



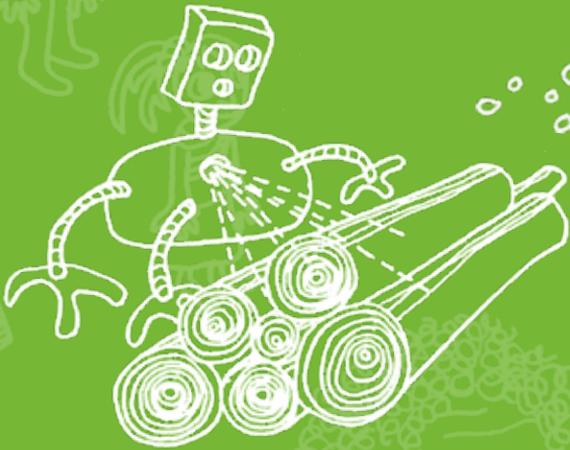
# People in the Bioeconomy 2044

Sustainability, closed circles,  
and use of biomass woven  
into solutions





BRAIN Activity  
BREAKFASTS



ON LINE

STEPS

VTT VISIONS 4

A green line-art illustration of two hands, one above the other, with fingers spread, positioned on the left side of the page.

# People in the Bioeconomy 2044

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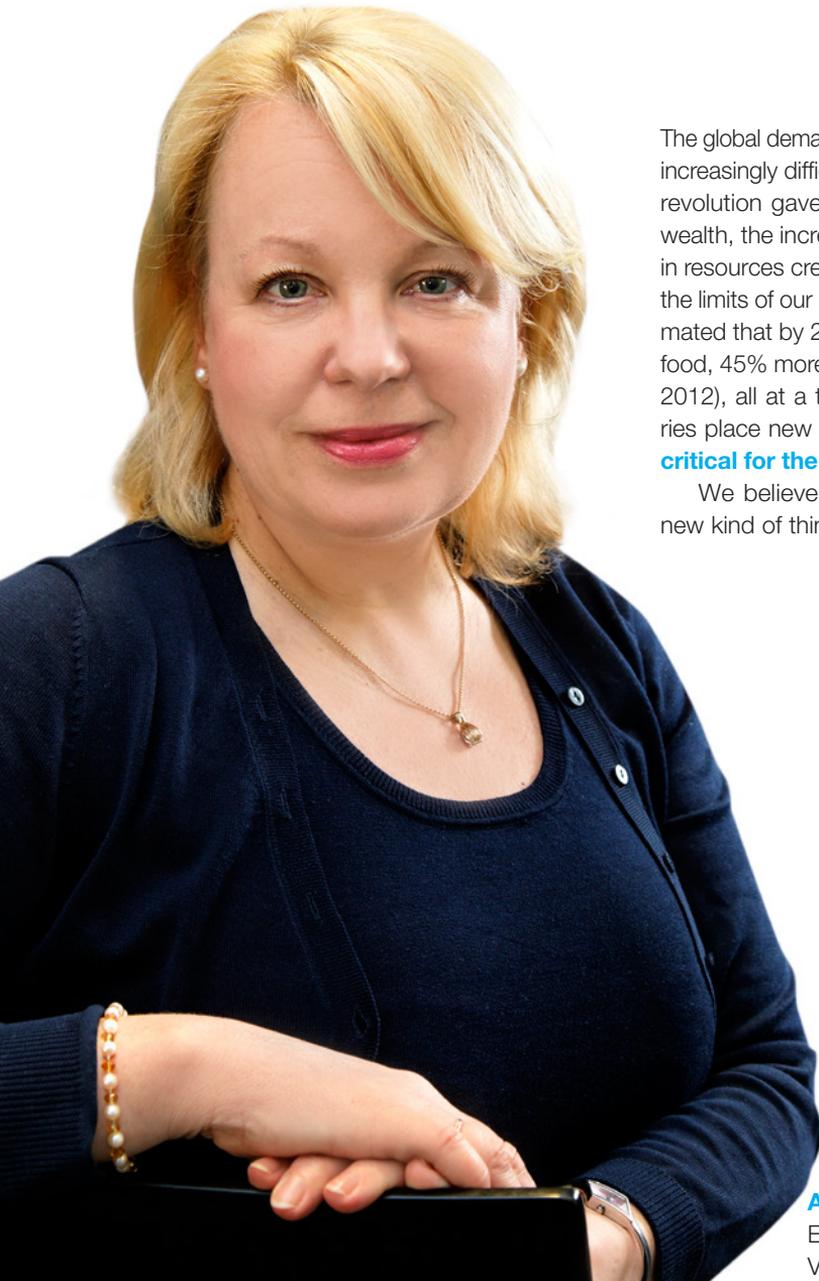
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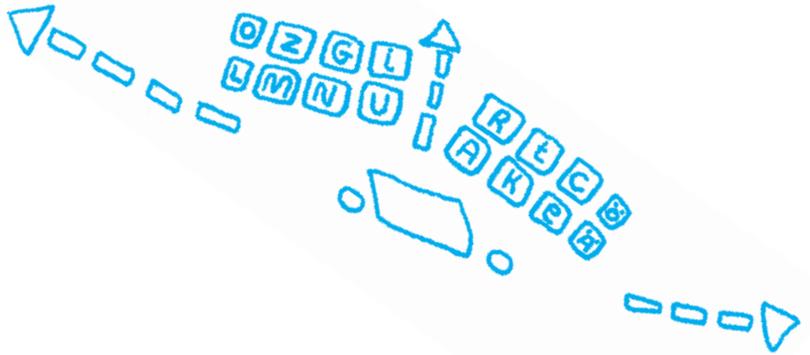
# Preface



The global demand and supply equation has become increasingly difficult to solve. Although the industrial revolution gave rise to unprecedented growth in wealth, the increased pollution and overall scarcity in resources created by this development is testing the limits of our planet. The United Nations has estimated that by 2030 the world will need 50% more food, 45% more energy and 30% more water (UN, 2012), all at a time when environmental boundaries place new limits on supply. **New thinking is critical for the sustainable future of the globe.**

We believe the Bioeconomy represents this new kind of thinking. Growing national and global

**Anne-Christine Ritschkoff**, Professor  
Executive Vice President, CTO  
VTT



interest in sustainable development is expected to make the Bioeconomy an essential part of the economic system in the years to come. The Bioeconomy, in our view, is economy based on a sustainable, resource-wise society. Furthermore, bioeconomy is new, sustainable thinking on how to live. As a cross-cutting approach it has an effect on the whole of society, linking food security and people's well-being to the sustainable use of raw materials and natural resources.

By 2030, European industries aim to produce over 30% of specialties and fine chemicals from renewable feedstocks. Sustainable biofuels will fulfil 25% of transport energy needs. The European forest has renewed itself and supplies the global markets with competitive, advanced bio-based fibre and polymer products, using novel textile and carbon fibres, nano-cellulose derivatives and bioplastics as raw material. Paper, of the conventional fibre products, remains to create further value from the forest. Recycling and reuse of renewable materials has become part of everyday life, and waste and industrial side streams are exploited thoroughly.

In today's reality, significant changes only take place if they are commercially viable. There is clearly room within the Bioeconomy for such new openings and new innovations. As an example, the Bioeconomy today in Finland accounts for about EUR 60 billion of GDP, and a doubling of this amount by 2030 is considered feasible. Cutting edge innovations are nonetheless born solely out of skilled

commercialisation and technological excellence. Both are necessary for realising the Bioeconomy potential. In the case of the European forest sector, pressure to create more value from the forest has meant on-going structural change and the need for radical renewal. To make this happen we need radical innovations, and the courage to take on the role of forerunner in the successful Bioeconomy.

Here, science and research play a key role. Scientific excellence paves the way for the emergence of innovations and new businesses. The successful Bioeconomy requires a multidisciplinary approach, combining disciplines ranging from chemistry, biotechnology and nanotechnology to electronics and information and computer technology, and on to social sciences and economics, and even design. Expertise is also required in understanding market dynamics and business concepts. Research organisations are pivotal in bridging all the above for the benefit of business, and consequently society.

At VTT, the Bioeconomy encompasses almost 40% of research activities and services. VTT's role in providing breakthrough innovations and new competences for the novel Bioeconomy value chains is crucial to the renewal of the Finnish Bioeconomy industries: **together with its strategic partners, VTT forms a platform for an innovation ecosystem attracting industrial stakeholders from Finland and elsewhere. At VTT we go boldly beyond the trends, and breed the emerging bio society and industries within.**

# The Bioeconomy is holistic

The world's decision makers face immense challenges from aging societies, population growth, climate change, sustainability, scarcity and food security. Such challenges clearly represent risks, but they also provide exciting opportunities for a whole new economy which is altogether smarter, greener and more inclusive. The Bioeconomy – or 'biosociety', as some are calling it – places itself in the framework of natural resources and sustainability, and the cross-cutting nature of it touches almost every aspect of the way we live. Furthermore, its paradigm shift offers challenges to many existing industries and how they interrelate.

The Bioeconomy is defined by the EU in their The Knowledge Based Bio-Economy (The Knowledge Based Bio-Economy in Europe, 2010) as the sustainable production and conversion of biomass for a range of energy, food, health, and industrial products. The increased use of biological materials is accompanied by many other defining issues, one of them being changes in lifestyles and eating habits, which is also at the centre of VTT's approach to Bioeconomy. The shift towards a Bioeconomy is a shift towards a new kind of society, where things are produced and consumed in a sustainable manner.

The Finnish Ministry of Employment and the Economy set up a working group in 2010 to explore the concept of a Bioeconomy. The background report for this work defines a Bioeconomy from three perspectives: 1. the ecosystem (sustainabil-

ity), 2. the use of bio-based products, and 3. the nature of production processes (Kuisma, 2010). Bio-based and biodegradable products emphasize the circulation of materials in the system.

The Finnish Innovation Fund (Sitra) also defines the Bioeconomy as a cross-cutting theme that affects a whole society (Luoma et al., 2011). According to their definition, a bio-based economy is not only a bundle of new technologies and bio-related economics but also a new way of thinking on how to live sustainably. This view is close to VTT's understanding. In our view, the Bioeconomy is a large, socio-technical system that binds together technologies, markets, people and policies. It is defined by principles rather than the sectoral borderlines of existing industries. A Bioeconomy actively forges links between industries that previously had no connection, within a new, symbiotic relationship where one industry utilizes the by-products of another.

