VTT Technical Research Centre of Finland

The Making of BIOECONOMY TRANSFORMATION

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Published: 01/01/2017

Document Version
Publisher's final version

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EDITED BY: Kristiina Kruus & Terhi Hakala
ISBN 978-951-38-8503-8 (printed); **ISBN** 978-951-38-8504-5 (online)
 PUBLISHER: VTT Technical Research Centre of Finland Ltd
P.O. Box 1000 FI-02044 VTT Finland Tel. +358 20 722 111
IMAGES BY VTT, iStock, Shutterstock and Antonin Halas (Studio Halas Oy)

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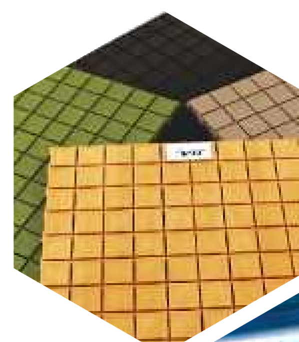


VTT
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BIOECONOMY TRANSFORMATION PROGRAMME PROMOTES INDUSTRIAL RENEWAL

The Bioeconomy Transformation programme, started in 2012, was a five-year internal spearhead programme of VTT Technical Research Centre of Finland Ltd. The name of the programme implies a journey having a set of goals and a desired final outcome. This programme has ultimately targeted support of industrial renewal and implementation of the National Bioeconomy Strategy. Since 2012, we have witnessed substantial development in the bioeconomy both nationally and globally. Many companies have invested in new biorefineries and developed supporting ecosystems, also new start-ups have entered the field. These developments have strong national support through the Finnish Bioeconomy Strategy and the government key programmes.

IN PARTICULAR we have focused on sustainable use of biomass and its components and developed novel value-added product and process concepts often in cooperation with industrial stakeholders for energy, pulp and paper, packaging, textile, chemical and food sectors. We have also developed generic technologies for biomass fractionation, product recovery and enzymatic and microbial tools for bioprocesses. Raw materials have been diverse agro- and forest biomasses and recently also various waste and side streams. The unique research environment at VTT has allowed a truly multidisciplinary approach. We have successfully combined chemistry, bio-, process-, and nanotechnology, modelling, techno-economics, machinery, electronics and sensor technology, up-scaling, socio-economics and foresight research.

During the course of the programme we have evaluated the impact of our work from three aspects: industrial, scientific and societal. Some examples highlighting the impacts include opening of the Bioruukki piloting center in March 2015 and starting a large programme with 20 industrial players to commercialize the foam forming technology, developed at VTT. Our experts have been working in contract research projects with ca. 200 customers promoting the bioeconomy. In total, 140 patent applications have been generated in the programme. We work actively at the EU level: we participate in five BBI projects and have coordinated 11 EU-projects in the bioeconomy area. We have also two large Tekes' strategic research opening projects and one Academy of Finland Center of Excellence, implying the high scientific level of our research. In addition, we have published ca 1200 peer-reviewed scientific articles and finalized 28 PhD theses in the program. VTT experts had an active role in preparation of the National Bioeconomy Strategy and continued to support its implementation through various stakeholder events and active dissemination. Several roadmaps and scenario works have been done within the programme and many high-level seminars and meetings have been organized.

We have seen in this programme, and during the 75-year history of VTT, that new innovations and business opportunities can be generated by combining scientific and technological excellence. More highlights have been collected in this report; I hope you find it interesting.

I would like to thank the Ministry of Economic Affairs and Employment, Tekes, Academy of Finland, the European Commission and various industrial partners for financial support, many collaborators in Finland and abroad for developing together the bioeconomy, the Programme Advisory Board for valuable discussions and numerous VTT colleagues for their hard work and passion for the bioeconomy. ●

Espoo, December 19, 2016
Kristiina Kruus
Programme Manager,
Research Professor

VTT'S SPEARHEAD PROGRAMMES PAVE THE WAY FOR TRANSITION

Growing global and national interest in sustainable development addresses grand challenges due to the overuse of our planet's resources. The major drivers behind the bioeconomy are aligned with the growing need to decrease oil dependency, resource sufficiency and mitigation of climate change. Bioeconomy is defined as an economy which targets growth by fostering and enabling sustainable use of renewable resources. Bioeconomy provides a basis to a society which is no longer dependent on fossil raw materials for energy and other industries, and which promotes the resource-wise use of assets according to the principles of the circular economy.

FINLAND IS a rich country in terms of natural resources, e.g. forest, water and minerals. The Finnish bioeconomy targets increased competitiveness and renewal of forest, agro, chemical and energy industries, establishment of an ecosystem of growth-intensive SMEs and startups and new jobs, improved trade balance and societal wellbeing.

Science and technology play key roles in a successful bioeconomy, paving the way for emerging businesses and new innovations. A successful bioeconomy requires a multidisciplinary approach that combines a range of disciplines, from chemistry, biotechnology and nanotechnology to electronics and information and computer technology. Understanding of markets, consumer behaviour and new business models is furthermore required for acceleration of the bioeconomy. Research and innovation activities have also been demonstrated to foster the economic growth and competitiveness of the companies in the bioeconomy sector. Spending on research and innovation is, thus, not a cost but an investment for success.

VTT's spearhead program instrument was created to target sectoral breakthroughs and technological leaps by integrating knowhow throughout VTT. As impact driven and forward looking entities, they are expected to contribute to industrial transformation, initiate disruptive openings, and generate significant and measurable societal impact.

Bioeconomy is at the core of VTT's strategy and research, development and innovation activities. The VTT spearhead program "Bioeconomy Transformation" was wholly aligned with the national bioeconomy strategy and targeted providing solutions for transformation and profitability advances for the biomass sector. Our passion is to help customers and Finnish society in industrial renewal and to become bioeconomy frontrunners! ⬢

Anne-Christine Ritschkoff
Executive Vice President,
Strategic research

MAKING OF TOMORROW'S BIOECONOMY

Finland is taking a leading role in the bioeconomy. The Finnish Government has chosen the bioeconomy as a future growth area of the Finnish economy. The national bioeconomy strategy, published in May 2014, sets ambitious growth targets for the future bioeconomy. The bioeconomy is already an important part of Finland's economy due to our strong biomass processing industries, and the technology industries serving the whole ecosystem from biomass harvesting to processing. We have an excellent combination of strengths: raw material is plentiful, we have industrial traditions and ecosystems, and very knowledgeable people. The country's renewable resources can substitute a significant amount of domestic use of fossil resources and provide solutions and products for the rest of the world.

THE BIOECONOMY relies on natural resources, but we must resist taking a pure supply-driven approach. Too often we justify the bioeconomy with the argument that there are plenty of renewable resources that need to be used. From the forest management point of view this is a valid point – in order to maximize the yield and carbon sink, we need to manage the forests and remove trees at different stages. But how do we ensure that there is a demand for all that harvested biomass? How do we maximize the economic, environmental and social impact from the limited renewable resources? These are the questions that we are only starting to address comprehensively.

Rapid generation of new business and regeneration of the existing sectors will be vital for the evolution of the bioeconomy. A majority of the new business will grow alongside the existing businesses of forest, chemical and food industries, agriculture, the construction sector and energy production. Despite all these advances and opportunities, we are still in the early phases of development.

Biomass is not an endless resource. We need to utilize it in a sustainable way. We must develop technologies for resource-efficient use of biomass, produce various products with different values and minimize waste. New innovations, like nanocellulose, open up very exciting possibilities for future biomaterials. There is exciting research going on to expand the limited raw material supply to waste, fast growing biomass like algae and even CO_2. Synthetic biology may revolutionize the way we produce chemicals and materials.

VTT has broad expertise in technology and product development and can help companies and society in their transition to the bioeconomy. In this report we have collected highlights from the Bioeconomy Transformation spearhead programme. I hope these examples will illustrate the significant potential of the bioeconomy, and inspire us all to continue building the bioeconomy of tomorrow. ⬢

Jussi Manninen
Executive Vice President,
Solutions for natural
resources and environment

Business opportunities

THE ROCKY ROAD FROM SCIENCE TO BUSINESS

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During the five years of the programme 1200 research articles have been published at VTT in the bioeconomy field. This shows that a wealth of new knowledge, scientific discoveries and promising technologies has been created. A true challenge affecting the whole academic world is how to turn the scientific results into new innovations and business. A multitude of options exist to commercialize research findings. How can we speed up the process and choose the right path in each case?

IT IS IMPORTANT to identify the most promising concepts early on and support their development from an initial, original idea to a mature business case. Connecting business development with research projects and researchers speeds up commercialization of research results.

At VTT, business development experts seek initial ideas and concepts. They support the researchers to validate and develop their concepts according to the need-approach-benefit-competition framework. Twice a year a specific selection round has been organized to gather commercialization ideas from researchers, and proof-of-concept projects have been started. The ideas may range from a concept for a potential technology spin-off company to developing a VTT offering for customers. Many of the cases identified in the bioeconomy space have been later developed by the support of Tekes – the Finnish Funding Agency for Innovation, leading to licensing cases and VTT spin-offs.

Commercialization is considerably speeded up if the new technology and business concept finds ownership from existing industry. However, sometimes there may be a gap in the value chain or the industry evaluates the technological or business risk as being too high. In such a case, a VTT spin-off company may remain the only option to commercialize the new technology and business concept. During the past few years several potential spin-off cases have been evaluated. Two examples of realized cases are Paptic Ltd and Spinnova Ltd. Both of the spin-off companies strive to be successful in the biomaterials space addressing a lucrative market opportunity (see case examples below).

Intellectual property can be an important asset. Often a lot of detective work and discussion is needed to identify an industrial partner who recognizes the benefit of a new technology and wishes to secure it for their own commercial use. In such a case, licensing and technology transfer take place. In 2015 the Finnish grain processor and bakery company, Fazer Ltd., licenced the oat fractionation technology of VTT. Today Fazer Ltd. processes top-quality Finnish oat grains in their Lahti mill and use the different fractions in their own grain and bakery products.

