood solutions are the primary choice for residential housing and hold their ground well in comparison with other materials for shops, offices and other buildings. Sweden boasts substantial exports of wood-based building systems.

### REQUIRED RESEARCH

Research activities focused on demonstration of models and new industrial value chains are needed to establish greater collaboration between forest industry processes and construction processes. An example of this is the development of the timber housing industry, which includes systems for augmented reality (AR), the development of construction information management systems and BIM (building information modelling) systems plus circular-economy criteria for product design in development processes of new biobased products.

Automation needs to be developed so that factory robots can be controlled using BIM. Furthermore, there is a need for research concerning obstacles and opportunities for the export of timber-building elements and timber-building systems. On the technical side, there is a need for research into fire and durability, development of new manufacturing methods for biobased materials, biobased adhesives and additive manufacturing. Research is required in construction physics, heat and moisture transport, connected to both increased energy requirements and new building processes, for example. This also includes the development of integrated sensors for monitoring. Expertise in the moisture dynamic of various biomaterials needs to be developed. The resistance of climate-exposed biomaterials is often linked to an uncontrolled moisture load.

There is also a need for research on calculation models and systems for timber construction. This is to give designers security in their choice of wood as a construction material and the possibility for a new rational building system.



# Timber products for construction

Timber products for building can be separated into “invisible” products that do not come into direct contact with people, such as studs, trusses and floor structures on the one hand, and assembled systems such as products for the wood and furniture industries, like modules with windows, mouldings and interiors, on the other.

The main use for wood products can be found in the building sector. Considering that the biobased society will be meeting major demands and volume over coming decades, new and efficient products will be needed. They must meet the demands from users, while allowing efficient construction methods and corresponding to expected requirements on sustainability, recycling and reuse.

As construction increases, the amount of wood being used in the building sector will also increase. Most wood products are of a traditional character. In addition to these products is a smaller number of wood products that can meet the demands of industrial building and new building processes. The trend is towards ever-higher buildings that create new demands on the component materials and for this the level of expertise is not yet sufficient.

## RESEARCH IN BRIEF

- Wood products adapted to renovation and energy-efficient solutions
- Improved characteristics that strengthen the competitiveness of wood-based products
- Hybrid building structures of wood, steel, concrete, polymer materials and glass
- Calculation models, especially for demanding structures
- Systems for reuse and recycling

## EXPECTED ACHIEVEMENTS

By 2030, new wood materials and wood products have guaranteed characteristics that mean they compete under the same conditions as other building materials. The proportion of wood frames for multi-dwelling buildings has increased from 13 per cent in 2015 to 50 per cent in 2030. Sweden is a leading exporter of timber-building elements and timber-building systems to other European countries and is a world-leading exporter of raw materials for buildings and housing. Material combinations are a natural feature in buildings. Methods have been developed to see the whole building as one system, with component parts that give longer maintenance intervals and simplified management.

## REQUIRED RESEARCH

Research is needed for new wood products for the renovation and extension of existing buildings. Furthermore, the development of a new generation of industrially produced building components is needed that meets new demands for smart and energy-efficient buildings and timber-building elements. It is also imperative to have new support processes that are adapted to the traditional construction industry.

Research also needs to be focused on the development of new wood-based building products, for example composites for weight-bearing structures, high-performance biobased heat insulation, wood products with improved characteristics regarding fire, flame arrest, fire resistance and acoustics, among other things. To increase the use of biobased materials, their function must be ensured. The characterization of raw material characteristics also needs to be addressed.

There is also a necessity for creating new hybrid structures of wood, steel, concrete, polymer materials and glass.

For demanding structures, such as sports stadiums and large halls, new construction solutions must be developed together with new products and production concepts. There are no calculation models developed for components and systems either, which is why this is an important area for investment, in order to reach this target. It is also important that wood products are prepared for recycling, already in the design phase. This also applies to systems for reuse and recycling of building elements and biobased building materials.



## Visible wood

This area covers wood products found in people's everyday lives and can be everything from simple interior details such as mouldings, to composite products such as windows, interiors or furniture.

Products may also be components that are included in building systems. Visible wood is the product group that has the largest value-raising potential for Swedish wood raw materials.