**More importantly, the Bioeconomy brings together phenomena that have thus far been disparate: business and sustainability; ecosystem services and industrial applications; biomass and products for mainstream consumers. Economy and sustainability need to fit the same big picture.**

All in all, the Bioeconomy is about sustainability, cross-sectoral cooperation, 'closed circles' and the use of biomass. The Bioeconomy is neither a new sector, nor a list of applications. It is a holistic con-

**THE BIOECONOMY  
ATTRACTS  
OPPOSITES.**





cept that touches life in a myriad of ways. It would be nigh on impossible to present the applications of a Bioeconomy across the board. For this reason, in this paper we kick-start a description of the Bioeconomy with three examples illustrating individual lives. We then discuss the technology-driven themes that are key to a 'biosociety' from VTT's perspective.

However, to reach the vision of a sustainable Bioeconomy, many issues need to be tackled. We need to find solutions to several problems before we have crossed the gulf between the situation today and the sustainable potential we describe for the year 2044. These issues include:

- the investment required for production units with advanced technology platforms is vast
- the availability, cost and quality of biomass may cause problems for the enterprises involved
- their supply, cost and quality mean that the competitiveness of bio-based products against traditional output is not guaranteed, especially in the early stages
- consumers may adapt slowly to new products and services if the benefits are not clear
- the timing of policy instruments implemented to best effect is hard to gauge and control

These obstacles suggest that to achieve a Bioeconomy, a significant boost is needed. To cross the gulf, it needs to be high on Europe's political agenda. Such a large transition will not take shape without conscious efforts by governments, companies, research organizations and citizen-consumers.

We trust the following stories will shed light on the key issues in the implementation of the Bioeconomy, giving a sense of the opportunities, and most importantly, providing inspiration.



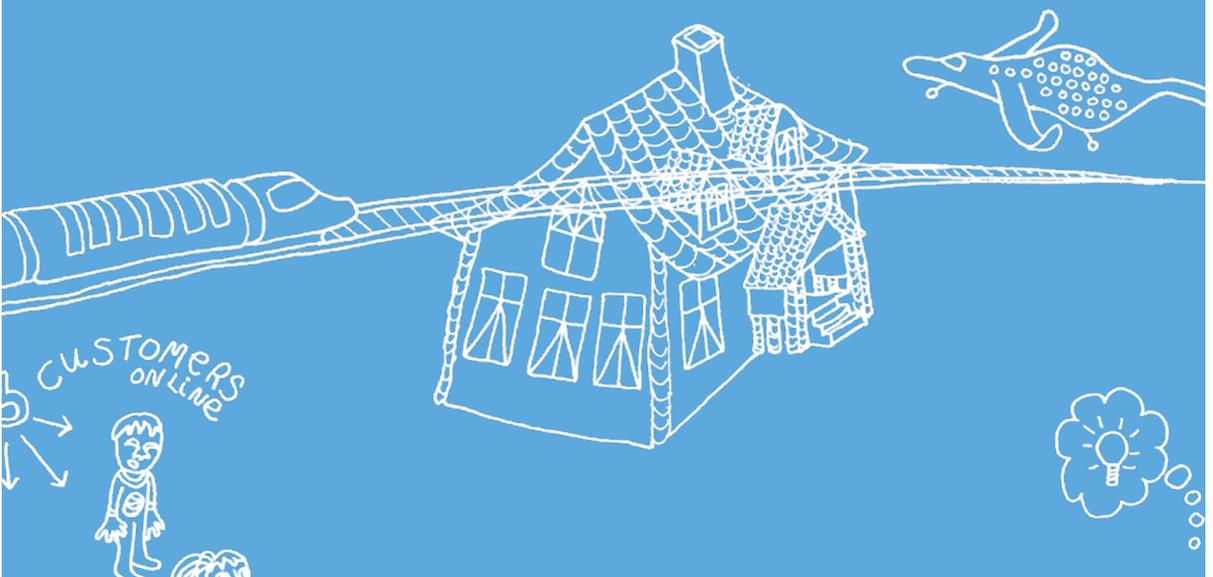
# Snapshots of life in 2044

Even as the Bioeconomy harnesses innovations and industries, it is centrally about people – us – living our lives in sustainable ways. Innovations are only real when they are put to use. It is crucial, therefore, to step down from the macro level and see how the Bioeconomy fits and reshapes the everyday.

The following stories describe life as it might be in 2044. They are speculative snapshots of possible events in a few private lives, not forecasts aiming at accuracy or scenarios drawn from extrapolated trends. We introduce three personas and their fictional lives, reflecting some of the important themes in the Bioeconomy. This kind of persona technique is often used in foresight as a way to make abstract, macro-level developments more tangible. These stories were created by VTT technology and foresight experts, and the aim was to blend different types of knowledge accumulated in earlier research on future challenges and solutions. The stories embody a key characteristic of good foresight work: they weave together elements that are typically discussed separately in academic research. **Thus, society meets technology meets economy.** We trust these persona stories serve as a fertile introduction to possible futures.

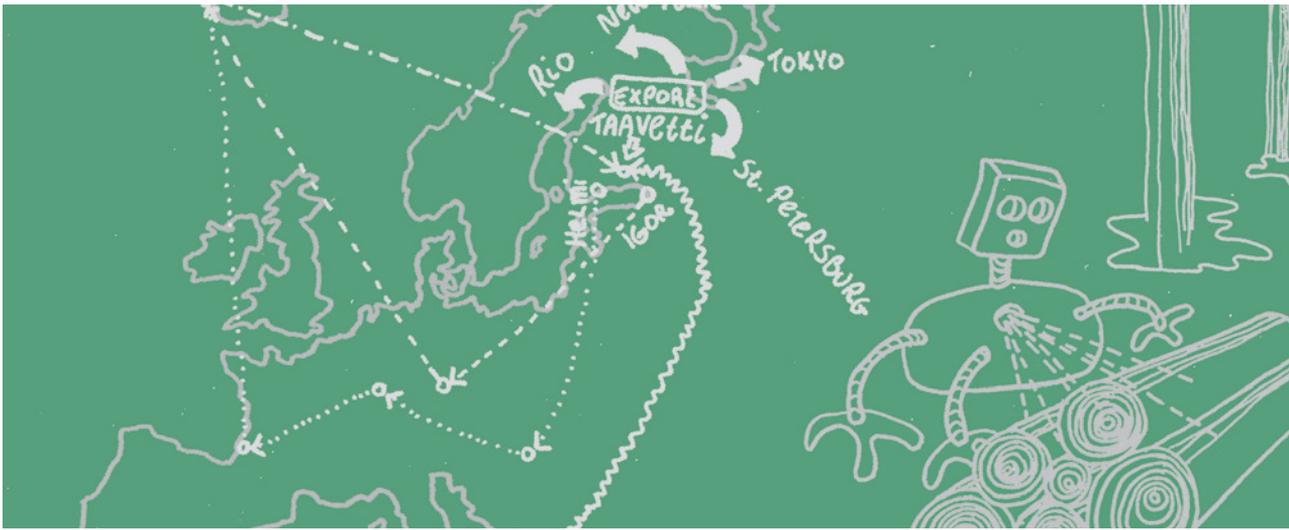


So, let's meet Helmi and her family on their farm in Taavetti; the Anderson family in their metropolitan, retro-house and, finally, the ultra geek, Jonas "Brad" Salmi, in his Oulu-based laboratory.



# Helmi, 30 – Adding value to agro products





In 2044, the start-up culture that began around 2010 is still strong. Finland has become a lucrative place for agricultural enterprises as various catastrophes have rendered some traditional farming regions abroad non-arable. The old maps drawn by economic geographers have become invalid as agricultural production seeks new areas. Finland is known for its unpolluted environment and good quality agro products. Farmers – or bio-economic entrepreneurs as many of them prefer to be called – aim to add as much value as possible to their products.

Helmi is a 30 year old, city-born, eco-minded Finn who has moved back to the family farm in the village of Taavetti in Southern Finland, taking her family with her. Her husband, Igor, is Russian, and through his Russian connections they export their berry-based, high-end delicacies and cosmetics products mainly to retailers and online customers in St. Petersburg, Russia. In addition to berries, they grow flax for the textile industry and mushrooms to guarantee income in bad years. They also harvest the forest to produce

### ADDING VALUE TO AGRO PRODUCTS

fibre materials for industry as a contract manufacturer. The trees are cut and sprayed with enzymes that start a chemical process that softens the wood. Their food is as local as possible, including roach from the nearby lakes and game from the forests.

Helmi and Igor's kids Avena and Linum are a bit too young to help with the farm, but they adopt a sustainable lifestyle when participating in the farm routines. Most of the manual labour, however, is automated and performed by robots, so Helmi can work on coordinating the production, logistics, marketing and administration. Customers order their tailored berry products online and Helmi controls the production lines accordingly. The most passionate end-users follow the process through their online customer account, which shows values for various indicators, such as the vitamin levels in the lingonberries.

Helmi and Igor are committed to sustainable farming practices. They use raw materials very efficiently and the left-overs from the production processes are recycled, as is the household waste.





The bio-based fertilizers are acquired from a nearby biogas facility that processes organic household and agricultural waste. Solar energy, stored in large, bio-based batteries and electricity from the biogas facility dominate their domestic power use, while biofuels are used in machinery and vehicles. Some of the rural roads no longer have asphalt, instead they are treated with a lignin-clay solution to prevent dusting.

In Helmi and Igor's family, the older generation plays an active role. Helmi's 89 year old grandfather, Tapio, living and working on the farm, uses some of his old skills which have proven most useful. He tells the grandchildren stories about how he rode his bike on the same country roads back in the 60s, and how he used to eat ice-cream at the local kiosk. It was there where he, by accident, met Gianna a few years back. Gianna knows a lot about farming, as her family used to own a vineyard in Sicily before the climate got hotter.

The fossil economy is vanishing as new, sustainable practices are adopted. The new economy has not, however, solved all the problems – not

everyone has a job. Instead, robots carry out the production work in many facilities. The bio-based products and processes require significant investment, some of them being too heavy a burden for individual farms. A few local farms have joined forces and established a cooperative to build a bio-refinery. It is common to ally with neighbours to create things that are too expensive or workforce intensive for individual households. New forms of cooperation are developed to match the needs of innovators.

Increasing immigration also sets challenges. How to populate the countryside? How to live in dense urban areas? How to better utilize arable land? Helmi and Igor have increased the efficiency of their farm, but they also care for the landscape. They preserve old meadows and feed the butterflies. Rosemary honey is produced for demanding customers. The family's own food is mostly grown at home, and Helmi dreams of a home-grown linen dress, but there is little time for that, with the business to attend to.