Sometimes it makes sense to join forces with multiple potential beneficiaries. The FADOUC cluster project of 8 companies and VTT cooperatively develop the foam forming platform. The target is to build on original VTT technology and make a commercial platform for web-based fibre products using foam forming.

The examples in the following pages describe some of the most successful cases where commercialization of research results and technologies is at full speed. Commercialization, if anything, requires hard team work. It can be also great fun. Ultimately, it turns the R&D investments into a tangible benefit for society. ⬢

HIGH-VALUE INGREDIENTS FROM OATS

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OATS ARE A FINNISH "super grain" and a good source of a diverse set of nutrients. The Finnish oat is high in quality and adding value to it as a high-value ingredient creates a great business opportunity for the Finnish food industry. On the global scale, using oats is a growing trend, and oat products are in high demand particularly due the well-proven health effects. The EU has approved several health claims related to the benefits of oats in terms of blood sugar level balancing, blood cholesterol lowering and gut health. In 2015 Fazer Mill & Mixes answered global need by launching a new product line of value-added oat ingredients including oat beta glucan, oat protein and oat oil.

The process of manufacturing the new ingredients is based on a patented technology from VTT (developed in cooperation with the Natural Resources Institute Finland, Luke) and has been exclusively licensed to Fazer. The process does not include any harsh processing steps and thus the valuable oat components are obtained in a safe, natural, and un-denatured form. According to Fazer the new oat ingredients enable improving nutritional content of food and can significantly improve their positive health effects. They are excellent ingredients for different food applications such as breakfast products, smoothies, drinks, food supplements, biscuits, snack bars and even for cosmetics. Finnish oat protein is also a great product to respond to the growing diet trend for using more plant protein.

- At the moment VTT is looking for partners outside Europe to commercialize the technology.

INNOVATIVE WOOD FIBRE YARN: ECO-FRIENDLY AND COST-EFFICIENT

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SPINNOVA LTD., A VTT SPIN-OFF COMPANY, was established in late 2014 and started operations in the beginning of 2015 to commercialize Fibre-to-Yarn technology globally. Spinnova meets the globally growing need for environmentally friendly, high-quality and low-cost textile yarn production. The demand for environmentally friendly textile products is increasing and currently there are no truly sustainable pathways to produce textile yarns. Increasing population, tightening legislation and scarcer natural resources will continue to increase this demand.

Invented at VTT in 2011, the new patented Fibre-to-Yarn technology allows simpler and more flexible production of bio-based, resource-efficient textile yarns with excellent recyclability and significantly lower production cost. Fibre yarn production uses virgin pulp fibres directly as yarn building blocks maintaining all the good properties of natural pulp fibres with no need for dissolution chemicals. Thus the technology provides a perfect economic and environmental alternative to cotton- and oil-based textile yarns. The developed technology uses a wet spinning process enabling the production of a wide variety of yarns from thin textile monofilaments to thick decorative yarns. Fibre yarn can be functionalized in many ways to meet the demands of different applications. Fibre yarns can be coloured, they can be made conductive and fibre yarn properties like strength, smoothness, stretch and hydrophobicity can be adjusted.

The most interesting market segment is apparel and textile products, with the objective to give cost-efficient and sustainable alternative to cotton, oil and man-made cellulose-based yarns. Other very interesting market segments include medical applications, bio-composite reinforcements and even the traditional paper yarn market.

At the beginning of 2015 Spinnova Ltd. started its operations to upscale the technology to the industrial scale. During 2017 and 2018 Spinnova will build an industrial pilot line capable of producing

300 tons of yarn annually. With this production economical calculations and consumer acceptance of fibre yarn will be tested. Finally, building of a full-scale industrial production plant will be started in 2020–2022.

- 99% less water than cotton production
- 60% less production costs than cotton
- up to 20% of global cotton usage could be replaced with Finnish harvesting surplus alone
- 1.95M€ investment secured for first phase
- Commercialization plan:
  2018: Production capacity of 300 tons/a
  2020: The first industrial scale production plant with 30,000 tons/a capacity

REVOLUTIONARY NEW MATERIAL REPLACING PAPER AND PLASTIC

Tuomas Mustonen, Founder, Managing Director, tuomas.mustonen@paptic.fi, +358505987516

PAPTIC LTD. was founded in April 2015 as a VTT spin-off company with the target of offering a sustainable and renewable alternative to plastic films. The first application area is carrier bags, while flexible packaging as a whole offers wide future growth potential.

Non-degradable, poorly recyclable, easily littered and long-lasting plastic products cause extensive accumulation of problems and endanger marine ecosystems. About one trillion plastic bags are used every year, with 89% of them only once. Despite the urgency of the problem, no viable material alternative has been found until now.

Paptic Ltd. addresses this global challenge and satisfies the needs of consumers, retailers and brand owners for sustainable carrier bags. The novel wood fibre-based material PAPTIC® combines the renewability of paper with the resource efficiency and functionality of plastics. Once fully developed, PAPTIC® bags will be 100% biodegradable, renewable and recyclable.

The patented PAPTIC® bags are the world's first economically sound and environment-friendly alternative to plastics bags. Although market entry is achieved through carrier bags, PAPTIC® will enter the whole flexible packaging market expected to be worth 200 billion € by 2018. The business model for scaling up the production of PAPTIC® is based on utilization of existing and excessive paper industry infrastructure.

Today PAPTIC® material is produced in a pilot-scale environment in Espoo and the production will be scaled up to the range of 10 000 tons annual production in 2018. In order to speed up the scale-up, Paptic received from the European Commission (Horizon 2020) a grant of 2.2 million EUR in July 2016. Paptic Ltd. is currently conducting tests with a number of the best-known brands and retailers in the world, with extremely favourable feedback from brand owners. The first deliveries of Paptic® Bags were made in June 2016 and the feedback both from the customers and consumers has been thoroughly positive.

PAPTIC®

FOAMOSS – NATURAL MOSS-BASED CULTIVATION PRODUCTS BY FOAM FORMING

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THE DOMINANT material for growing fresh vegetables in green houses in Europe is currently rock wool. It is a proven industrial material with well-established irrigation and nutrient management qualities. On the other hand, the material is of mineral origin, has an unappealing appearance and low water retention capacity. It provides no particular protection against plant diseases and requires special waste collection and treatment after use.

Peat is also used in greenhouses as a natural material alternative. However, some restrictions have been planned with regard to using peat because of its long renewal cycle. Further, peat as loose material is not convenient to handle, and further, there are seasonal availability issues.

VTT has developed an industrially applicable method to manufacture solid easy-to-handle growth media by combining our expertise in foam forming technology and fibre processing. The method has been patented in cooperation with our partner, Natural Resources Institute Finland (Luke). In the process, sieved sphagnum moss is mixed with air, water, foaming agent and a binder to form a foamy fibre suspension. The foam is delivered to a frame and then water is removed by suction to form a slab with the desired density and thickness. By applying cup-shaped, curved or other moulds inside the frame, also pot shaped, waved and other designs have been created.

Foamoss material provides a cost-effective and naturally anti-microbial alternative for the green house grower. The material can be formed into innovative home and garden products. Even seeds and fertilizers can be added already during manufacturing. For the product manufacturer, the technology provides an opportunity to differentiate in the professional product market and to design totally new products for new user groups. The technology is in industrial scale-up with our licensing partner Novarbo Oy.

TIME TO MARKET: 0–2 Estimated years	TRL 6-7	TECHNO-ECONOMIC EVALUATION ✔	LCA ✔

I am motivated by combination of business development and saving the planet together with customers.

- Key Account Manager at VTT

FAST PYROLYSIS TECHNOLOGIES – FROM BIOFUEL OIL TO TRANSPORTATION FUELS

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SEVERAL YEARS AGO VTT identified that all biofuels are, and for the near future will be, more expensive than their fossil counterparts. This has become increasingly obvious lately as technologies are moving towards demonstration. Thus, the emphasis has been on reducing biofuel plant capital and operating costs by developing new concepts and improving existing alternatives.

Related to fast pyrolysis, the solution VTT has patented and licensed to industry, has been integration of the pyrolysis reactor and fluidized-bed boiler, which is widely employed in combined-heat-and-power production in industry and in district heating. The integrated technology, invented already in 1996 at VTT, was developed on an industrial pilot scale together with Valmet, Fortum, and UPM in 2008–2013. Valmet has subsequently built a demonstration plant for Fortum in Joensuu. The bio-oil product is used to replace fossil oils in district heating.

VTT is also developing fast pyrolysis further for the production of transportation fuels. Tekes, US DoE and industry are co-funding research, in which VTT and Pacific Northwest National Laboratory (PNNL) (Washington, Richland) are hydrotreating primary pyrolysis oil (both thermal and catalytic oils) to higher-value products. While the bio fuel oil application is at demonstration level, the transportation fuel concept is only at laboratory scale. Further development needs have been identified based on techno-economic assessments and a LCA on these technologies. Currently the emphasis is on employing catalytic pyrolysis using modified in-house catalysts, product hydrotreatment, and also on co-refining of pyrolysis bio-oils in standard mineral oil refineries.

TIME TO MARKET: 3 Estimated years	TRL 4-7	TECHNO-ECONOMIC EVALUATION ✔	LCA ✔


Food

RETHINK THE FOOD CHAIN!

Further information: Emilia Nordlund, emilia.nordlund@vtt.fi, +358405042963

Food production is an important part of the bioeconomy; in the EU the turnover of the food and drink manufacturing industry is over 1.2 trillion euros with 206 billion of value added and employing a total of 4.2 million people. Food is a basic need for humankind, but also a source of pleasure and a way to express lifestyle and values. The food production chain from primary production to ingredient and consumer food production and further distribution and use has evolved into a global system with many new challenges. These include the increasing population and urbanization, climate change and water scarcity. To improve the sustainability of the food supply chain, there is a need to use arable land and food raw materials in a much more efficient way to assure global food and protein security. At the same time, there also is a need to provide healthy convenient foods with high eating quality, since eating pattern is an important lifestyle factor contributing to the prevalence of non-communicable diseases.