Consumer products in wood have a high added value and fill an important role in the shift from fossil-based materials to biobased materials. Wood products must be developed to fulfil users' needs for a long-term sustainable solution. Services linked to wood products is an area that is expected to have great potential, but little has been done so far.

The building trade constitutes an increasing portion of the total sale of wood products. Today, the industry finds everything from traditional products to high value-added products sold on the market. Wood is an easily workable material which means that many consumers can also use it for do-it-yourself projects.

### RESEARCH IN BRIEF

- Hardness, endurance, colour fastness and fire resistance
- Biobased products integrated with electronics
- Perception, design and communication
- Consumer demands with regard to important product areas
- Improved health through use of wood products

### EXPECTED ACHIEVEMENTS

An increase in the use of wood has replaced fossil-based materials and wood products have attained new areas of use.

Attitudes to wood and products produced by the joinery and furniture industries are consistently positive both at decision-maker and planning level, as well as at user level. Innovative added value processes that enhance wood characteristics have been developed, above all to create new and interesting surfaces that fulfil user requirements for cleanability, colour resistance, hardness and fire resistance. This provides an increased possibility for adaptation to other consumer requirements and values.

The Swedish joinery and furniture industries are successfully active on the international market, and wood is seen as the best alternative to fossil-based materials. The export value of Swedish products from the joinery and furniture industries is several times higher than today.

### REQUIRED RESEARCH

The need for research principally concerns the development of the hardness, durability, colour fastness and fire resistance of the material. The industry needs to research "intelligent products" that combine electronics with biobased products. This includes the development of maintenance systems and new services.

Communication expertise and new ways to communicate with legislators and customers is essential. The perception of wood raw materials, with regards its technical, aesthetical and tactile values, needs to be enhanced, in order to enable it to be manufactured and sold profitably.

One of the most important products of visible wood is flooring. A major trend for many years has been floors that look like wood but that are made of other materials. The strong aesthetic appreciation of wood must be combined with new, improved and strengthened characteristics that satisfy customer needs. This is an imperative area of research that demands knowledge of both raw materials and materials treatment as well as manufacturing techniques, but also consumer preferences.

Research must also be done to map what impact products have on people and human health, as well as how products should be adapted to meet the needs that are placed on them. This also includes research on consumers' needs and their perception of wood. Test beds and "living labs" are needed where new wood products can be evaluated under realistic conditions. There is considerable need for expertise on business models adapted for wood products.



## Basic areas of research

Fundamental knowledge and understanding of the use of forest resources is needed. A well-balanced use of raw materials is essential for the transition to a biobased society. A greater understanding of cellulose interaction with water, wood and wood component properties are focused on as well as the conditions needed for new moulding processes.



# Forests for sustainable development

The most quoted and internationally accepted definition of sustainable development, “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”, forms part of the Brundtland UN report “Our Common Future” (1987).

Knowledge based on research, development and innovation is needed to achieve this, where economic, environmental and social aspects are assessed and evaluated at the same time.

Forests and forest land are valuable community resources owned and cared for by private owners, forest companies, the state and local councils, the Church and various foundations. Continued sustainable development of silviculture and forest utilization is based on all kinds of forest owner being given the expertise and tools needed to set up well-founded economical, ecological and social goals according to the preconditions available. Sustainability, clarity and transparency need to be the main drivers when research and development efforts are being formulated by forestry stakeholders, the forest industry and society, in order to improve the conditions for long-term silvicultural management and forest ownership. Social science research and communication about the forest industry’s contribution to finding solutions to social challenges is needed. Natural science research for knowledge-driven development of technology and sustainable methods is another fundamental condition, with a view to future/long-term development of the value-chain.

Society today has a good understanding of and concern for the impact that people have on climate change, but at the same time disagree on what forests and forestry can offer to counter this. There is a need for fundamental knowledge on issues such as the current and potential effects of active and passive carbon storage, sustainable material and energy substitution, and the possibility to develop both wood production and ecosystem services.