# The Anderson family – worms, willow dresses and wetland biotypes





3 CUSTOMERS ON LINE

The Anderson family – Philip (44), Vilma (40), Lisa (8), and Sam (6) – live on the outskirts of the Helsinki metropolitan area but within reach of the railway connections. The style of their house reflects the 19th century villa heritage. It may look old but it is built according to the zero net energy principle, utilizing energy from the appliances and residents, so that there is no need for extra heating. The family travels regularly to Thailand with a plane that uses fuel produced by microbes. In Thailand, they have become accustomed to eating insects and invertebrates, so worms cooked in different sauces has become a favourite dish, especially for the children.

The environmental impact of flying is not something the Andersons need worry about – the CO<sub>2</sub> debate has died down since the 2020s, when the footprint issues were tackled with efficient policies and widely-adopted bio-energy innovations. The car pool vehicle they use at weekends is another

good example – its electrical battery is state-of-the-art, so driving range is no longer a problem. In addition, good public transport into the city allows carless commuting.

Dr Philip Anderson works from home – he is a life extension specialist who diagnoses emerging diseases based on patients' data. This branch of medicine has boomed since the rise of the availability of genetic information in the 2010s. Philip's patients wear clothes and accessories with sensors, or they exhale directly into devices that automatically send data securely over the internet so that Philip can work on it. He creates individualized diets for his patients or prescribes plant-extract molecules to be slowly released into the air in their homes. By the 2040s, this kind of preventive medicine has been a central part of the Finnish healthcare system for years, and Philip has already established his name in the field. Some of

**WORMS, WILLOW  
DRESSES AND  
WETLAND  
BIOTYPES**







his patients come from outside of Finland, mainly from the Baltic area, due to a region-wide health-care agreement.

Vilma works as bio-product development manager in the Otaniemi Bio Hub, participating in the development of forest biomass-based textile fibres. The team's inventions have made it possible to create dresses from willow and birch, for instance. Despite teleworking being the norm in many professions, Vilma emphasizes face-to-face presence amongst her core developer team to maximize the creation and transfer of new knowledge in the lab.

During the construction of their house, however, the Andersons exceeded their budget and so now they carefully monitor their cost of living, including the shopping bill. Although they have already reduced the amount of meat in their diet for health and environmental reasons, it is still necessary to avoid expensive ingredients, like synthetic meat, too. At Vilma's office, the firm offers the lab staff a specially-designed breakfast which boosts brain

activity and reduces stress.

The children, Lisa and Sam, spend their weekdays in the local school, except when it's time to study independently. Philip keeps an eye on them, making sure their homework is uploaded to the cloud for their teachers. Their grandparents – living some distance away – also participate in the children's activities, over the internet. Grandma Anderson appears as a hologram in the living room and sometimes the kids use their touch-gloves to stroke Grandma's cat. The parents take the children to the nearby Milieu Heritage areas which include 19th century farms, untouched forests and suburbs with low-rise buildings. The farms are committed to keeping traditional biotypes alive, such as meadows, areas of old road verge, and wetlands. In their garden, the Andersons have ordered an easy-to-install mini-forest with a lichen, juniper and lingonberry plant combination.

Jonas "Brad" Salmi, 57 –  
All the fun of the bio-garage





Jonas “Brad” Salmi (57, living in the old city centre of Oulu) prides himself on being an open-minded type, always ahead of the curve, always among the first to try out new technologies and experiences. He adopts new ideas from sources in his global networks. In this way, he tailored his education – a combination of technology studies, philosophy, design, and marketing. He adopted sustainability as his starting point both in business and personal life in the early 2000s while he was still studying.

Jonas has established several businesses with partners around the world. Most of these focus on biotechnical products, but he is also an associate of Aurora Borealis Industries, a firm that sells hologram-based communication and entertainment. Its impressive creations are used by another start-up he is involved in, namely, Boreal Experience, transmitting Arctic sound and vision in daily chunks to customers in

the Far East. Another interesting business he is contributing to is Pihka Therapies, which produces pitch-based medicines for skin care, especially for the elderly and in trauma therapy.

Jonas spends a lot of his time in his bio-garage. It’s a domestic lab with all the requisite equipment for his prolific output. His most recent success is

a plant that produces tomatoes in varying colours and flavours, depending on how he modifies the lighting and nutrients in the water tank. Local gourmet circles applauded his creations when seeing the range available for their

designer dishes. Jonas rides his composite bike to deliver the latest batch, as trendy as ever, wearing techno-glasses with printed electronics under their biotechnological, silk surface.

Cooking has been Jonas’ favourite hobby since his early years, and he can’t resist new kitchen

### ALL THE FUN OF THE BIO-GARAGE





gadgets. His key concern is the energy consumption in cooking, so he hacks the appliances and develops solutions for others to try out. The ingredients come from nearby farms. Jonas is part of a group that buys food in bulk to cut costs and, even more importantly, to lessen the environmental impact of transportation. When they find a good provider, they help that farm to thrive with their regular orders. The local food also keeps Jonas' CO<sub>2</sub> budget low, so he has a clear conscience when he leaves for his dream holiday on a tiny island in the Pacific, although, even then, the aircraft uses bio-fuel.

Experiments with 'additive manufacturing' are Jonas' second hobby. Not the additives you'd find in food, mind. Jonas upcycles existing objects into new items using a 3D printer. It gives him a certain freedom – whatever he needs next week, he prints from the materials from previous printings. There's no more pressure on space at home, as almost everything needed can be freshly printed on

demand. The dinner table and chairs for his guests next Saturday were an extra bed for his colleague from Sweden last week. He's happy with his latest purchase – an upgrade to his printer – the ability to print objects from logs.

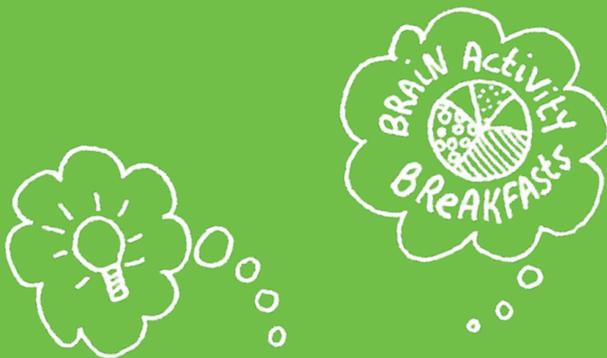
Jonas has re-invented himself numerous times, and that's the way he plans to continue for at least the next fifty years.

# People in the Bioeconomy rely on resource wisdom and technology

The previous chapter introduced us to a few fictional people in the Bioeconomy. The stories of Helmi and Igor, the Andersons, and Jonas “Brad” Salmi illustrate applications of the Bioeconomy as a part of their everyday routines. Next, we look at what makes the everyday Bioeconomy possible. How are oil-based products replaced? How is the yield from fields and forests utilized? How does all this take place with minimal waste whilst maintaining nature’s diversity?

The key enabler of the Bioeconomy is chemistry. It is chemical processes that make it possible to create more sustainable products and to use bio-based raw materials in place of fossil ones. There are three platforms that form the chemistry toolbox, namely, cell factories (an example of industrial biotechnology), thermochemical processing, and biochemical conversion. These very same technologies can be used in different industries. They connect previously separate industrial sectors in the pursuit of new, sustainable business opportunities.

Energy issues and, consequently, lifestyle, transportation and construction sectors, where the Bioeconomy has a strong role have been recently discussed in the VTT Visions 2 publication Low Carbon Finland 2050 (Koljonen et al., 2012). Our themes are closest to the Onni-scenario in that publication, in which industrial production has moved in a less energy-intensive direction. In the Onni scenario, the emphasis is on small-scale services and innovative new businesses that utilize renewable energy.



## CLOSED CIRCLES AND INDUSTRIAL SYMBIOSES – NO WASTE IN SITE!

Material efficiency is a prerequisite for the Bioeconomy. One way to achieve material efficiency is to ensure no waste is produced by using all by-products as raw materials in other processes. This kind of relationship between manufacturers is called 'industrial symbiosis'.

In practice, zero waste is very difficult to realize. However, various techniques for capturing valuable compounds from waste are under increasing R&D&I interest, and we have already seen cases where entire business models are based on refining somebody else's waste, for example, the commercial production of biofuels by ST1 Biofuels from bakery waste.

Industrial symbiosis does not require all players to be situated on the same site or in a purpose-built bio-park, like the well-known Kalundborg in Denmark, instead it can grow organically around existing players within a reasonable distance. This model does not allow the utilization of waste heat between partners as is the case in an industrial park, but material streams can be shared. As the focus here is on side streams (the by-products of a business activity), a reasonable distance between symbiotic partners is limited to approximately 50 kilometres due to transportation costs. Thus an existing, distributing, industrial base can form a suitable platform for a regionally integrated Bioeconomy.

Industrial symbiosis has many apparent benefits for business and society. In order for it to become mainstream we need to move towards action. Real world cases are needed in order to demonstrate the opportunities and quantify the benefits. Challenges lie in the related economic risks as tighter material integration of industrial players decreases their resilience to changes in the supply networks. Organizational and juridical solutions related to, for example, contracts, need to be developed. Naturally, policy instruments should be aligned with these developments and encourage piloting and learning-by-doing.

### Side-streams and residues contain valuables

**Industrial, agricultural and forestry operations produce material flows that are not used for the production of the primary product. These side-streams and residues include, for example, spent grain from breweries, press cakes from seed oil or juice production, husks, straw, bark, waste water, sludge, fish offcuts, and a myriad of others. These streams contain valuable components such as proteins, sugars and fatty acids which are suitable raw materials for further bio-based products. The quality and quantity of these streams vary greatly, and often they are used for biogas production, animal feed or bioenergy due to economic challenges related to the extraction and further processing of the components. Some of the processing technologies are described in more detail in the following sections.**

## A FUTURE HISTORY OF SATAVUO

As with our future personas presented above, this is the story of the fictional region of ‘Satavuo’. **It illustrates how a regionally integrated Bioeconomy can grow from existing industrial structures** (Figure 1).

So, to ‘Satavuo’ in 2044. Satavuo is known for its spreading broadleaf forests and picturesque lakeland countryside and for the region’s local speciality *kivisärki*, a unique dish prepared from traditionally air-dried fish. It also boasts the Satavuo Sampo Festival in honour of the claim that the Sampo – a mythical mill generating wealth and fortune – was forged in Satavuo a thousand years ago.