AT VTT OUR SLOGAN has been to “Rethink the food chain”. We wish to reconsider the way plant raw materials are used for food, and target increased use of original plant material in final food products. Innovations in plant-based food and eating solutions would not only support the transition from a less sustainable animal-based diet to a plant-based alternative, and reduction of the amount of side-streams, but also would yield foods higher in dietary fibre, plant protein and bioactive plant phytochemicals. Rethinking the food chain also means development of new fractionation processes from the very beginning, so that various components can better be valorized in their native form resulting in less waste. Incorporation of new sustainable ingredients, e.g. multifunctional food components from wood raw materials is one of our novel approaches to create new business opportunities in the bioeconomy.

We have emphasized fractionation and hybrid processing of side-streams to concentrate and improve the functionality of new plant ingredients. We have developed bioprocessing methods to allow for more robust ingredients with controlled interactions of different plant constituents. We also have developed in vitro methods to predict healthiness in food design and the bioavailability and conversions of food in the gastrointestinal tract. We also have initiated work on new food production methods such as additive manufacturing and plant cell cultures to respond to the consumer trends of customization, health and snacking, but also to increase sustainability in the food chain.

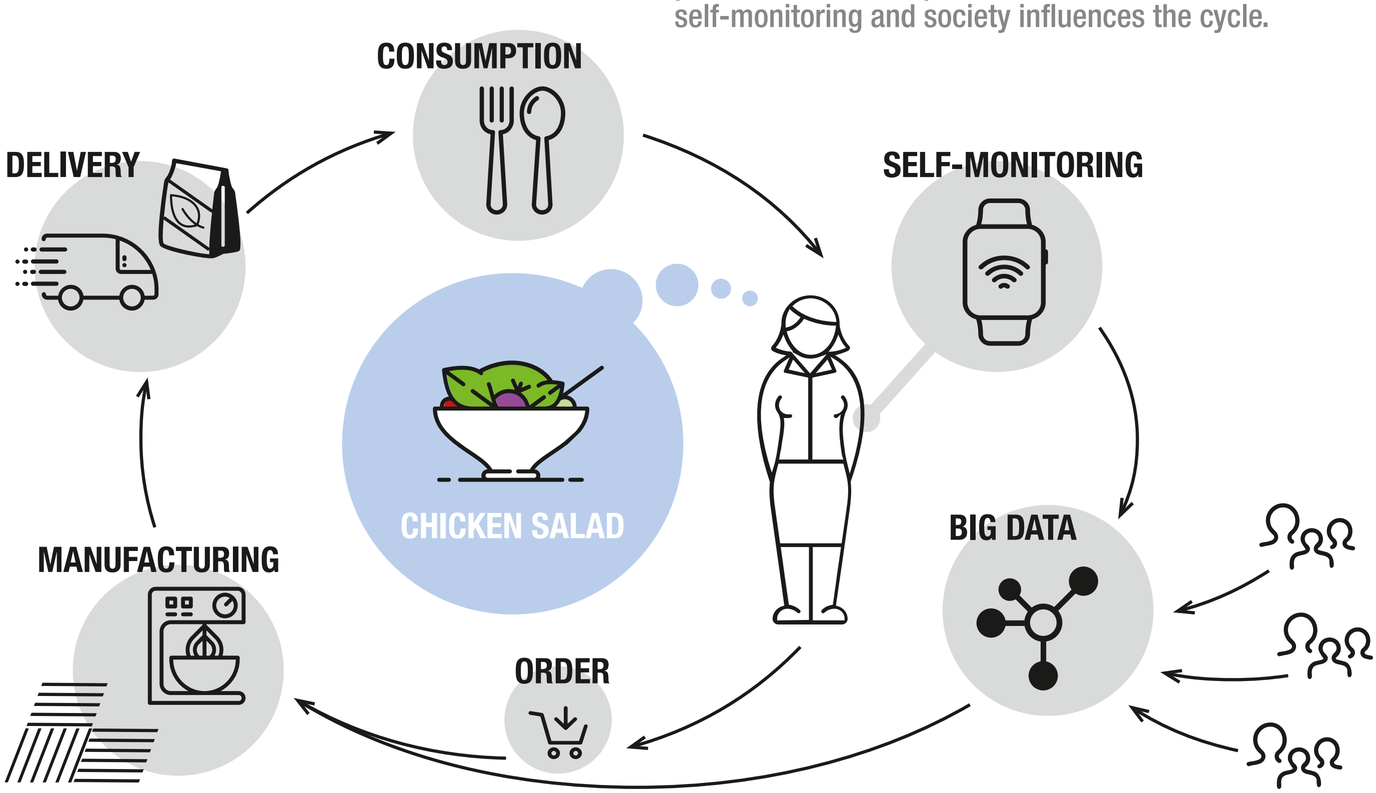
OUR RESEARCH HAS CONCENTRATED ON THE FOLLOWING:

- Better use of food processing side streams
- Sufficiency of food protein: new sources of plant proteins and their applications
- Production of palatable foods high in dietary fibre
- Use of novel unconventional food raw materials (wood, insects, plant cell cultures)
- Working on a roadmap towards a New Food Economy with consumers at the centre of a new food supply system in the rapidly developing digital world ⬢

RETHINK THE FOOD

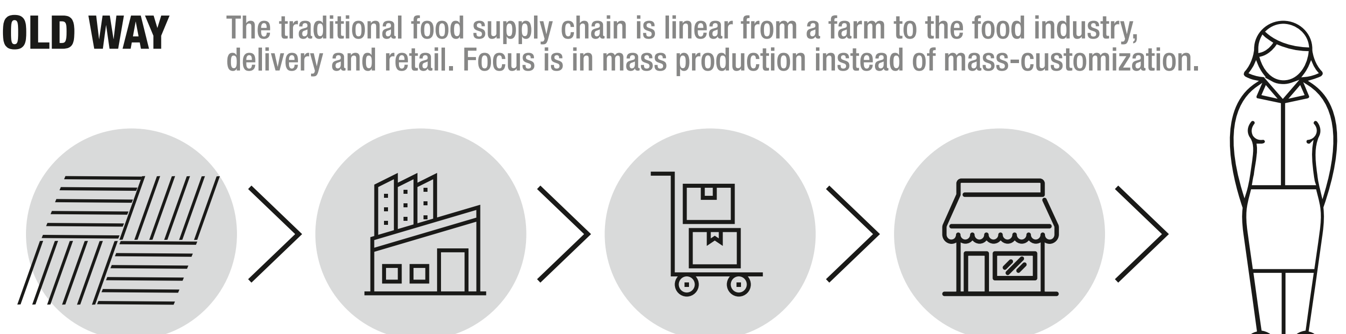
CONSUMER-CENTRIC PRODUCTION

Consumer-centric production means smart food production and delivery systems according to personal needs and preferences. Feedback from self-monitoring and society influences the cycle.



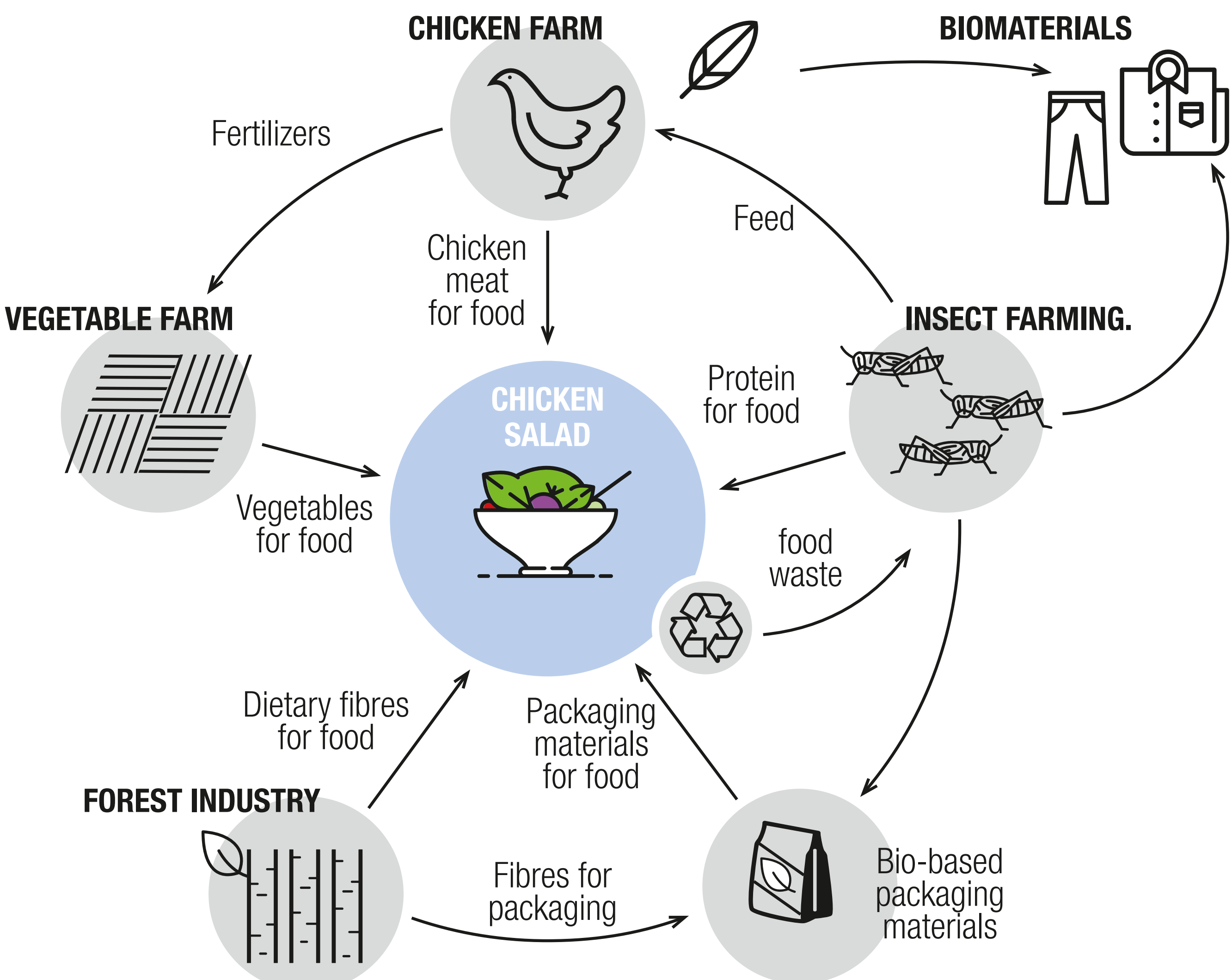
OLD WAY

The traditional food supply chain is linear from a farm to the food industry, delivery and retail. Focus is in mass production instead of mass-customization.