## RESEARCH IN BRIEF

- Knowledge-based information and decision support plus analysis tools
- Life-cycle analysis and systems for reporting sustainable production of forest raw materials
- Comprehensive outcome and sensitivity analyses for setting goals and plans of action
- Forms of effective communication that build confidence between the forest-based sector and society
- Landowners’ motivations for decision making

## EXPECTED ACHIEVEMENTS

Collaborative research on sustainable development, involving both civil society and industry and with a wide range of skills and disciplines amongst participants, has developed a common view of the importance of forests and sustainable forest utilization. There is effective and easy-to-use support for analysing goals and well-developed decision support, where economic, environmental and social consequences are presented and specific suggestions are assessed. Tools and techniques for comprehensive, transparent accounts of life-cycle analysis and sustainable development exist and are used for Environmental Product Declarations (EPD) of forest-based products and continual improvement efforts.

## REQUIRED RESEARCH

It is of critical importance to have a system view of development. Increased globalization leads us towards competition between value chains rather than between individual companies. Research must, therefore, be directed towards how value chains and sustainable flows of forest raw materials can be developed and optimized.

How are actors integrated into various value chains and how are various value chains integrated amongst themselves? How are raw material production and value chains affected by other ecosystem services and social demands? Research on sustainability in general is a priority but it should be focused on different value chains which promote forest policy goals for increased biomass production, higher value exchange from the forest and increased contribution to achieving climate goals, where the forest’s ability to replace fossil-dependent products is an important part.

Knowledge-based decision support and analysis tools need to be developed and validated continually. This is necessary in order to design well-researched goals and plans of action for sustainable use, with respect to both forest raw materials and other ecosystem services.

Comprehensive outcome and sensitivity analyses for various scenarios and maintenance plans with a regional perspective need to be carried out. Behavioural science research that clarifies landowners’ motivations is an essential part of this, as is the impact of regulations and standards.

# Understanding and utilizing raw materials

Knowledge of the variations, strengths, weaknesses and volume fractions within and between trees, harvest sites and various material flows is needed for the development of efficient processing operations and competitive products.

This is important ground for developing efficient, knowledge-driven and well-cooperating production systems that can give Swedish silviculture a leading position in the bioeconomy. It is also needed to combat competition from countries that have faster-growing raw materials.

Diverse climate, fertility rates, growth competition, maintenance, genetics, structural variations and tree age give substantial variations in the characteristics of different Swedish forest raw materials, between and within sites, but also within the stemwood of individual trees. Some features can be predicted and calculated whilst others must be measured. Variations from root to tree top and from pith to bark through the tree's stem cross-section, including the volume fraction of each component of wood, give rise to a wide scale of mechanical, visual and chemical characteristics. The key to sustainable competition is in the possibility of utilizing this knowledge in detail, for technology, and methods and systems that can efficiently put these variations to use. This applies all the way from the production and harvesting processes in the forest, through various and at times interactive industrial processes, to a sought-after mix of expedient end products.

## RESEARCH IN BRIEF

- Methods for extracting tomographic information from wood at different structural levels
- Relationship between wood structure and its physical and chemical properties and wood raw material properties
- Process analysis systems for more efficient sawing
- Availability of wood and fibre and its reactivity

## EXPECTED ACHIEVEMENTS

There is well-established knowledge regarding the variations in the structure of biobased raw materials and chemicals at different structural levels. This includes fundamental knowledge of the variation in growth conditions and wood formation as well as the link between the material properties and the physical and chemical composition of wood and fibre. This knowledge is coupled with more-efficient manufacturing processes, giving a higher raw material yield, fewer structural variations and a better value utilization. Industrial producers get the right raw materials that are best for the product being manufactured.

New methods exist for efficient raw material steering and information feedback between market, industry and forest, as do new business and logistics systems affecting the entire forest industrial system. Digitalization of the various value chains plays a key role in the integration of this new knowledge.

## REQUIRED RESEARCH

Knowing the amount of forest raw materials available and their properties is central for both producers and industry customers. With analysis and measurement methods as well as property models, key information on the structure can be obtained for different resolution, stem average value and spread dimension for example, micro-scale of fibre dimensions, fibril angles, coarseness, density and heartwood. Today, tomographic information is being developed on micro- and macro-scale but research should also focus on providing information about the nanoscale and micro-scale areas with synchrotron x-ray tomography, 3D spectral imaging with synchronous IR microtomography and other methods. This research will result in new knowledge of how the chemical components are distributed in the wood raw material.

As new methods of process analysis in the sawing process develop, the requirement for knowledge of the structure of wood and sub-components increases, meaning that the new knowledge can also be utilized in production.