In the 2010s, the industrial base of Satavuo consisted of a pulp and board mill, a brewery, a sawmill and a bio-energy power plant. These businesses had been the backbone of the Satavuo region but, by then, were struggling to survive. The plants were operating on their own with some integration in the raw material supply, and their by-products were used mainly on-site for energy purposes, with the exception of the brewery where the spent grain was sold as animal feed. Agricultural and forest residue was burnt for power and heat in the local power plant.

Gradually, other companies established their production in the region due to the alluring business potential offered by the region’s natural resources. A factory producing wood-based structural elements for houses was established, utilizing both timber from local forests and by-products such as sawdust from the sawmill to produce solid wood products and bio-composites. Its core market was residential construction and fit-out. Later, the factory introduced new products, such as fibre from the pulp mill used as reinforcement material.

The pulp and board mill went through a transformation where one of the two pulp production lines was converted to the manufacture of textile fibres for the export markets. This change of direction created a substantial by-product in hemi-cellulose (a component of pulp which is retained in paper production but must be extracted from wood-based textile fibres) that initially was burned

in a boiler for energy. A few years later, one of the board machines was converted for high-efficiency production of non-woven textiles for technical use. Textile fibres intended for export also gained ground among domestic consumers and the local fashion industry was reborn, with an emphasis on high-end garments with designer value.

Local entrepreneurs saw a market opportunity for locally produced fish, but they were confronted with stringent regulations concerning the release of nutrients into the water. In order to comply, the fish farm diversified into algae production. The algae fed on the nutrients released by the fish farm and carbon dioxide originating from the nearby brewery. This provided extra revenue in the form of a protein-rich feed that was produced from the algae.

Finally, the power plant provided the perfect host for an integrated bio-refinery. Here, a range of agricultural and forest industry by-products (or ‘side streams’) were converted into methanol using gasification technology. Methanol was primarily converted into transportation fuel but, depending on market demand, it was sold to the chemical industries to be converted into a large array of green chemicals.

Now, in 2044, there are plans for the further use of protein, fats and carbohydrates from the spent grain and algae reactor. These will be converted into higher value products such as biopolymers used in the production of bioplastics. Combined with natural and wood fibres, these create recyclable, bio-based materials. The business plan and the technology required for the job stand ready to go, but investment is just as hard to secure as it was 30 years ago.

Individual firms are also constantly looking for ways to mitigate the risks associated with being more dependent on each other. Alternative raw material sources are being sought and the network of providers has expanded. New insurance instruments have been introduced to help companies cope with possible interruptions in the symbiosis-reliant, raw material supply.



CLOSED CIRCLES AND INDUSTRIAL SYMBIOSES

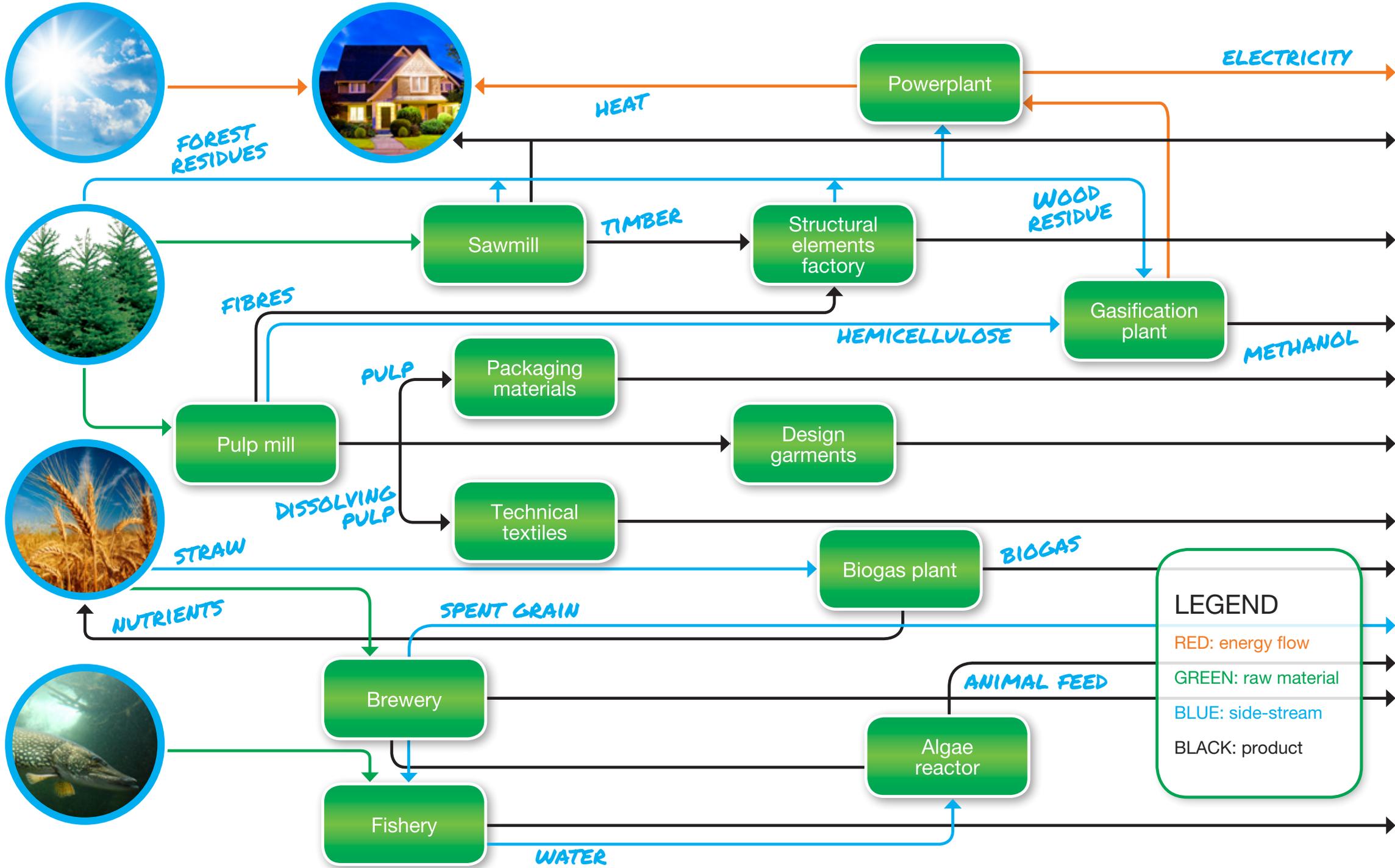


Figure 1. 'Satavuo region'. A fictional example of a regionally integrated bioeconomy in which different businesses can form symbiotic relations and create win-win relationships.

## MAKING EVERYDAY PRODUCTS USING CLEVER CHEMISTRY

Returning to the present day, the production processes, materials and chemical commodities of 2044 will in many ways be similar to those of the 2010s. The key difference is in the raw materials from which the products originate. Instead of oil, coal or

### WE ARE MOVING FROM HYDROCARBON-BASED CHEMISTRY TO CARBOHYDRATE-BASED CHEMISTRY

unconventional hydrocarbons such as shale gas, a Bioeconomy will deploy biomass components such as lignin, cellulose,

hemicellulose and fatty acids as building blocks. In essence, we are moving from hydrocarbon-based chemistry to carbohydrate-based chemistry.

In this section, we explore three chemical platforms – cell factory, chemical conversion, and thermochemical conversion (Figure 2) – that enable the production and use of bio-based consumables. These technologies will play a crucial role in any Bioeconomy.

All three platforms aim at transforming biomass – be it forest residue, agricultural, or municipal waste – into something with a higher, added value.

As in any production, the choice of chemical platform and pre-processing method depends on the raw material at hand and the intended end product. Production must also be economically viable, so whilst the technologies may exist in theory, they may not all be actionable outside the lab. Correctly selected, however, these chemical platforms enable both the carbon- and energy-efficient production of the requisite chemicals and bio-based products.

Feasible solutions have currently been found, for example, for the bio-based production of PLA plastics from polylactic acid, typically derived from corn starch, that can replace the oil-based chemicals traditionally used for plastics. In the long run, however, this is not a feasible solution as edible starch should be used for food. Another example is the production of regenerated textile fibres from wood cellulose without the use of harmful chemicals. **In the future, we will be able to produce a wider variety of basic chemicals to replace the current oil-based chemicals, and even to improve their performance and reduce their environmental impact.** As the technologies develop as described below, we will also be able to use non-hazardous, bio-based methods for further chemical processing.

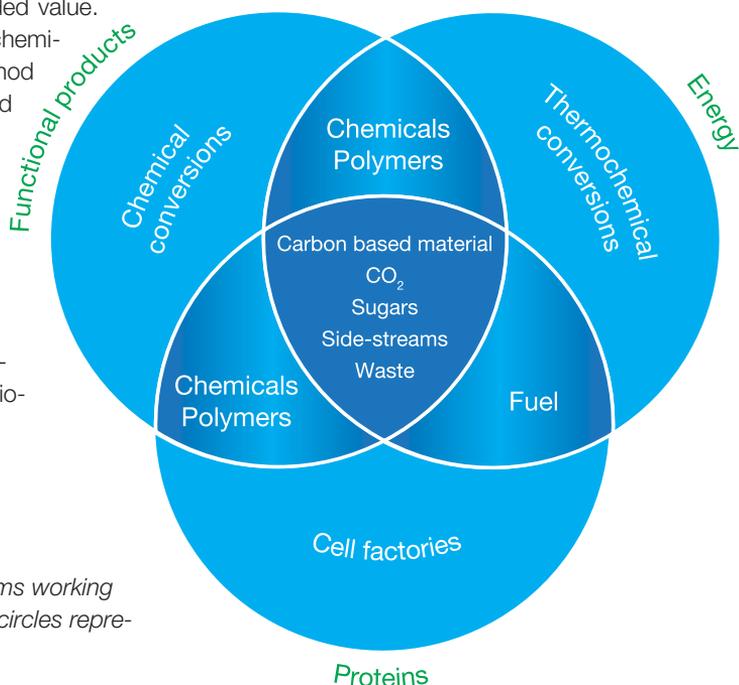


Figure 2. The three chemical platforms working together. The cross-sections of the circles represent possible products.

## 1. A single cell – the smallest factory in the Bioeconomy

Microorganisms are ‘cell factories’ that metabolize sugars into new compounds. Microbes, single cell or multicellular living organisms can be engineered so that their metabolic reactions produce the desired chemical compounds very selectively and with high yields. In the future, these ‘cell factories’ could enable the production of the majority of the industrial chemicals which today are oil-based (Figure 3).

Some well-known examples of cell factories include the production of alcohol using live yeasts and of antibiotics using moulds. Exploiting microbes in this manner is nothing new, but what makes cell factories revolutionary are the new technologies boosting efficiency and product potential, along with the ability to control the outcome of these biological processes very precisely. What they offer is an environmentally sustainable way to add value. These processes can be used to add value to a range of industrial side-streams that today are treated as waste.