All circular to prepare your hybrid chicken salad

CIRCULAR RAW MATERIAL ECONOMY



Integrated food production saves nutrients, raw materials, water, energy and produces less waste or emissions. Raw materials are maximally utilized for food and package manufacturing.

INNOVATIVE PLANT PROTEINS

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THE CURRENT TRENDS in the food market, health and well-being and increasing consciousness on the part of consumers regarding sustainability of food production creates a need for new domestic plant-based protein ingredients. In addition, sustainable and efficient exploitation of side-streams from the primary production and food industry requires novel production technologies and business models. There is also a governmental push to increase protein self-sufficiency at both the EU and national level in Finland.

The global plant protein market is currently dominated by soy-derived proteins with over 50% share of the market. Today, 200 000 tons of soy is imported on an annual basis, the most of which is used as feed. Imported soy protein could easily be compensated by recovered losses of the grain chain and domestic protein crops, since at the same time 150 000 tons of cereals and bread is lost as loss in production and as biowaste. Other alternative plant protein sources include legumes, oil crops and their side streams as well as grass for livestock feeding.

Plant proteins are typically entrapped within the cell matrix, which hinders their bioavailability and performance as food ingredients. Entrapment and interactions with other cell components also reduce the efficiency of protein extraction from the fibrous matrix. Other limitations for food ingredient use of protein from plant materials and their side streams are the presence of anti-nutritional factors in the raw materials, and inferior techno-, nutritional and sensory functionalities of the proteins compared to animal-based proteins. Based on sophisticated combinations of bioprocessing, thermo-mechanical processing, wet or dry fractionation and supercritical carbon dioxide (SC-CO_2) extraction technologies, VTT has developed fractionation and extraction methods to concentrate protein from plant materials and their side-streams into fractions having improved nutritional, techno-functional and sensory properties. One key target has been development of multi-functional protein ingredients via minimal processing technologies.

The newly developed plant protein ingredients have been applied to diverse food matrices covering liquid (e.g. drinks), semi-solid (e.g. puddings, gels) and solid (e.g. pasta, bread, extrudates) applications. VTT has two approaches to improve the applicability of the protein ingredients in such foods: 1) modification of the protein functionality in situ by, e.g. bioprocessing, and 2) direct modification of protein ingredients by controlled hydrolysis, mechanical modification, or crosslinking of proteins by enzymes.

PROTEIN SOURCES	TRL	TECHNO-ECONOMIC EVALUATION	LCA
Faba beans	9	✓	✓
Oats	9	✓	⌛
Rapeseed press cake	7-9	✓	✗
Cereal brans	4-6	✓	✗

Hybrid processing consisting of milling, air classification and fermentation significantly reduced the major antinutritional factors (e.g. vicine, convicine, trypsin inhibitor, condensed tannins) in faba bean protein concentrate by 40 to 90% depending on the component. Fermentation further improved the solubility particularly around the pH range of minimal solubility (3–5). Foam formation and stability (after fermentation) was improved to levels even higher than the benchmarking pea protein concentrate (overrun 600% vs 200%).

Dry and wet fractionation technologies have proven useful for valorization of rapeseed cold-press cake, a side-stream from high-quality food oil production. Supercritical carbon dioxide extraction, milling and air classification yielded a light-coloured protein-rich powder (46% protein) showing high dispersion stability after microfluidization and transglutaminase treatment. In the wet fractionation approach, water extraction assisted by carbohydrate-hydrolysing enzymes produced protein-sugar extracts exhibiting lighter colour and better protein solubility and dispersion stability than conventional alkaline extraction, at the same time with a similar yield and estimated production costs.

VTT has focused on the utilization of the domestic European plant raw materials and side streams such as faba beans, oats, barley, cereal brans and oil press cakes for protein extraction. All these raw material sources have a natural image, are GMO free and their extraction steps are simple and green consisting of mechanical fractionation and further bioprocessing.

WOOD TO FOOD – MULTIFUNCTIONAL FOOD INGREDIENTS FROM WOOD

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THE FOOD INDUSTRY and consumers demand food products that are healthy, safe, natural and have a long shelf-life. Many of these functionalities are achieved with wood-based ingredients. Cellulosic, hemicellulosic and lignin fractions from wood possess unique properties, such as thickening, film forming, emulsifying, emulsion stabilizing and antioxidant characteristics that are exactly the same functional properties that the food industry seeks for their products. The proof-of-concepts performed recently at VTT illustrate that wood-based fibrillar cellulose is a promising hydrocolloid to tailor the viscosity and stability of dairy products.

Hydrolysed birch xylan improves the texture and stability of model yoghurt by improving the smoothness and reducing the separation of a liquid layer upon storage. At the same time, *in vitro* studies predict that it is also beneficial for gut health since xylan is fermented slowly by colon microbiota. Lignin has been proven to be a promising emulsifier in oil-in-water dressings or baking products.

The constant quality, better performance in selected products, sustainable production processes, gluten-free feedstock and low production costs make wood-based ingredients attractive alternatives for commercially existing ingredients. Research is still needed to validate the technical performance in real products, assess safety and realize the novel food status for these wood-based ingredients. Therefore, these could enter the market in 5–10 years.

TIME TO MARKET: 5–10 Estimated years	TRL 2-3	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

PLANT CELL CULTURES BRING THE NATURAL RESOURCES OF THE ARCTIC TO THE TABLE

Further information: Lauri Reuter, lauri.reuter@vtt.fi, +358401592273

URBAN DWELLERS are hungry for fresh and healthy foods, while being increasingly aware of the sustainability of food production. Getting involved in the production of food is also an emerging trend: consumers are becoming prosumers, meaning that they want to take part in the food production process themselves. Many plants found in the Arctic are of interest to global markets, but cannot be foraged or cultivated at large scale.

An exciting approach is the use of plant cell cultures for food. Cell cultures can be made from any living plant, also from species not traditionally used for food, such as birch. Cultured cells retain the potential of plants to produce bioactive molecules, but are free of many limitations. Growing the plant cells in contained bioreactors avoids over-harvesting of wild plants and excess use of agrochemicals, arable land, potable water or fertilizers in agriculture. Furthermore, VTT's home bioreactor concept enables anyone to grow plant cells, fresh at home.

The VTT solution constitutes a disruptive technology making agriculture ultimately redundant. Food production becomes independent of seasons, geographical area and political situations while being sustainable and environmentally sound.

The research at VTT aims to develop scalable and economically feasible cultivation of plant cells for food applications, either fresh or as ingredients. The composition of cell cultures from native arctic plants is analysed in detail and cell lines with unique characteristic are continuously being developed. Cell cultures from VTT´s collection are already utilized commercially in cosmetics; the next step is to take the same technology to the food sector and even to home cultivation. The home bioreactor is the first bioreactor designed to bring cellular agriculture to the home environment and into the hands of the end-user. The prototype is developed further towards commercialization.

TIME TO MARKET: 3 Estimated years	TRL 6	TECHNO-ECONOMIC EVALUATION ✔	LCA ✘

My motivation for bioeconomy research is related to the complex nature of challenges. My passion is to innovate new.

- Senior Scientist Matti Tähtinen

SUSTAINABLE ANIMAL PROTEIN? BUG-BASED FOOD INGREDIENTS Á LA VTT

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WITH A GROWING world population, sufficient production of protein from livestock, poultry, and fish represents a serious challenge for the future. Insect farming is one of the most affordable and sustainable future solutions to complement the global shortage of protein.

Insects are an underexploited but promising resource of animal-based food protein. They are rich in minerals, vitamins, unsaturated fat and high-quality protein that contains all essential amino acids. Insect farming beats conventional meat production in sustainability: bugs have high feed conversion ratios, require limited space and emit low levels of greenhouse gases. Insects can be grown on organic side streams such as food waste to transform them into a high-protein, high-oil feedstock that has potential for broader food and feed use.

To increase utilization of insects, cost-effective processing technologies that provide palatable, functional, stable and safe food products and ingredients are needed. Processing technologies for insects to fractionate the valuable components such as proteins are widely unexplored, although significant benefits in terms of stability and sensory quality could be achieved.

Insects are primarily composed of protein and fat inside a chitin-containing exoskeleton. Taking advantage of vast dry fractionation know-how and the milling behaviour of insects, VTT has developed a simple dry technology to produce insect fractions with improved sensory properties. Gentle supercritical carbon dioxide extraction allows production of high-quality insect oil and facilitates dry processing of the remaining protein-rich insect mass into high-protein food ingredients. The new insect protein ingredients are expected to show broad applicability in various food products.

VTT's dry fractionation technology yields insect protein fractions which have potential to replace more expensive and less sustainable animal proteins in both existing and new food products. This technology as well as knowledge about the nutritional and sensory quality, functionality and performance of these ingredients in various foods will benefit the sprouting insect market in Europe and worldwide.