Information about porosity, availability and reactivity is important in order to modify fibres and wood in an optimal way. The technical purpose of modification is to create new wood components and utilize the modified component, as an additive in chemical products or as a constituent in different materials, for example. Scientific issues are about being able to control the modification at different structural levels to achieve new specific characteristics. These new features can then be used in the development of materials and processes.

# Physical properties of wood and wood-based composites

The world's forest industry is facing a major paradigm shift, through the transition from paper-based to digital media amongst other things.

The Swedish forest has the challenge of competing with the fastest-growing tropical forest plantations. Knowledge of the composition of Swedish wood raw materials and their interacting physical properties can provide system solutions where wood qualities, such as stiffness and strength, provide competitive advantage.

Climate issues and societal needs will be the focus for future changes in industrial forest research. It is therefore likely that new business ecosystems and products will be developed on the boundary between various business sectors. Swedish forest industry production has a very low carbon dioxide footprint, while Swedish forests reduce the amount of carbon dioxide in the atmosphere by around 60 million tonnes annually. The forest industry is therefore the only large-scale material-producing sector that actually reduces the impact of carbon dioxide. Meanwhile, the construction and housing sectors represent around two thirds of society's total climate emissions. New wood-based building components and systems for increased building with timber will therefore be a decisive factor in Sweden's ability to mitigate the impact of climate change.

## RESEARCH IN BRIEF

- Strength models (FEM) based on quantitative structural information in wood
- Structural hierarchy and heterogeneity of wood material
- Physical property characteristics for wood joinery and wood composites plus hybridization with other materials
- Understanding and greater efficiency in cutting processes

## EXPECTED ACHIEVEMENTS

Expertise in wood and wood-based composite physical properties is used to create more efficient building components of newly fabricated wood materials, i.e. engineered wood products (EWP) and new hybrid materials. The complexity of the new materials is enabled by increased robotized industrial construction.

The characteristics of building components on a macroscale can be predicted, and integrated design procedures for products and components developed. There is a scientific knowledge platform that links to empirical experience feedback.

## REQUIRED RESEARCH

Research in robotized industrial construction enables the use of more complex building components and systems based on EWP, such as CLT (cross laminated timber), wood veneer products and glulam. Different types of EWP can then be combined into hybridized building components. In the end, hybridization can also be achieved with steel, concrete, glass and other useful materials.

Since there is an inherent structural hierarchy and heterogeneity in wood – as well as in other biological materials – the meaning and potential of the structural hierarchy in various wood composite systems must be researched. With methods to quantify structural heterogeneity in wood, new strength models can be developed, such as those used to predict the mechanical properties of wood composites. Models need to be developed at different structural levels, which are today mainly on micro and macro-scales, but in the future also on nanoscale.

Various methods are used today to manufacture different wood and cellulose-based materials but predicting the future characteristics of such materials is still in its infancy. When it comes to wood materials, it is necessary primarily to utilize the positive natural properties of wood and building composites at the lower structural levels to minimize, if possible, the effects of property variations in the wood material. Log scanners can already improve saw yield and product value today. Research is needed, however, on how to digitalize and link together large parts of the value chain, from tree felling to industrial building.

Knowledge of wood's 3D physical properties, strength, stiffness, elasticity and rheology is of crucial importance, not just for efficient building elements but also as a knowledge platform for wood joinery and composites and, for example, for wood cutting processes.

# Increased understanding of the interaction between cellulose and water

The most important constituent in forest raw material is cellulose. Understanding the interaction between cellulose and water is therefore central to both the manufacturing process and today's products, as well as to create the conditions for new products and processes.

Moisture content, water content and sorption kinetics control the mechanical properties of fibres, paper, cardboard and wood materials: its swelling ability, creep properties, dimensional stability and barrier properties. The interaction between lignocellulosic material and water has been studied for a very long time. However, many so-called established truths are based on inadequate data or on obsolete ideas and theories.

It is known that moisture absorption is necessary for biodegradation, whilst at the same time being an Achilles' heel for the products' dimensional stability, creep and barrier properties. Therefore, in order to develop tomorrow's products, moisture absorption must be controllable by mechanical, enzymatic or chemical modification without destroying biodegradability.