As cell factory engineering develops, enzymes from microorganisms will be able to be used to give the cell factory certain desired characteristics. Ideally, these could be the ability to harness sunlight as its energy source or the ability to transform CO<sub>2</sub> into a more useful carbon compound. The aim is that, in future, a wider variety of raw materials and compounds will be produced and processed using cell factories, including the base chemicals that will replace oil-based chemicals. These replacements are typically bioethanol, biobutanol or polylactic acid but, in practice, dozens of base chemicals have already been produced in this way. The processing technologies based on cell factories are much more carbon- and energy-efficient than current petrochemical processes.

Today’s first-generation cell factories are mainly used to add value to raw materials containing starch, but second-generation cell factories are already using raw materials containing lignocellulose, such as wood. Traditionally under-exploited agricultural wastes, such as straw and other fibrous by-products, are good sources of cellulose and hemicellulose, containing sugars that the cell factory can

exploit. Many by-products and waste from food production, such as press cake from juice manufacture, also make great sources of these sugars. Second-generation raw materials therefore also make good alternatives to starch, which, as previously noted, should be reserved as an important nutrient for humans.

### THINK!

**Sugars include a large group of chemical compounds. ‘Cell factories’ need these sugars for nutrition, and in practice, a variety of polymeric, organic matter can be used as a source for these sugars. They simply need to be broken down into their building blocks. For example, starch from corn waste or cellulose and hemicellulose from plants can be used.**

# Cell factory

AND EXAMPLES OF WHAT COMES OUT

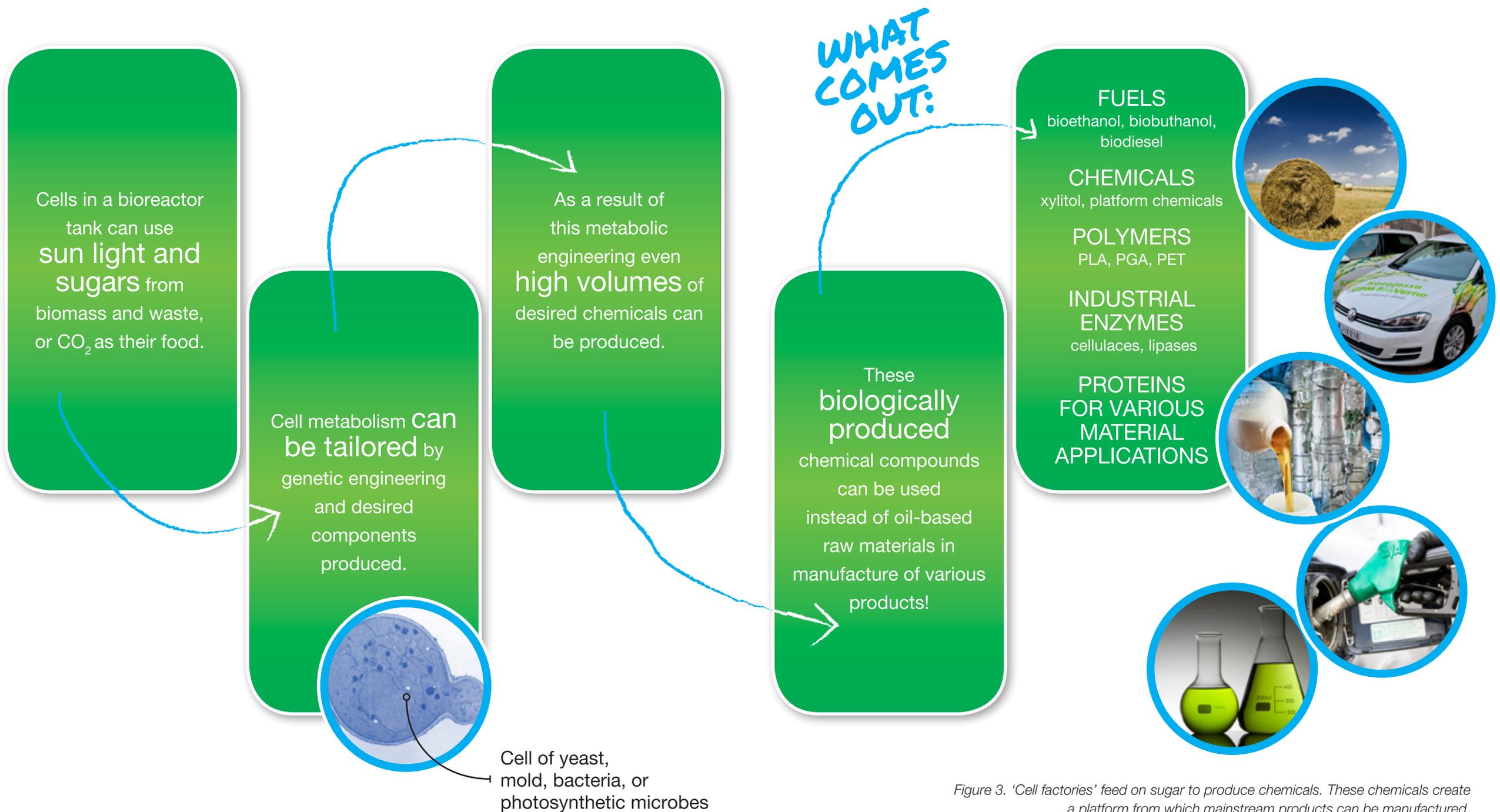


Figure 3. 'Cell factories' feed on sugar to produce chemicals. These chemicals create a platform from which mainstream products can be manufactured.

## 2. Energy, fuels and chemicals from mixed biomass via thermochemical conversion

The thermochemical processing of biomass uses heat and catalysts to transform plant polymers into fuels, chemicals, electric power or heat. Thermochemical processing occurs at temperatures of at least several hundred degrees centigrade and sometimes over a thousand degrees centigrade.

### THE THERMOCHEMICAL ROUTE IS SUITABLE FOR MIXED- AND LOW-QUALITY BIOMASSES

At these temperatures, thermochemical processes occur very rapidly, even without catalysts. Catalysts are however often deployed to improve product quality and increase yields.

Thermochemical conversion routes can be categorized as combustion, gasification, pyrolysis and hydrothermal processing. Direct combustion

produces thermal energy, which can be used for generating electric power, process steam or district heat, whereas the other routes provide avenues into bio-based fuels and chemicals.

From a raw materials point of view, thermochemical processing uses all the plant matter, whereas a cell factory needs the sugar only (Figure 4). The thermochemical route is therefore suitable for mixed- and low-quality biomasses. Two of its processes, gasification and pyrolysis, require relatively dry biomass, whereas their sister method, hydrothermal processing, is ideal for wet material that can be handled as slurries.

Fast pyrolysis occurs at moderate temperatures of around, 450–550 °C, and in the absence of oxygen, to produce mostly condensable vapours and aerosols, which are recovered as liquid 'pyrolysis oil'. This raw oil can be used instead of fuel oil for heating, or refined into more valuable fuels and

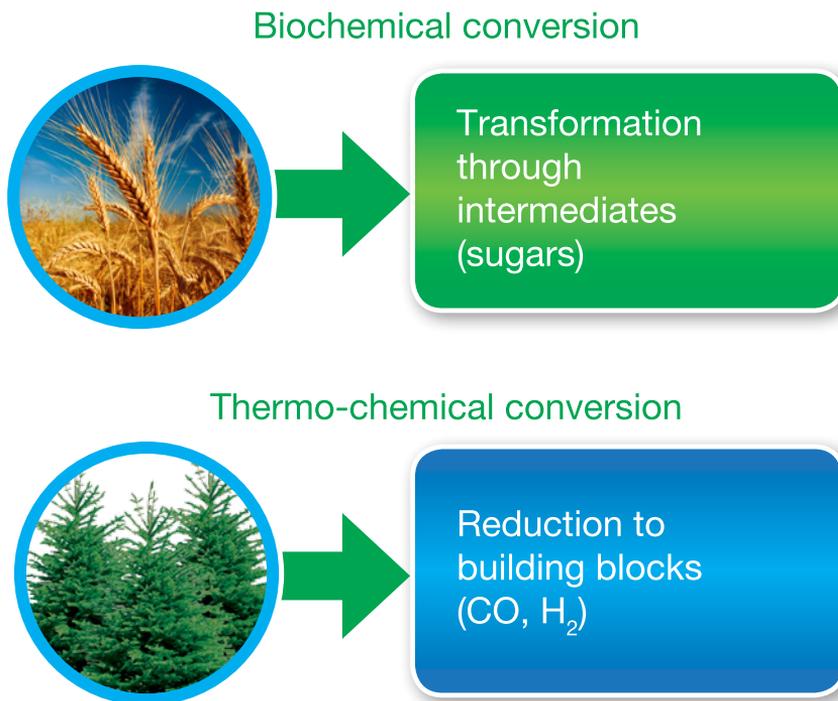


Figure 4. Comparative outputs of different types of chemical conversion used in bio-based industry.

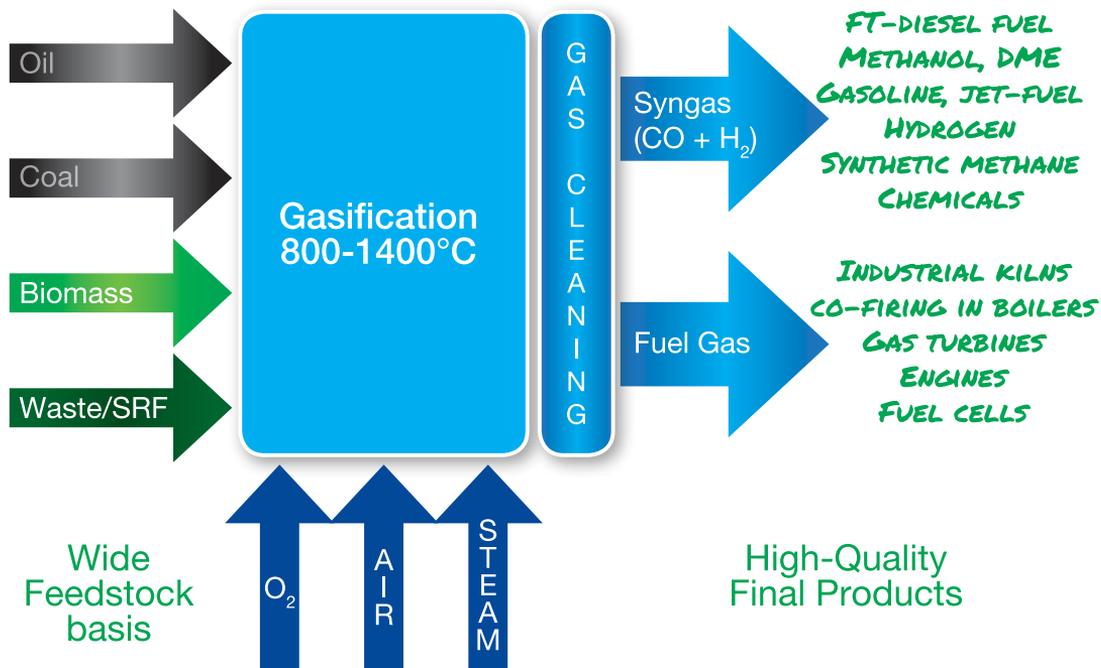


Figure 5. Gasification is one way to transform raw materials into chemicals, and is particularly suitable for mixed forest residues and sorted solid waste.

chemicals. Pyrolysis occurs under milder conditions than gasification and, consequently, the biomass structure is not decomposed so severely. This offers intriguing opportunities for the co-production of a variety of biomass-derived, high value products and energy.