TIME TO MARKET:	TRL	TECHNO-ECONOMIC EVALUATION	LCA
2-5 Estimated years	4-5	✗	✗

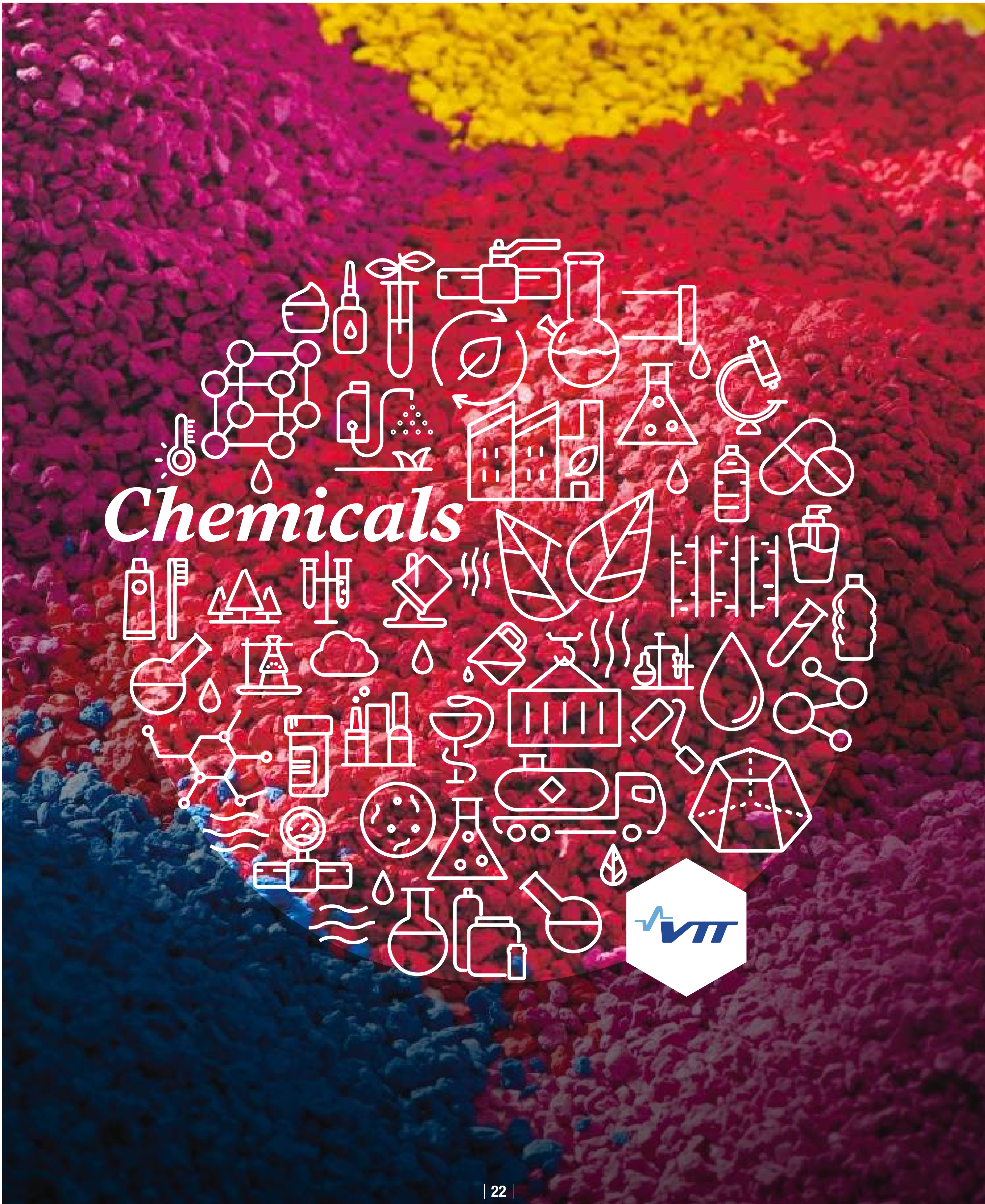
My target is to make the circular economy a viable reality.

\- Principal Scientist David Sandquist

My driving forces are curiosity and the possibility to "save the planet".

\- Principal Scientist at VTT

Chemicals



CHEMICALS FROM RENEWABLE SOURCES

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The biobased economy targets replacing fossil resources with renewable biological resources from land and sea to produce food, materials, chemicals and energy. The concern over climate change is often seen as the main driver for production of chemicals from renewable sources. However, there is also a need to secure sustainable food production, clean water and resources for housing, clothing and everyday life commodities for the ever-increasing human population. Renewable platform chemicals can offer a significant contribution in solving these challenges, in addition to the gained decrease in carbon footprint.

PRODUCTION of renewable chemicals and their different end-applications have accelerated during recent years. MacKinsey & Co estimates that the world sales of renewable chemicals will increase from € 205 billion in 2012 (9% of total chemical sales) to € 344 billion (11% of total chemical sales) by 2020 with a GAGR of 8%. This development can be attributed to the following challenges and drivers, to name a few:

- In order to battle against climate change, fossil-based fuels, chemicals and materials need to be replaced.
- In the long run fossil resources will be depleted.
- The bioeconomy is an integral part of the circular economy, guiding the future use of raw materials.
- International brand owners seek sustainable chemicals in applications such as packing materials, solvents, inks, fibres, resins and paints.
- There is an effort to replace toxic and harmful chemicals in applications related to food or human contact.

VTT has developed different technologies for the production of renewable chemicals from biomass, in particular from side- and waste streams. Biotechnology, chemistry and thermochemistry offer viable and attractive options for the production. In addition, VTT has developed technologies to produce bio-based chemicals and materials directly from one-carbon resources such as CO_2 and biogas methane, paving the way towards the C1 economy, broadening the options to produce commodities and food in the future.

As the maturity of the developed technologies increases the different production value chains gain increased attractiveness. The aldaric acid platform where pectin from sugar beet pulp or citrus fruit peels, side/waste products, exemplifies the combination of biotechnology and chemistry to achieve production of bio-based monomers for bio-plastics. C5 sugars from biomass are an underutilized bioresource as of today, and need attention in order to gain feasibility in biorefineries. The economics of fast pyrolysis has been improved by developing a two-stage process for production of higher-value chemicals in addition to bio-energy. Gasification, Fischer-Tropsch and aromatization technologies have been used to produce α-olefins and BTX (benzene, toluene and xylene) from forest residues. Some of these developments have already been practised on a larger scale during the VTT Bioeconomy spearhead programme, however, piloting is seen as a crucial next step to demonstrate their feasibility.

Importantly, side- and waste streams of biomass are not the only options as raw materials for the production of future chemicals. VTT is developing several technologies to utilize CO_2 for this purpose. These include, e.g., production of methane and methanol from bio-based hydrogen and CO_2, and polyols and polyurethanes from CO_2. Additionally, as exemplified below, biological systems can offer ways to produce bioplastics from CO_2 and biogas.

Future steps target commercialization of the already developed production platforms, and towards introduction of new renewable chemicals to be produced using renewable resources. VTT shares the vision for the future (> 2030) foreseeing that a major part of chemicals is produced from renewable resources and that a significant part of them is produced partly or completely from CO_2.

BIO-BASED POLYAMIDES AND POLYESTERS FROM WASTE STREAMS

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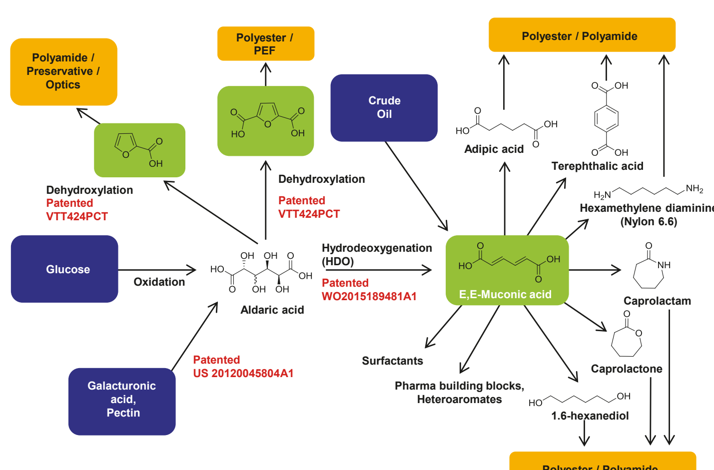
The need for bio-plastics is growing. Brand owners are looking for sustainable solutions for packaging, fibres, paints, inks and plastics. This creates a need for high-performance bio-plastics such as polyamides (PA) and polyesters (PET). The total global production of PET polymers was over 50 MT and that of PA over 10 MT in 2015. Furan dicarboxylic acid (FDCA) -based polyethylene furanoate (PEF) polymers offer a bio-based alternative to petroleum-based PET polymers. Polyamides are used in applications calling for high durability and strength. Muconic acid is a versatile monomer which can be converted to multiple PA monomers such as adipic acid, terephthalic acid, hexamethylene diamine, caprolactam, caprolactone and 1,6-hexanediol. Polyamides (PA) are used as engineering plastics, for example in automobiles.

VTT has developed a process to convert pectin biochemically to an aldaric acid, which in turn can be chemically converted to monomers for bio-based polyesters and polyamides. Pectin is a side stream obtained from citrus fruit peels or from sugar beet pulp. Sugar beet pulp is currently used as animal feed, but the goal is to use the pulp for higher-value applications. Pectin is currently underutilized as the production is only about 40 000 t/a, with the potential of several tens of million tonnes available annually. Its current use is in the food and beverage industry as, for example, a gelling agent. In addition to pectin, wood- or plant-based glucose can be used in the production of aldaric acid.

VTT has patented a technology combining biotechnical and chemical reaction steps to produce FDCA and muconic acid from aldaric acids. The first step consists of the oxidation of galacturonic acid, a constituent of pectin, to galactaric acid with a fungal biocatalyst. The conversion efficiency is high and this step has been scaled up to pilot scale (300 l) delivering kilogramme amounts of galactaric acid for the second step conversion. The second step converts the aldaric acid into furan carboxylic acid (FCA) and FDCA or muconic acid depending on the reaction conditions. FDCA is a monomer for polyethylene furanoate (PEF), a bio-based alternative for polyethylene terephthalate (PET). Muconic acid is a precursor for polyamide monomers. The techno-economic analysis shows competitive pricing and the life cycle analysis shows that the carbon foot print is lower compared to petroleum-based alternatives for both monomers.