## RESEARCH IN BRIEF

- Spectroscopic methods and molecular dynamic simulations of cellulose-water interactions
- The relationship between water sorption and its influence on the material physical properties of cellulose
- Quantification of the cumulative size distribution of the local free volume of cellulose at different moisture levels
- Sorption kinetics and relaxation effects in cellulose materials at different moisture levels and moisture variations

## EXPECTED ACHIEVEMENTS

Through in-depth knowledge of the interaction of cellulose with water the drawbacks of water in its present form, which have an effect on swelling, dimensional stability, creep and so on, can be reduced. Knowledge of different types of new analytical methods on the cellulose supermolecular structure, as well as advanced spectroscopy, are used to understand cellulose-water interaction significantly better. Knowledge of the effects of water on the free volume of cellulose has been mapped. This knowledge allows for control and manipulation of the structure of cellulose so that it can alleviate cellulose weakness in the presence of moisture and moisture variations.

## REQUIRED RESEARCH

Fibre wall accessibility in chemical or physical modification, as well as the fact that hornification phenomena are controlled by the moisture and drying history of the material, is central to the recyclability of lignocellulosic materials. These issues are key to moving forward with new processes and product development. The scientific development of a number of new methods simultaneously opens up new possibilities for studying both the importance of the supermolecular structure of lignocellulosic material, as well as its connection to the interaction between cellulose and water. This new knowledge can then be linked to atomic molecular dynamic simulations and modelling. The kinetics of moisture absorption and the effects of moisture absorption on the free volume of cellulose are key research areas. As for wood materials in practical applications, it is also doubtful that the material ever approaches equilibrium, since it takes a long time and, in reality, the humidity is seldom constant. In the case of hygro-expansion and sorption hysteresis, the situation is further complicated by the sorption kinetics.

Due to heat development, the enthalpic addition of moisture during water absorption, the final state will be completely affected by the kinetics and heat transport in the material. Another central and historically "well-known" factor is that moisture absorption is affected by the swelling pressure in the material and that kinetics therefore will be of great importance for the relaxation of the material and will ultimately be a key to hysteresis effects. Non-equilibrium effects make it difficult to apply thermodynamics to the system, for example, to understand sorption hysteresis, for which today there is no consistent physical theory. If the role of water at different ultrastructural levels can be understood, it might be possible to control its chemical and physical properties, for example, by modifying the cellulose.

## New moulding processes

New products based on lignocellulosic materials require new types of efficient processes with a high process speed.

Areas of development can be carried out on the basis of existing infrastructure, but new products will require the development of completely new forming methods. The forming of new material components include, for example, fibres or fibrils to form composite materials or products of specific composition, material structure and geometric form.

The material systems can be solid or liquid in the form of solutions, colloids and suspensions. There are many examples of challenges in this field of research. The scientific issues are about forming concepts, flow phenomena in suspensions, colloids, fluids, chemical reactions and processes and their kinetics, fibre network deformations and their architecture, rheology, hybridization between different materials and more.

Plastic manufacturing based on thermoplastics in the form of different production methods such as extrusion as well as compression moulding has a high process speed. Since cellulose is not thermoplastic and there is no efficient plasticizer, new methods and materials must be developed. The development of improved bioplastics as packaging materials based on lignocellulose-based materials is one example. Plastic composites that utilize cellulose stiffness in the form of fibres, cellulose filament or nanocellulose are interesting developments that allow increased resource efficiency and can greatly reduce the proportion of fossil-based materials used. Another area in which lignocellulosic material has been given a major role is to replace foamed plastics with aerogel-based cellulose materials for insulation and impact protection in packaging. Thin film technology is a high-level area for advanced applications. These technologies enable nanomanufacturing of biobased materials and their usability has already been demonstrated in flexible solar panels and printed electronics. Finally, it is worth mentioning that new methods of spinning cellulose are under development.

### EXPECTED ACHIEVEMENTS

Fossil-based plastics can be replaced, for example, in packaging, construction and building materials, as well as textile materials. This is possible thanks to a range of new material-forming methods, with which materials with high geometric complexity can be created.

### REQUIRED RESEARCH

Research should focus on developing principles for the design of new materials. Perhaps the most important technical challenge is process speed and the ability to make materials with complex geometries.