The gasification of biomass is an especially powerful route for manufacturing bio-based fuels in cases where the excess heat generated by its production can be integrated into other industrial processes (Figure 5). These may include power generation or district heating. Gasification creates, in addition to thermal energy, a carbon monoxide- and hydrogen-rich gas mixture known as ‘producer gas’ or ‘syngas’. This can be used to generate electricity or to synthesize fuels and chemicals using catalytic synthesis, or by cell factories using syngas as feedstock.

Technologies based on methanol synthesis and the Fischer-Tropsch process (chemical reactions that convert carbon monoxide and hydrogen into liquid hydrocarbons) open up the route to the production of fuels and chemicals where the potential is in applying mixed- and low-quality biomass. Because the cost of the technologies is currently comparable to those of coal gasification, investment would require strong, including political, funding support.

### 3. Waste transformed into value and usefulness

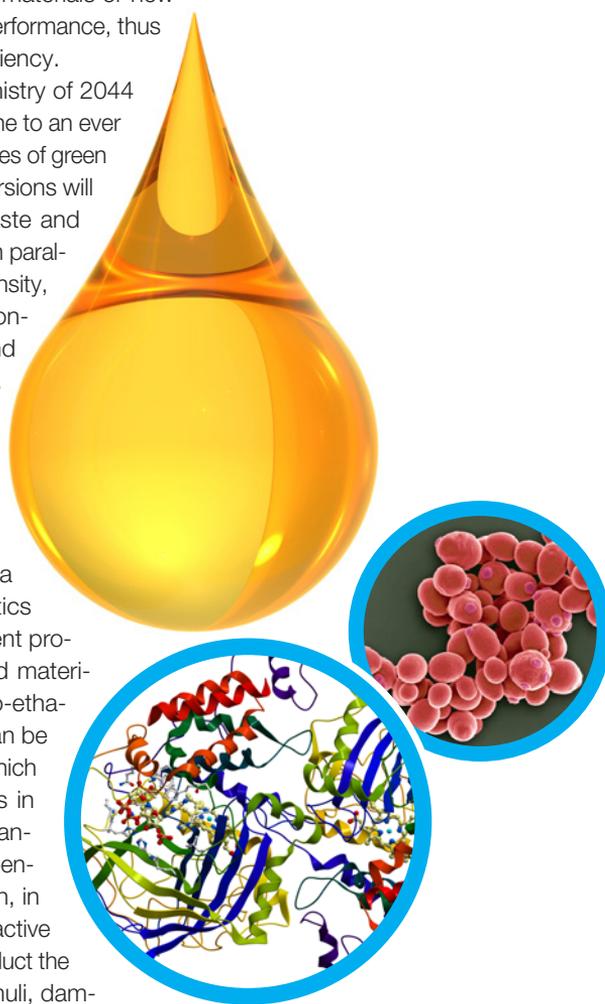
Chemical conversions are carried out with the aid of catalysts. These catalysts can be chemical or bio-chemical. The conversions themselves are central enablers that solve a myriad of problems ranging from the degradation of biomass, to simple chemical transformations and conversions of the inherent properties of bio-based materials. The outcome is smart, functional components. Examples of these may include the upgrade of platform chemicals, the conversion of lignin to smart materials and the utilization of naturally-occurring bioactive components. These can take place in existing materials or new materials made superior in their performance, thus improving the whole system efficiency.

A central theme for the chemistry of 2044 will be that transformations are done to an ever greater extent following the principles of green chemistry. This means that conversions will be carried out by minimizing waste and maximizing selective throughput. In parallel, aspects of toxicity, energy intensity, auxiliary chemicals and the environmental impacts of processes and products are carefully calculated.

In 2044, much more so than now, bio-based materials and platform chemicals will be converted to polymers that replace those traditionally produced from oil. Equally, the world will see a more diverse range of bio-plastics compared to the number in current production, including lactic acid and materials derived from glycerol and bio-ethanol. These polymeric materials can be blended with active ingredients which may also have bio-based origins in plants, trees or tailored microorganisms. Going further, a smart microencapsulant can be included, which, in a controlled manner, releases an active ingredient that gives a finished product the ability to respond to external stimuli, dam-

age or other factors. For example, such methods may result in a paint which gives wood and metal a longer service life even in severe applications.

Other bio-based materials that can be converted into beneficial products include triglycerides. Commonly known as fats and vegetable oils, their uses will be vastly increased in the Bioeconomy. Their application, through selective transformations, has the potential to revolutionize their use as chemicals, plastics and other commodities far beyond their current limitations as fuels and lubricants.



## EAT YOUR FUTURE GREENS!



The cuisine of 2044 will be increasingly vegetarian. The production of animal-sourced food has such a huge negative impact on our ecosystem that, by 2044, the world will be fed with plant-based foods. Animal protein is not imperative for humans. Adequate nutritional values, including proteins essential for growth and maintaining body mass can be achieved by eating a balanced vegetarian diet. Therefore, the role of meat-based meals will change significantly from today's menus.

The traditional food guide pyramid will be yesterday's news – new guidelines will include, in Finland for example, the Baltic Food Pyramid, emphasizing affordable vegetables instead of meat and favouring regional fare such as rye bread, berries, fish, vegetables and fermented food. Elsewhere, Britain and Italy will develop their Atlantic and Mediterranean Food Pyramids, and Austria its Alpine variant. This 'new nutrition' will overturn the role of meat and dairy. Traditional meat stews and creamy meat sauces thus become meals for special days, and naturally-grown tenderloins a luxury. The main source of proteins will be vegetables, as their production has a less negative impact on the environment. Artificial meat and other protein substitutes produced in laboratory environments to replace animal husbandry will have a role in 2044, although plants will form the main ingredient in daily meals.

**Resource-wisdom is key in the Bioeconomy. Arable yield is harvested to the very last stalk. Even parts of plants that were thought to be inedible or unappealing as food will be used after fermentation or other processing.** These include nutritionally valuable by-products from the production of vegetable oils, potato starch and sugar beet to mention a few. Previously-overlooked protein sources can easily satisfy the daily protein

needs of populations across Europe.

Even now, researchers are developing ways to enrich protein, dietary fibre and other nutritionally valuable substances from a number of overlooked sources by converting them into appealing and affordable ingredients to be used in future foods. Of course, where the results do not measure up for human consumption, they can be designated as animal feed in a much-reduced husbandry sector, thus further reducing its environmental impact and cutting the amount of food suitable for humans that is currently used for animal feed.

There are other novelties in the food industry in addition to by-products adapted from the production of vegetable oils, white flours, sugar, potato starch, peeled potato products, berry and fruit juices, etc. A typical lunch plate may contain tasty, wood-fibre-based, cholesterol-lowering snacks, or insects that replace red meat as a key protein source. Protein drinks – already familiar to consumers – will become a regular component in diets. Carefully-designed snack meals will also help keep the diet healthy, for example, when food rich in vitamin-C is out of season.

Packaging is a key issue in food retail. Acknowledging the imperative to avoid waste, food still needs to be kept safe until consumed. In 2044, packaging will be light and made from bio-based materials, and the recycling of used materials will be more complete than it is today. From the consumer's point of view, the packaging may track the external conditions during its journey from the manufacturer to the consumer and notify them if the temperatures en route have risked the product quality. These sensors may also help to reduce food waste in terms of shelf life, showing the actual condition of the meal or ingredient, whereas today,

### THINK!

**Future is not only about new things. Old food plants, such as broad beans, may return to Finnish kitchens.**





## WEARING WOOD, BRANCHING INTO CHEMICALS

Forests will have a special role in the Finnish Bioeconomy of 2044. They will become a crucial raw material for many industries, replacing fossil materials (Figure 6). They also have strong value as part of natural ecosystem services.

Wood is the basis of many products. Currently, almost all pulp production is used for paper and board production, while timber products comprise sawn goods, plywood and particleboard. The key word in the future use of wood is 'cellulose'. **Cellulose is the most abundant and widely produced natural polymer in the world.** It provides a sustainable raw material – especially in packaging, textiles and in the replacement of other polymers. Novel applications for cellulose are of major importance when thinking of new revenue streams for the forest industries. In short, wood is the new plastic.

Wood fibres have long been applied in the textile industry in the form of viscose. In the future, viscose will be replaced by more sustainable wood fibres, and new uses for wood-based textiles will be found in technical and hygiene textiles (as in the case of our future 'Satavuoto'). For wood-based textiles to flourish, new pulp production processes need to be developed to make the textiles more effective. Foam forming is one of the promising new technologies with the potential to create significant growth in this area. Similarly, natural fibres are already being increasingly used in various composites and in structural products such as car interiors.

Pulping generates by-products containing valuable chemical components, such as lignin, sugar acids and hemicellulose, from which a vast array of chemicals and materials can be derived. The main challenge is in the actual fractionation of these useful components for the chemical industry, since pulping has traditionally focused on producing fibrous cellulose. When targeting chemical cellulose, the

processes need to be re-engineered.

Chemical conversions improve and transform the pulping of forest biomass destined for new products and processes. For instance, environmentally friendly solvents can be used to modify cellulose into a material that can be spun into fibres. Such fibres can produce clothing unparalleled by those currently made of cotton. This would liberate water-intensive cultivated land for food production for a global population already fast approaching 10 billion. Similarly, chemical conversions have been deployed in preparing useful materials from the other main wood components: hemicellulose and lignin. These environmentally-friendly solvents can be used

to carry out many other transformations currently undertaken with common organic solvents. The reaction efficiency and selectivity has been improved in recent times.