TIME TO MARKET: 3–5 Estimated years	TRL 4-6	TECHNO-ECONOMIC EVALUATION AND LCA IN PROCESS

FAST PYROLYSIS AS AN AFFORDABLE BIOMASS FRACTIONATION TECHNOLOGY FOR THE PRODUCTION OF CHEMICAL FEEDSTOCK

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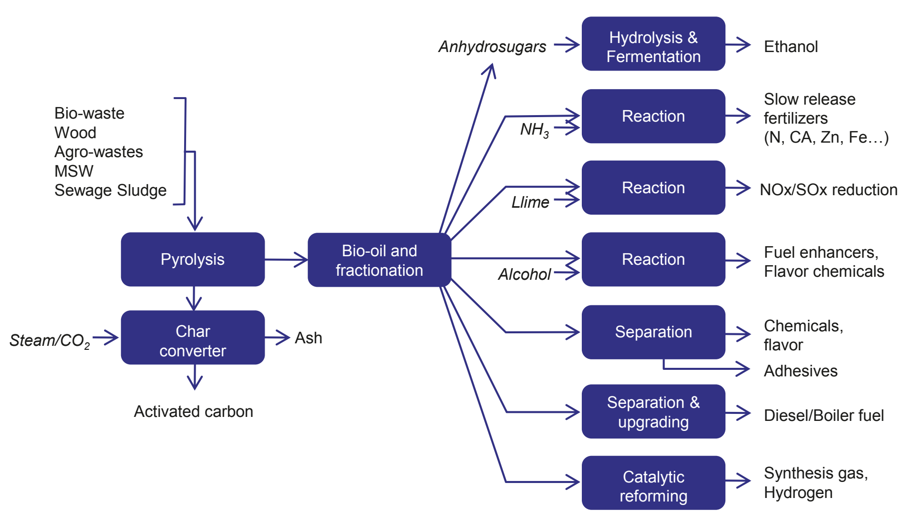
Fast pyrolysis, which has recently been demonstrated on an industrial scale in Finland, the Netherlands and Canada, can be employed to produce feeds for biochemicals. The challenge is the high production cost, which is related to the relatively low yields, and high specific capital cost. In fast pyrolysis, > 90 wt% of biomass ash is separated from other biomass components together with char, which may be used for energy production. Char utilization in many other applications (as a source of nutrients, a component for soil improvement, further conversion to activated carbon) has also been suggested.

To resolve the challenge, a two-step approach is proposed. In a low-cost primary separation step biomass is converted into intermediate product fractions, a lignin-rich and an aqueous fraction. VTT has been developing the fractionation stage to improve the separation efficiency. In the second step, fractions will be converted with high yields to products for chemical and energy use. The aqueous phase may be used for production of hydrogen through steam reforming. Hydrogen has many uses in the chemical and energy industries. Aqueous-phase organics can be hydrolysed, and further converted to chemicals via biochemical routes. Alternatively, the aqueous phase can be further converted to olefins. Through catalytic pyrolysis, both olefins and aromatics have been produced with good yields using different catalysts. The lignin fraction may be used for the production of phenolic compounds, which may be used in the production of adhesives. While the bio fuel oil application is at the demonstration level, the chemical production routes are still at laboratory scale.



TIME TO MARKET: 5 Estimated years	**TRL** 3-4	**TECHNO-ECONOMIC EVALUATION** ✗	**LCA** ✗

PROTEIN FEED AND BIOPLASTIC FROM FARM BIOGAS

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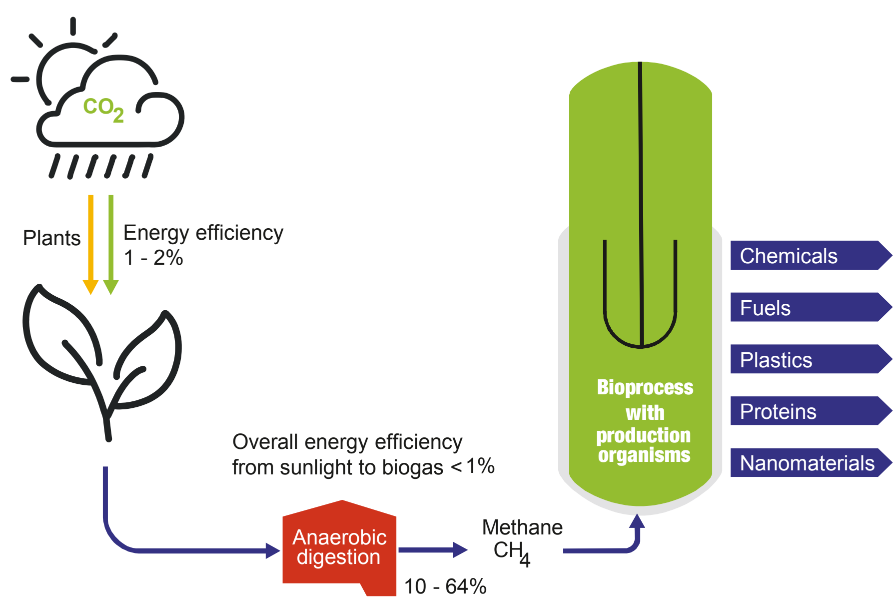
Methane-rich biogas is generated on farms, at landfills and wastewater treatment plants in anaerobic digestion of biological material. Until now, the processing of this type of gas into biomethane has only been viable on large biogas-producing sites; small biogas sources such as farms have remained largely unexploited.

The method developed by VTT enables reduction of emissions, increased use of biogas and improved protein self-sufficiency. It is based on the ability of methanotrophic bacteria to grow in aerobic conditions using methane as the source for carbon and energy. The technology presented here is targeted especially for farm use.

Methanotrophic bacteria may contain polyhydroxybutyrate (PHB) – a natural substance in the cells that enables them to store energy. PHB can be used as a raw material for biodegradable packaging material, instead of oil-based and non-biodegradable plastics such as polypropylene (PP). The cell mass may contain up to 50% PHB, in which case the protein content is around 30%. PHB and protein can be separated by extraction from the dried cell mass. The protein fraction could be used as an animal feed component. The production of single-cell proteins represents a good opportunity to improve protein self-sufficiency and reduce dependency on imported soymeal.

The production rate of microbial biomass still needs to be improved, which is expected to be accomplished during a couple of years of development work. In addition, the protein fraction's suitability as a feed component needs to be tested.



TIME TO MARKET: 4 Estimated years	TRL 4	TECHNO-ECONOMIC EVALUATION ✔	LCA ✘

CONVERSION OF XYLOSE TO VALUE ADDED CHEMICALS

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THE EFFICIENT use of all parts of plant biomass, preferably for higher-value products, is a necessity. The hemicellulose part of plant biomass, rich in the pentose sugar xylose, is still largely unused. As pre-treatment and fractionation technologies develop, xylose streams become available, and technologies to add value to xylose are needed. Converting xylose into a platform chemical is a potential way to enter high-volume markets. The market for xylonic acid is currently small, but it can be used as a chelator and as an intermediate in the production of, for example, 1,2,4-butanetriol, 1,4-butanediol, butadiene, ethylene glycol, glycolic acid and lactic acid.

VTT has developed a yeast biocatalyst for the efficient conversion of xylose to xylonic acid. The process has high yield and productivity even in low-pH conditions. Various hemicellulose hydrolysates have been tested, and the biocatalyst has been engineered for improved performance.

The benefit of VTT's approach is that xylose does not need to be purified before use. The biocatalyst and process can be tailored for xylose streams originating from different biomass sources and pre-treatment processes.

VTT is currently looking for partners for realizing the business potential of xylonic acid production and exploiting the priority yeast biocatalyst. The intention is to demonstrate the production and downstream purification of xylonic acid at a larger scale with an industrially relevant hemicellulose stream and actively seek further chemical conversions, as well as direct applications using xylonic acid/xylonate.

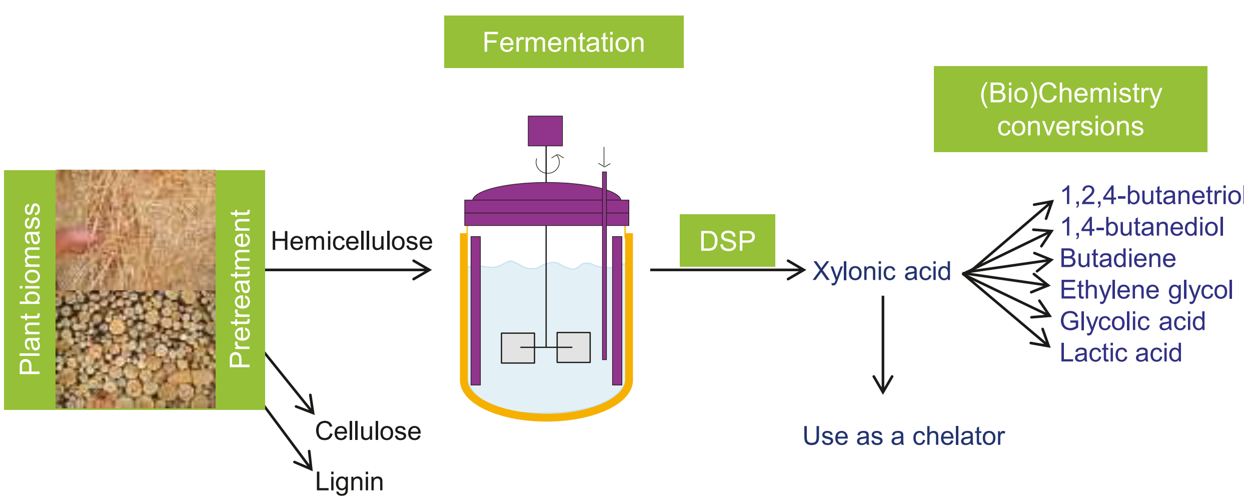

Figure. Conversion of plant biomass hemicellulose fraction to xylonic acid and further.