For biobased barrier materials, the process speed is too low for wet forming of materials based on nanocellulose. In addition, all biobased materials have the disadvantage that in an untreated state they always absorb water, which is common to all biodegradable polymers, which in turn means that these materials have limited barrier properties. In the case of lignocellulose-based plastic composites, there are challenges in mixing, fibre dispersion, fibre and matrix compatibility and moisture stability. Wet spinning of cellulose solutions and dispersions is an interesting research area. Furthermore, there is no fundamental research about dissolution, aggregation, orientation and rheology of cellulose solutions and dispersions. For nano-based aerogels, it is important to remove the water in an energy-efficient manner in wet processes, without causing a structural collapse of the gel. Research challenges are in many cases well recognized but basic research in the field requires the next step before industrial application.

### RESEARCH IN BRIEF

- Cellulose-reinforced composite material
- Processing for forming and mixing, as well as mechanisms for stress transfer in composite materials
- Manufacturing processes for thin film manufacture from cellulose dispersions
- Mechanisms for dissolving cellulose, aggregation in solutions and rheological phenomena relevant to cellulose spinning
- More efficient processes for removing water from cellulose dispersions



Comprehensive  
knowledge  
development





The forest industry has a great interest in and need for sectoral research. Below are the most important areas in which the forest industry needs to see increased investment in joint sectoral research. Collaborative programmes between actors from several disciplines and sectors, with combined industry and state funding, are a must. This will ensure that it happens and it will also open up opportunities for new actors to be involved, and business areas that do not yet exist today.

### **Climate change and life-cycle analyses**

Materials made from forest raw materials can be recycled and used for new fossil-free products. In order to achieve sustainable overall solutions, analyses of how the sub-processes throughout the system work, and also where products, raw materials and associated services are included. As part of Sweden's further development as a sustainable bioeconomy with high material and energy efficiency, there is a need for more knowledge and research on the role of biobased raw materials in a sustainable society, and how they can replace fossil-based materials. Here too, social science research is important.

### **Political processes and means of control**

The forest industry is affected by a wide spectrum of policy measures, not least at the European level. These decisions directly or indirectly affect production of forest-based products and their use. Due to the considerable complexity of the forest industry, political decisions directed at a particular issue can have undesirable knock-on effects in other parts of the system. Methods founded on scientific outcomes and defined by relevant system boundaries, create the necessary conditions for policymakers to make objective, well-informed decisions. There is an important need for scientifically based methods for consequence analysis of political processes and instruments.

### **Consumer attitudes and preferences**

The understanding of consumer attitudes and preferences is crucial for companies in the forest industry. This presents a research need to learn what drives people with regard to sustainable consumption. Another focus area is understanding what kind of environment people want to live in. In new markets, for example, health and safety issues are central. Research on market issues and new business models creates knowledge hubs that can be used by the forest industry.