Advances in chemical conversion have enabled practical uses of lignocellulosic components. Some everyday examples of these include hemicelluloses (a lignocellulosic component) used in biodegradable nappies, in water treatment chemicals and as surfactants. Meanwhile, thermoplastic and other lignins have found a use in coatings, plastic components and even as ingredients in food.

Recycled fibres and timber by-products are important raw materials that must be exploited even after they are no longer suitable for their primary application. However, fibres can be recycled only a few times and a constant supply of new fibre is required. Therefore, it is important for global markets to have places like Finland, which can reliably maintain a high quality, fresh supply.

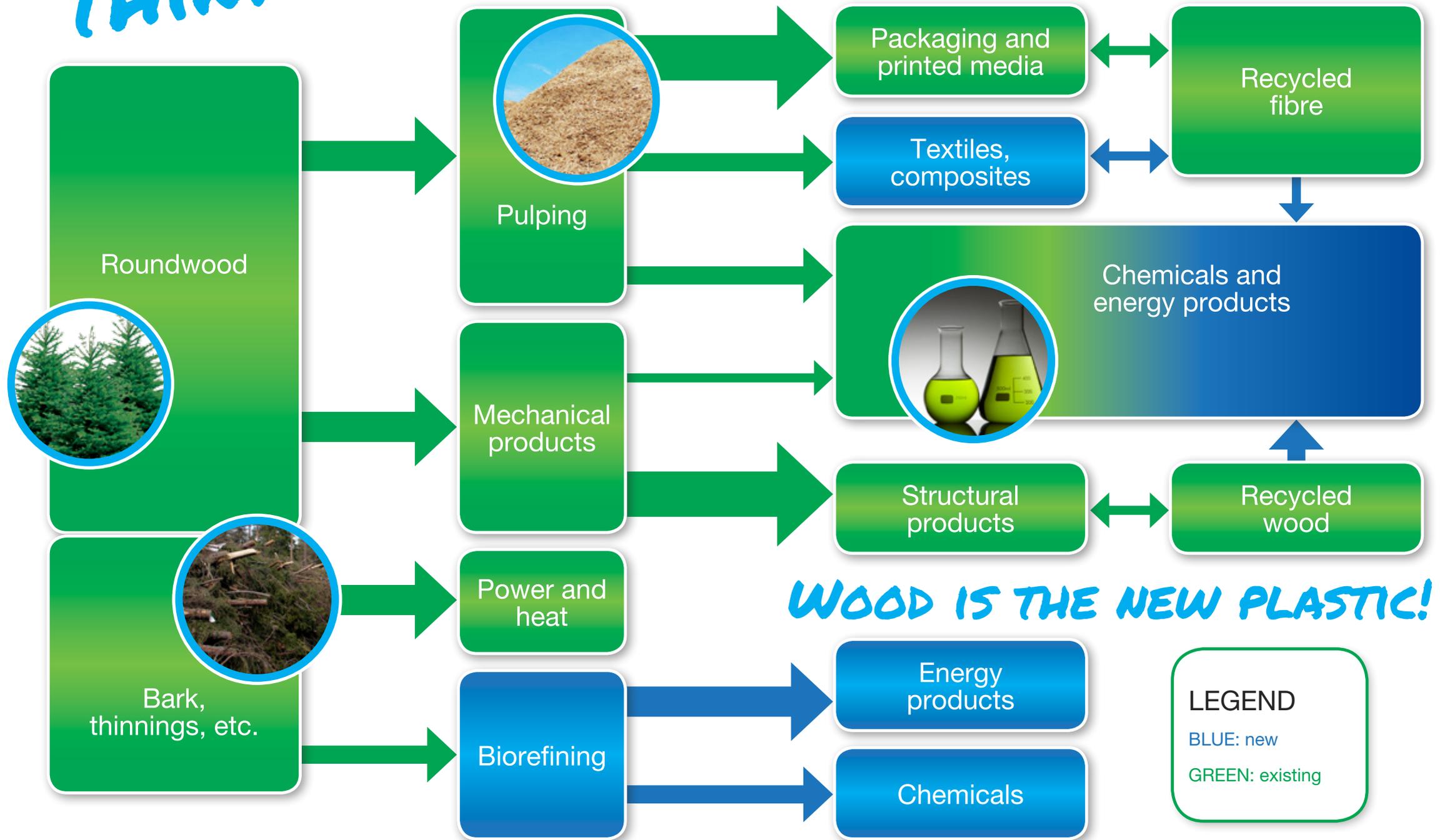
Forestry residues such as thinnings, bark and branches are currently combusted in boilers to produce bioenergy. However, bio-refineries can provide a cost-effective way of producing biofuels and



THINK!

Wood is the new plastic!

THINK!



WOOD IS THE NEW PLASTIC!

Figure 6. Novel uses for wood as a raw material are of major importance when thinking of new revenue streams for the forest industries.

bio-based chemicals from these residues. These bio-refineries should be integrated into the existing infrastructure to utilize synergies with the existing plants, building sustainable industrial symbioses. Forestry residues such as thinnings, bark, and branches are currently combusted in boilers to produce bioenergy. However, biorefineries can provide a cost-effective way of producing biofuels and biobased chemicals from the residues. These refineries should be integrated to the existing infrastructure to utilise synergies with the existing plants, i.e. to build sustainable industrial symbioses.

## Forests have been a key component of the Finnish economy for centuries.

From the 1600s until the demise of wooden ships, tar production brought wealth to the Ostrobothnia region. In the 1800s, firstly sawmills and eventually the pulp and paper industry were established along rivers and waterways providing them with energy and transportation. At its peak at the turn of the millennium, the forest industry provided over 20% of the nation's exports. As long as there is demand for products derived from forests and the opportunity to produce them in Finland, the forests will provide wealth for the nation.

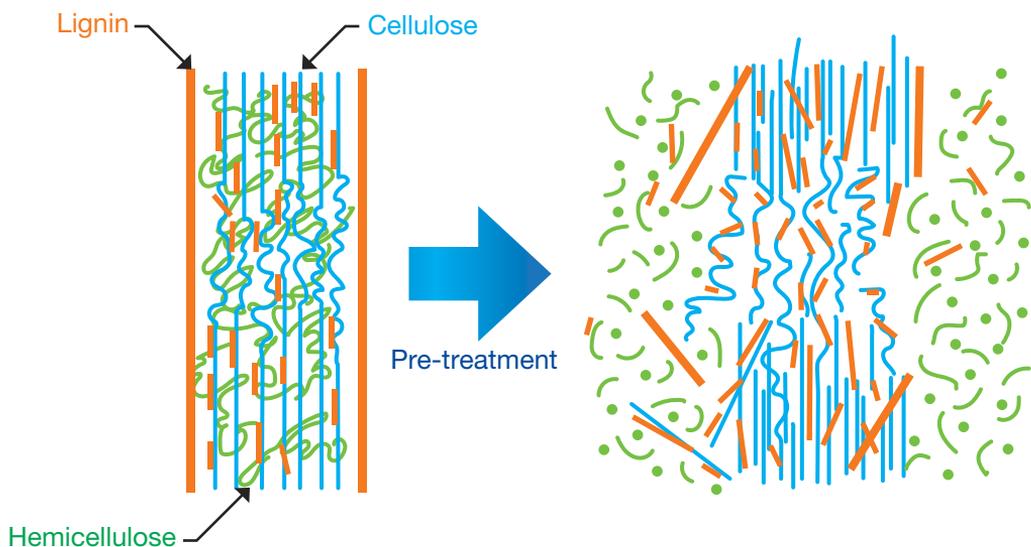


Figure 7. The resilient structure of lignocellulosic biomass challenges pre-treatment developers.

## IT ALL STARTS WITH BREAKING DOWN THE BIOMASS

Plant biomass, also called lignocellulosic biomass, is the most abundant bio-based raw material. It consists of three main polymeric components, namely cellulose, hemicellulose and lignin. Under ideal conditions, these components are separated, modified and converted into biomaterials and biochemicals while attempting to preserve the existing chemical structures, thus maximizing the added value from the biomass. In practice, however, this is a very difficult task.

Some of the key complications arise from the biomass itself. Cellulose, hemicellulose and lignin form complex structures in plants, providing the necessary structural strength and defences against natural threats. These properties are desirable in structural wood products like timber, but the strength of the structure makes it difficult to separate the components from one another (Figure 7). The chemical composition and proportion of the three main components vary from one biomass source to another, such that, for example, birch has a very different hemicellulose composition to pine. The conversion of hemicelluloses into chemical products, for example, is dependent on the structure and composition of these components, and therefore a process known as the 'fractionation' of the components is needed in many cases.

Biomass fractionation methods use mechanical, chemical or enzymatic processes or a combination of these, to achieve the separation of the main components. However, the current processes for fractionation are not selective enough to achieve the ideal fractionation of all components equally, but are nevertheless capable of separating a specific component. In this way, current pulping processes are optimized for the production of high quality cellulose. That said, new developments in ionic liquids and deep eutectic solvents may provide the

means for better fractionation in the future.

The alternative to fractionation is thermochemical degradation, such as gasification of the biomass into its basic chemical building blocks of hydrogen and carbon monoxide and then using chemistry to synthesize the desired chemicals and fuels.

Biomass is a renewable resource but with limitations – not all of it can be exploited industrially in a sustainable manner. New, high-yielding biomass sources, such as algae, are being developed, but in the longer term, the production of biochemicals and materials should be decoupled from the use of biomass (Figure 8). Instead, the key raw material for various applications could be CO<sub>2</sub> recovered from flue gases or from the atmosphere. **Using CO<sub>2</sub> itself as a source of carbon would be a solution that not only guarantees the abundant availability of raw materials and energy but also mitigates climate change.** Many technical innovations, however, are needed to achieve this on an industrial scale. Moreover, chemicals and fuels are made of both carbon and hydrogen, which means that if this route is to be pursued, an economically viable method of producing hydrogen would be needed, too.