TIME TO MARKET: 2-5 Estimated years	TRL 5-6	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

PLASTIC PRECURSORS FROM CO_2 USING MICROBES AND ELECTRICITY

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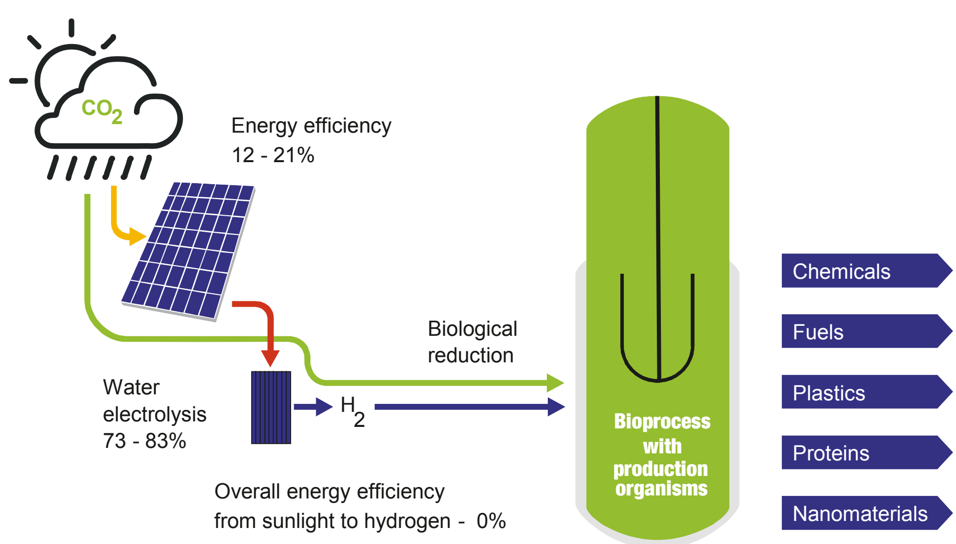
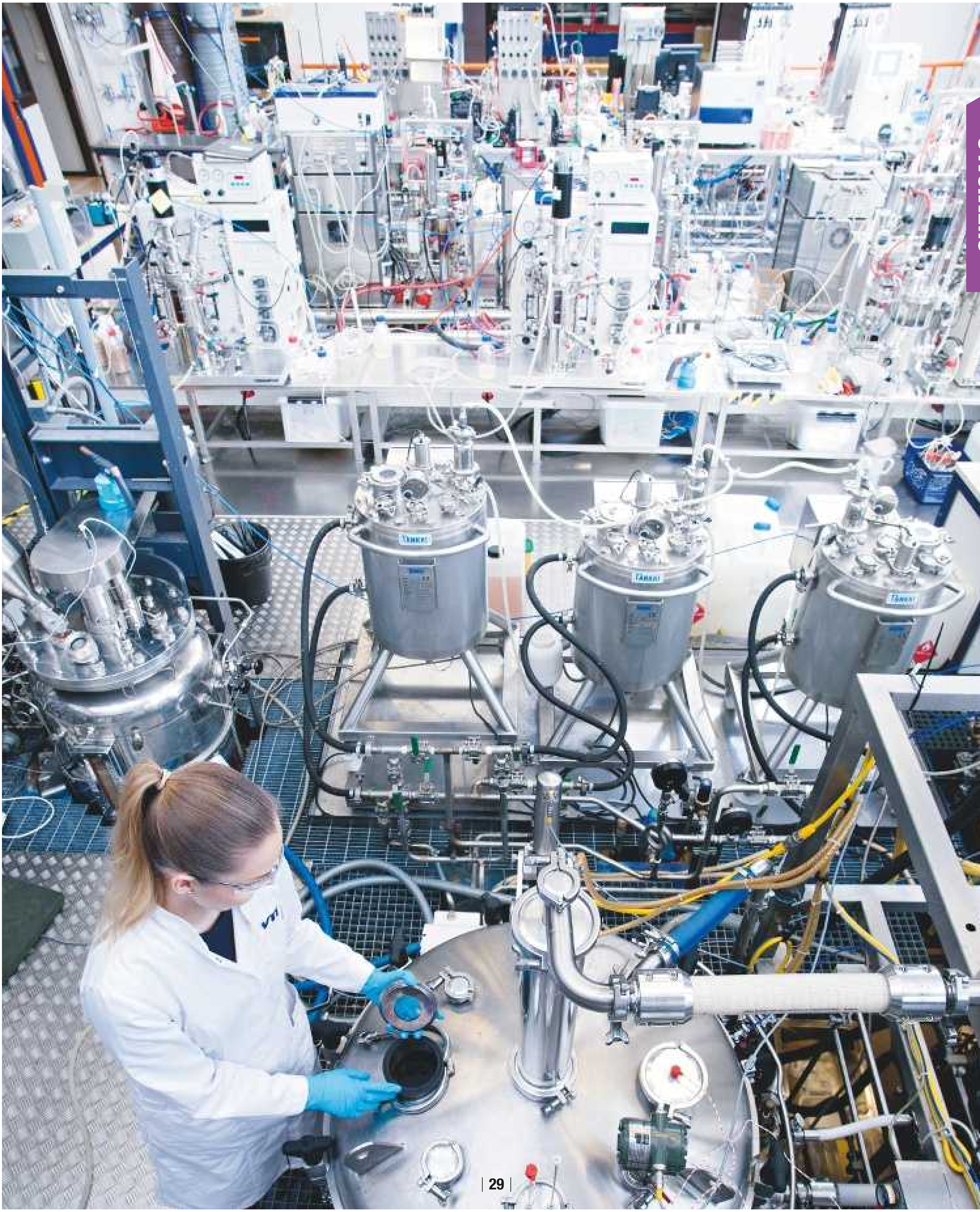
RE-USE of CO_2 is obviously a task with immense environmental importance, but it is also techno-economically challenging. On the positive side, CO_2 from flue gas or directly from the atmosphere is abundantly available as a carbon source for production of chemicals.

The direct utilization of CO_2 can be achieved through a bioelectrosynthetic system that converts sunlight to electricity and electricity to H2 via water electrolysis; coupled with autotrophic H2-oxidizing Knallgas bacteria fixing CO_2 in a dark bioprocess. Bacteria can produce a wide range of products from the assimilated CO_2. The overall stoichiometry of CO_2 fixation in the bioelectrosynthetic system is the same as in natural photosynthetic systems, but the bioelectrosynthetic system is not limited by direct access to sunlight, and uses land area more efficiently. An additional feature of the approach being developed by VTT is that water electrolysis is performed inside a bioreactor. The generated hydrogen is used directly by the microbes improving also the safety of the process. The aim is to convert CO_2 to acrylic acid using a genetically modified organism. The global oil-based production of acrylic acid is seven million tonnes with applications in paints, coatings, adhesives, diapers, resins, cleaners and elastomers. Development is at its early stage and currently aims at improving the growth of the organism in the bioelectrosynthetic system and improving the productivity of the precursor by genetic engineering of the organism.



TIME TO MARKET: 10 Estimated years	TRL 2-3	TECHNO-ECONOMIC EVALUATION ✓	LCA ✗



Materials

NEW MATERIALS, NEW SOLUTIONS

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There is an increasing worldwide demand for high-performing materials and their application in sustainable solutions. Solving contemporary challenges is strongly linked to everyday life involving food, packaging, textiles and interiors. The bioeconomy and industrial use of lignocellulose will create growth and wealth. From a boreal perspective, the forest industry continues to be a cornerstone of Finnish cellulose-based bioeconomy, the manufacturing industry and exports.

APPLICATIONS using wood cellulose traditionally have been based on utilization of fibres as elementary structures. Extensive research has been done on how to disintegrate wood structure and recover fibres efficiently and further to construct materials especially in a wet environment applying hydrogen bonding. Most of the application developments have been around web structures like papers and board, with the exception of some composites. Nanocellulose composed of cellulose nanofibrils (CNF), the finest fibre wall elements, has opened completely new dimensions for material constructions. Benefits have been seen ranging from simple improvements of mechanical strength to functional or self-organized materials. The high water content in traditional nanocellulose dispersions continues to present challenges in the handling of and conversion to nanocellulose.

Technologies for dissolving cellulose, such as viscose, have been available for a long time and their application in textiles and films have been produced in high volumes before the era of synthetic polymers. Novel, improved dissolving technologies have been invented with respect to sustainability and efficiency. Most recently, ionic liquids have shown advantages in lyocell-type direct dissolving. Dissolving systems, however, face disadvantages in process ability and recycling of chemicals, restricting their competitiveness against thermoplastic polymers.

The third challenge associated with lignocellulose is the heterogeneity based on lignin and various side components including extractives which keep the fractionation in a focal position. The kraft process currently used in pulping provides quality of fibre and high conversion to pulp through energy integration and chemical recovery. Even if the pulp has been found to be very suitable for existing products it may not in all ways be the best fit for added-value applications. In addition, a marked portion of the raw-material, especially lignin but also bark and some extractives, is combusted and applied only for energy purposes.

Efficiency has been a forerunning target when developing pulp and paper production. With respect to limited sustainable availability of boreal wood and its special properties, the benefitting model of our renewing resources must be reconsidered from the added-value standpoint. The target for the industries is reduction of carbon emission by 80% before 2050. Demand for forest preservation is increasing. And further, the water foot print and usage of arable land has to be minimized. There is thus a clear need to solve problems arising from demographic and social change, urbanization, climate change, raw material scarcity and the global marketplace with a sustainably zero footprint.

Recent, already visible changes in the forest industry after printing paper have been shown in the new kraft-based biorefineries, novel packaging board materials and energy products. Great expectations are put on deep eutectic solvents (DESs) in wood fractionation without heavy processes as well as reducing the use of ionic liquids (ILs) for dissolving wood and cellulose. Manufacturing methods and applications of cellulose nanofibrils are being created rapidly. In addition, development of technologies to produce advanced cellulose-based 2D and 3D structures as well as related materials and functions is on-going.

These are the game changers, which enable us to face the new boundary conditions and develop ground breaking material solutions for cellulose, lignin and extractives creating a totally new meaning for lignocellulose applications. ⬢

FOAM – FROM HARM TO AN ASSET!