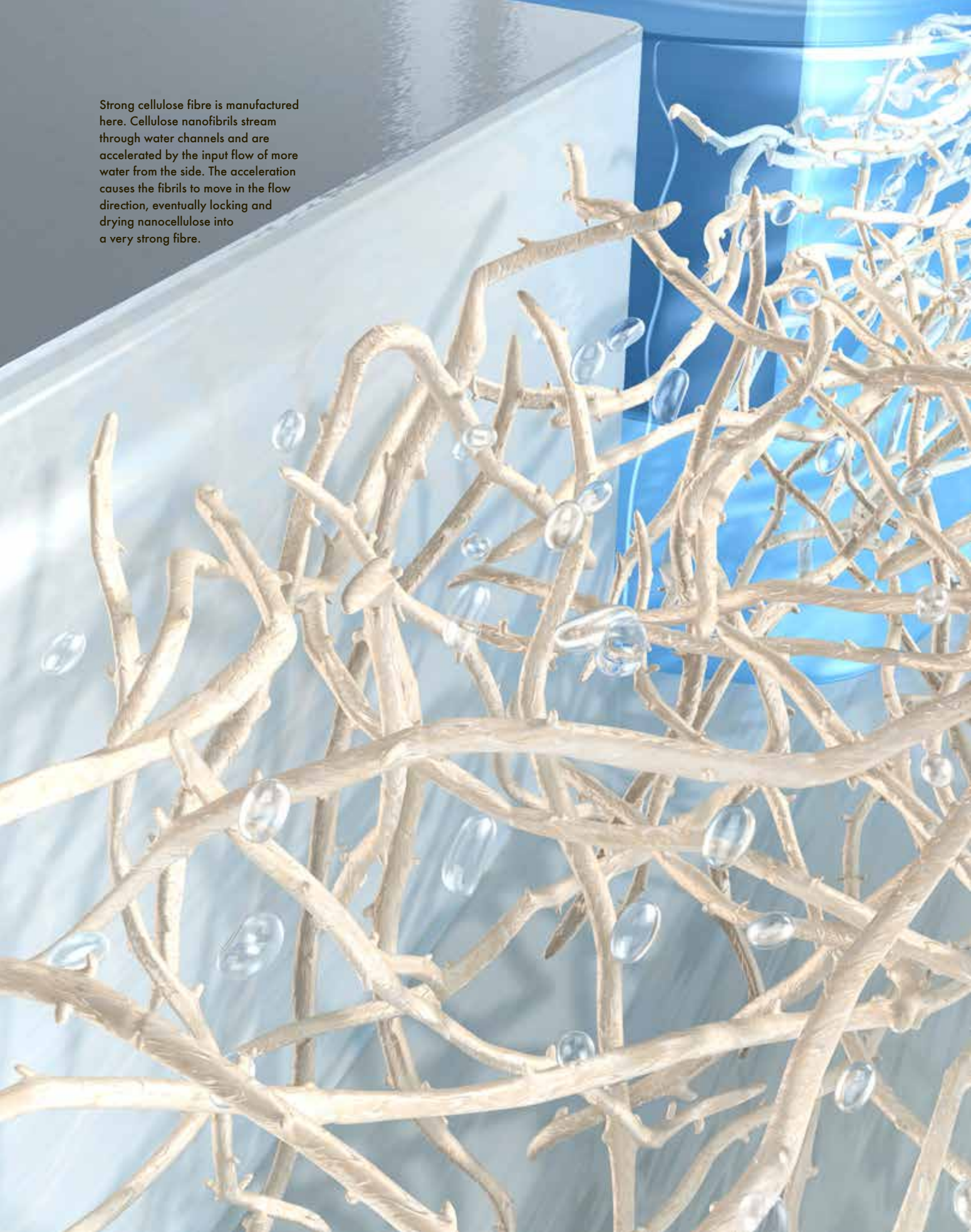
### **Energy systems**

Energy efficiency and the increased use of renewable energy are two major challenges to society. The forest industry is in a special position here, being both Sweden's largest supplier and user of renewable energy. It is important to investigate opportunities in the energy sector that could have a significant impact on Sweden's transition to a fossil-free bioeconomy. Knowledge gaps and research needs are also clear, for example, in efficient processes and finding a balance – both technically and commercially – in the product portfolio of the new biorefineries.

### **Digitalization**

Digitalization is changing our entire society, not least our consumption patterns. Digitalization also provides revolutionary opportunities to describe, control and integrate collaborative manufacturing processes into sustainable products. Research is needed on the standardization of concepts and data flows to achieve effective and unbroken communication, both through and between different value chains and actors. The structured collection and analysis of operating data on the information owner's terms is an important instrument, not least for forestry processes.

Strong cellulose fibre is manufactured here. Cellulose nanofibrils stream through water channels and are accelerated by the input flow of more water from the side. The acceleration causes the fibrils to move in the flow direction, eventually locking and drying nanocellulose into a very strong fibre.





# The organization behind the research agenda

The National Support Group Sweden (NSG), formed by the Swedish Forest Industries Federation, is the collective force behind the Swedish Forest-based Sector Research Agenda. NSG Sweden is also a reference group for the Forest-based Sector European Technology Platform (FTP).

NSG Sweden's operations are conducted within three reference groups with representatives from civil society, industry, private institutes and academia.

The three groups are: Forestry and Forest Raw Materials; Pulp, Paper and Biorefineries; and Wood Processes and Wood Products.

The reference group leaders coordinate the development of the research agenda, communicate activities to the sector and inspire new projects and programmes. A programme secretariat at the Swedish Forest Industries Federation is working on a daily basis and maintains contact with stakeholders and financiers.

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The cover picture shows 3D printing with an ink comprised of cellulose, water, sugar and alginate. If researchers add skin cells, a tissue is created that can be used for empirical testing.