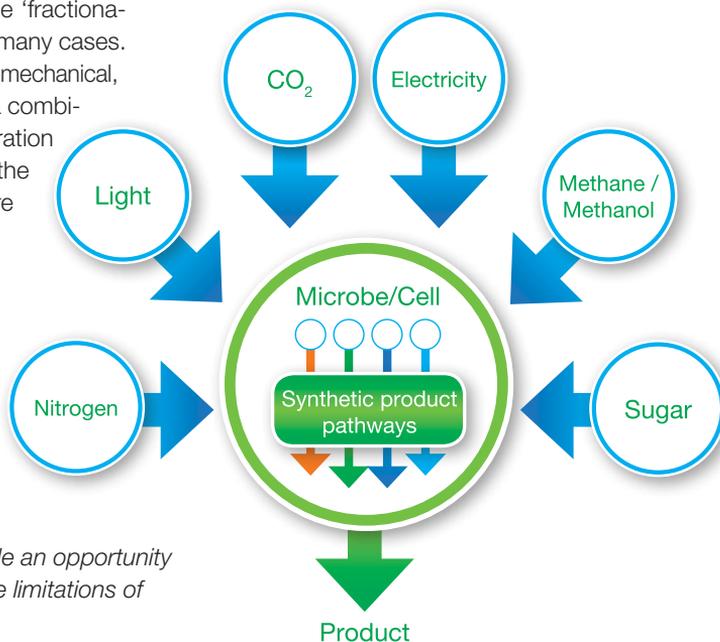


Figure 8. Engineered cells may provide an opportunity to decouple the Bioeconomy from the limitations of biomass availability.

# The Bioeconomy requires action

## THE OLD AND NEW JOIN FORCES IN THE FUTURE

When looking at snapshots of everyday life and the technologies and solutions enabling it, it is clear that life in 2044 looks both very familiar and very new to us. There will be new products, services and processes, driven by new technologies, market opportunities and regulation. These novelties will, however, blend with elements from the past. The future is not a total rejection of the past, but a combination of new technologies with familiar, everyday practices.

Due to significant challenges, however, such as climate change and increasingly scarce natural resources, the way we use our resources will be radically different. We can no longer consume energy or raw materials the way we have so far. Our limited natural resources need to be used wisely and

**LIFE IN 2044  
LOOKS BOTH VERY  
FAMILIAR AND  
VERY NEW**

sparingly. This is what the Bioeconomy is all about. Closed circles, materially efficient industrial symbioses and novel, bio-based raw materials and processes will be the cornerstones of the new, sustainable economy. In summary, the spheres of production and consumption will be transformed through radical new choices in raw materials, technologies, processes and policies.

**A Bioeconomy is defined not only by technology, however important they are, but a shared agenda for all the stakeholders. It is necessary to move ahead on several fronts, technological development being just one key asset for success. The transition should be guided by a common vision, fruitful coordination and a strong focus within each stakeholder's actions.**

## FINLAND'S PATH TO THE BIOECONOMY

Finland has a particularly good starting point for succeeding in the Bioeconomy. We are a country rich in natural resources such as forests, water and minerals. Finland's forest grows annually by 100 million cubic metres and only 70% of it is used in processes and products. Forestry provides a great opportunity for Finland, both in economic and societal terms. The production of the Finnish Bioeconomy related sectors was valued in 2008 at EUR 50 billion, accounting for around 14% of Finnish GDP. The national strategy on Bioeconomy aims at doubling the Bioeconomy related production by 2030.

In addition to the national level, the Bioeconomy needs attention at a very local level. It may sound self-evident, but the physical infrastructure must enable the networks that create economic value, such as the collection of biomass. The physical routes from fields and forests to processing and production units, and onward to consumers need to be operational and robust.

Wider still, at the European level, the nature of different areas in Europe may require flexibility from European legislators to allow some variation in practices. Regionally-integrated economies that develop around local resources may strengthen wellbeing in areas that have suffered from the negative effects of globalization. The way technologies are intertwined with economic and social issues give many areas new opportunities.

In Finland's case, to ensure the Bioeconomy becomes reality, Finland needs a long-term industry and innovation policy that defines and supports the necessary research and development work. At the same time, Finland needs to find a balance between supporting appropriate old industries and developing new industries. Many of the old industries serve as the economic basis for developing the new, although the new in this context needs policy instruments to guarantee a good start in its journey from technology push to market pull. The regional-

ly-integrated Bioeconomy, in particular, builds on existing investments and structures which may be part of completely new industrial symbioses with side-streams that connect hitherto unconnected processes.

To make technologies work for the benefit of a future Bioeconomy, Finland needs to pay more attention to commercialization and exploitation of research results. As the three chemical platforms presented above show how production can be enabled from almost any raw material, there is no single, self-evident technology path that should be selected from the beginning. Thus, it is crucial to invest in ways that do not exclude options but enable a variety of products, especially platform

chemicals that can be further utilized for industrial and consumer products. At the same time, regulatory standards are required to create markets for new product categories. Standards for pyrolysis oil, for example, would guarantee that the buyer knew exactly what

the product should consist of, and how it will work in the process for which it is purchased.

Finally, Finland should not focus only on technologies and solutions that are used domestically, but master a wider set of competences that may be needed outside the national context. This kind of wider focus guarantees export prospects and offers resilience to a small national economy.

**VTT CREATES  
THE PREREQUISITES  
FOR  
SUSTAINABILITY**

**VTT paves the way to a sustainable future**

**VTT transforms knowledge and technologies into solutions that enable the sustainable Bioeconomy together with other stakeholders. Knowledge is forged into solutions that benefit the customers, economy and ecosystem.**

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## VISIT ALSO

**[www.biotalous.fi/bioeconomy/](http://www.biotalous.fi/bioeconomy/)**, a website presenting the progress on the Finnish Bioeconomy strategy.

**[www.dmitre.sa.gov.au](http://www.dmitre.sa.gov.au)** and search for 'Cellulose Fibre Chain initiative' to find the results from a roadmapping study contracted by South Australian Government from VTT.

**[www.forestcluster.fi/sites/www.forestcluster.fi/files/Forestcluster\\_FuBio\\_Report\\_Reader.pdf](http://www.forestcluster.fi/sites/www.forestcluster.fi/files/Forestcluster_FuBio_Report_Reader.pdf)**, Future Biorefinery Programme Report 2009 – 2011. ISBN 978-952-92-9718-4 (paperback). ISBN 978-952-92-9719-1 (PDF).

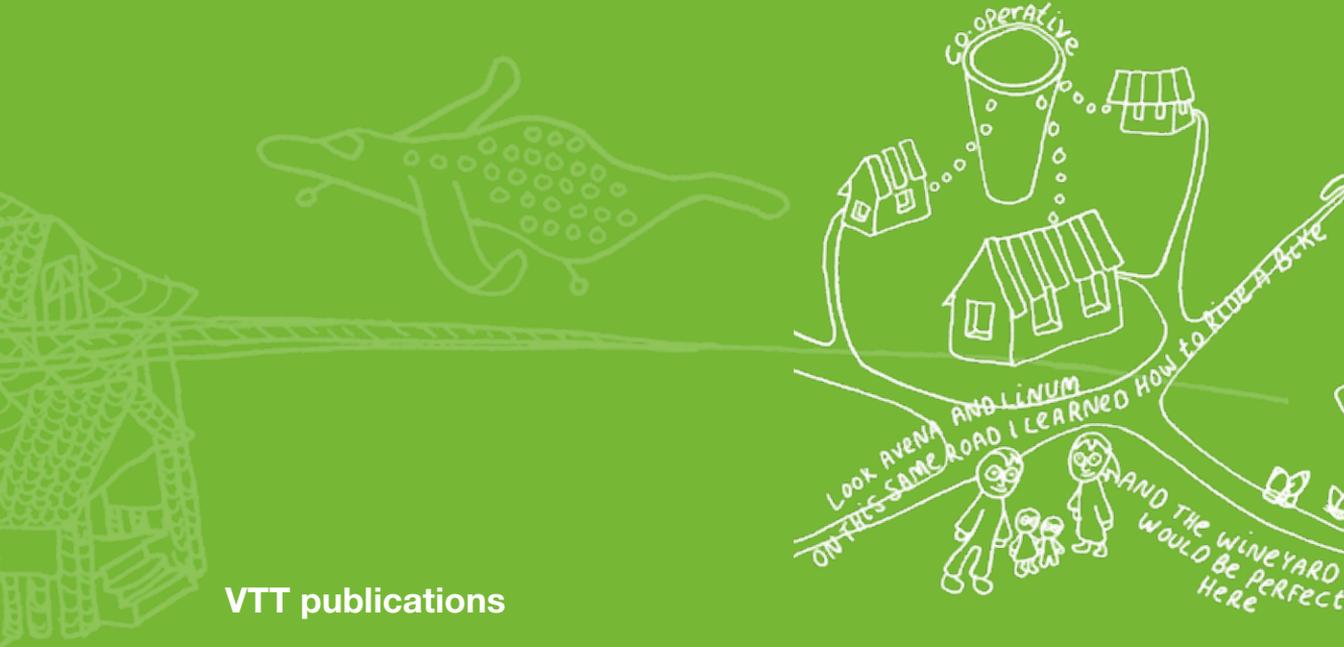
**[www.foresttech.fi](http://www.foresttech.fi)**, a website presenting R&D breakthroughs in biomaterials, packaging and media, brought to you by VTT.

**[www.nutritech.fi](http://www.nutritech.fi)**, a website rethinking the food chain, brought to you by VTT.

**[http://www.vtt.fi/service/bioeconomy\\_transformation.jsp?lang=en](http://www.vtt.fi/service/bioeconomy_transformation.jsp?lang=en)** for VTT's offering in Bioeconomy Transformation.

<b>Title</b>	<b>People in the Bioeconomy 2044</b>
<b>Author(s)</b>	Jussi Manninen, Riitta Nieminen-Sundell & Kaisa Belloni (eds.)
<b>Abstract</b>	<p>The global demand and supply equation has become increasingly difficult to solve, so new thinking is critical for the sustainable future of the globe. We at VTT believe bioeconomy represents this new kind of thinking. Growing national and global interest in sustainable development is expected to make bioeconomy an essential part of the economic system in the years to come.</p> <p>The Bioeconomy is especially important for Finland. It already accounts for about EUR 60 billion of GDP, and a doubling of this amount by 2030 is considered possible. The Bioeconomy does not happen by itself, but it requires a strong will, ambitious targets, and action towards these targets. New technical, societal and business innovations are needed along the way, with science and technology as the key enablers. A successful bioeconomy requires a multidisciplinary approach, combining disciplines ranging from chemistry to design. As a cross-cutting approach it has an effect on the whole of society, linking food security and people's well-being to the sustainable use of raw materials and natural resources.</p> <p>VTT forms a platform for an innovation ecosystem attracting industrial and other stakeholders from Finland and elsewhere to make the Bioeconomy happen.</p>
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# People in the Bioeconomy 2044

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