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IN THE 1990'S the paper industry faced its biggest challenge in decades – the consumption of printing paper decreased dramatically because of rapid development of social media, electronic readers and changes in the advertising business. Systematic screening of alternative products and technologies was successful and one possible candidate is foam forming – an enabling technology for papermakers. Foam technology allows papermakers to develop their current products, e.g. light-weighting, and opens totally new product opportunities using current raw-materials and assets.

In the foam process a lot of air (typically 30–70%) is mixed in a fibre suspension by introducing a surface active agent and intensive mixing. The result is a three-phase system – water, fibres and air bubbles – which is more viscous than a fibre suspension. Small bubbles fill the space between fibres and there is no room for flocculation. Bubbles also maintain the shape of the foam during drying and allow the manufacture of highly porous structures.

As a forerunner in fibre foams, VTT started its development work in the late 2000's. Firstly, the potential of foam technology was proven by using small-scale lab samples. There was a very limited amount of references available and practically all findings were novel and unique. Foam forming technology was up-scaled to the pilot scale in a national project in 2012–2014. Basically, an existing paper machine was converted with minor changes to accommodate foam forming technology.

VTT has demonstrated the raw material and energy savings of >10% on pilot scale for current products. In addition, some nonwoven webs have been made with the pilot. The world market of nonwovens is increasing rapidly and production of such, increased value-added products using an existing paper machine has been shown to be possible. Foam technology can also be an alternative when replacing some non-sustainable materials, e.g. in insulation and in packaging applications. These products are made from the same raw-materials as the papermaking foam applications – the only difference in manufacturing is that there is no wet-pressing in the production line.

Figure. Fibre foam, foam formed board and an example of a porous foam product.

TIME TO MARKET: 2-3 Estimated years	TRL 6-7 4-5	TECHNO-ECONOMIC EVALUATION ✔	LCA ✘

VIABLE AND PLIABLE CELLULOSE – CHALLENGES AND POTENTIAL

Further information: Hannes Orelma, hannes.orelma@vtt.fi, +358403543143

CELLULOSE NANOFIBRILS (CNF) have high strength and stiffness and high aspect ratio (length/width), which together with biodegradability makes them very interesting for both micro- and nano-scale structural material applications. New application opportunities have constantly been identified through increased knowledge generated based on the physical and chemical, as well as material properties of CNF.

The current CNF production methods are based on extensive grinding resulting in gel-like 1% CNF not well suited for applications requiring higher dry matter content. To overcome this drawback VTT has developed a ground breaking enzyme-assisted, high consistency (20–40%), low-energy production method of fibrillated cellulose. The high consistency CNF is suitable for production of various structural materials including, e.g. films, filaments, composite solid objects, and 3D printed single objects.

VTT's method for producing nanocellulose film from CNF in a roll-to-roll pilot scale is the first of its kind available in the world. CNF film has been the basis of cellulose material development for electronics, flexible energy harvesting and separation membranes. Based on the recent findings nanoscaled cellulosic materials can be considered as replacement materials for plastics and inorganic materials in electronic devices and optical structures due to the smoothness, transparency and density of the CNF films. The latest leading edge research attempts have shown that the intrinsic electronic properties of the cellulose crystal itself can be foreseen to be employed as components for, e.g. LEDs, sensors and nanoelectronics. The strong tendency of CNF packing into ordered structures when water is evacuated can be utilized to manufacture strong CNF filaments. In the filament manufacturing the CNF dope is solidified by evacuating water by using precipitation with an antisolvent or evaporation with air. VTT has developed a dry spin process that tackles the drawbacks of the traditional wet-spinning process, the limited spinning speed and fibre orientation capability. The VTT process is based on dry-spinning of CNF onto a high velocity non-adhering surface. CNF filaments are fully biodegradable and they exhibit excellent strength and stiffness properties. They can be used in a wide range of applications including substitutes for existing materials in traditional application areas, e.g. composites, nonwovens, and textiles. However, due to the unique chemical nature of CNF, the functional high-value applications are the most conceivable end uses for the CNF filaments. CNF filaments can easily be tailored to be conductive, magnetic, bioactive or flame retardant. Moreover, due to the high cellulose content of CNF filaments they could find applications from medical applications.

Nanocellulosic materials also are green and sustainable alternatives for synthetic surfactants as emulsion stabilisers in, e.g. food, pharma, and the paint industry as they operate over a wide process performance range with respect to pH, salt concentration and temperature.

VIABLE AND PLIABLE CELLULOSE	Electronic devices and as components	Optical structures	3d composites	Textiles	Water purification	Stability for Food, cosmetics and Paints	Packaging
TRL	2	2.5	3	4	5	5,5	6

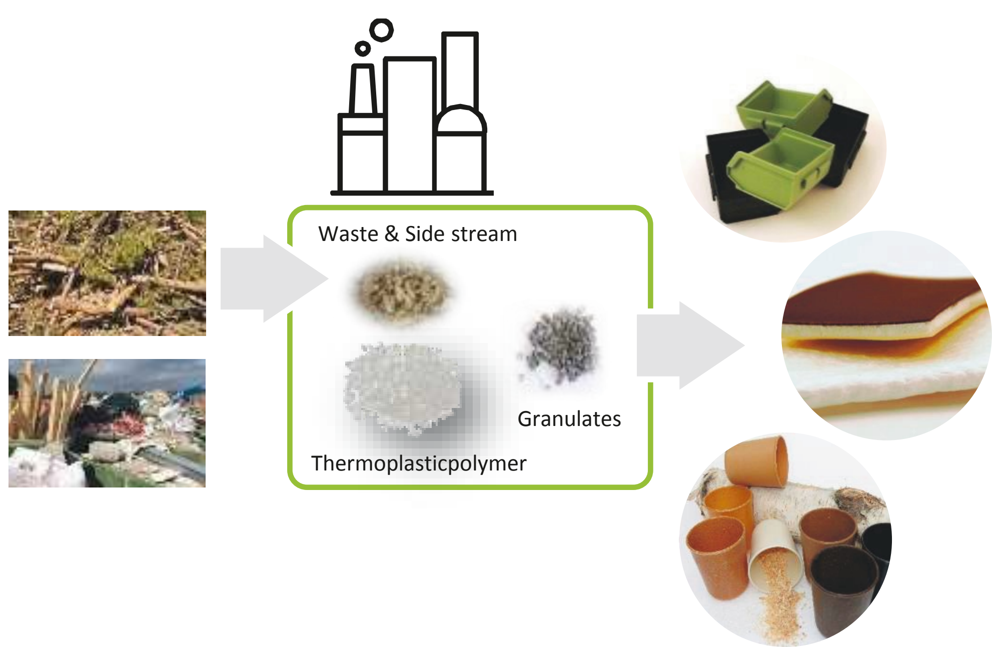
BIOCOMPOSITES - VIABLE PLASTICS FROM SIDE STREAMS AND NATURE

Further information: Lisa Wikström, lisa.wikstrom@vtt.fi, +358408614421

PLASTICS AND COMPOSITE materials have over the last century become integral and vital components of our lives, but with significant environmental and ecological challenges. Recently there has been significant concern expressed about plastics in water. It has been estimated that by 2050 there will be more plastic than fish in the world's oceans, with significant future ecological repercussions. These environmental challenges can be directly reduced through increased biomass utilization in polymer and composite applications. To further improve the energy balance of biocomposites, efficient recycling schemes will be required and are starting to emerge. Creating lightweight structures, by foaming or engineering, further helps to reduce energy consumption.

VTT has been working at the EU and national level for over 15 years in finding new material solutions for biocomposites by improving the material and processing performance and end use of these new materials including LCC and LCA evaluations.

VTT has created ways to utilize recycled materials and industrial side streams in composite applications. For example when recycled paper, deinking sludge and fly ash were combined with a polymer matrix up to 50% filler content, this led to improved stiffness and higher thermal resistance compared to a pure matrix giving new potential uses for the side streams. Another example of utilization of side streams is thermoplastic lignin – wood fibre composite with up to 80 weight-% wood-derived raw material contents showing ways toward using thermoplastic wood.



Novel cellulose-based biocomposites with superior properties have been developed in several projects utilizing renewable-based coupling agents for fibre-polymer coupling. These thermoplastic biocomposite materials with 50% fibre content are totally based on renewable materials and can be recycled as well as composted or burned as end use. The utilization of new coupling agents improves material strength properties significantly enabling new applications. Fibre-polymer coupling also makes it possible to produce thermally mouldable sheets for novel packaging applications.

Lightweight, energy-saving and bio-based materials have been developed at VTT by extrusion and foam forming with density and insulation properties similar to commercial insulation materials.

The developed sustainable materials have promising mechanical properties and clear market potential in various applications such as construction, furniture and consumer appliances. The cost calculations demonstrate that the novel material solutions are competitive against the state-of-the-art oil-based materials.

TIME TO MARKET: 1-10 Estimated years	TRL 4-9	TECHNO-ECONOMIC EVALUATION ✓	LCA ✓

CLOSED LOOP RECYCLING OF TEXTILES

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INCREASING DEMAND for textiles fibres is difficult to fulfil in a sustainable way. Increasing use of textiles leads also to an increasing amount of textile waste, while recycling of post-consumer textiles as raw material is still in its infancy. Valuable textile raw materials currently end up being incinerated. New upcycling methods will enable textile wastes to become a significant raw material source for textiles during the forthcoming years.

VTT has developed a concept for chemical recycling of cotton. The concept is based on VTT's proprietary cellulose carbamate process that enables production of fibres with existing viscose factories, but using more environmentally friendly chemistry. Instead of using CS_2 urea is used to solubilize cellulose. The regenerated CCA fibres are similar to viscose and can be used for the same application areas from clothing to technical textiles. The preliminary carbon footprint as well as techno-economical evaluations showed that the process needs further development in order to make fibres comparable with competing fibre sources, i.e. virgin cotton and viscose fibres. Currently this technology is being transferred from a laboratory- to industrial-scale pilot and the aim is to commercialize the concept within the next two years.

TIME TO MARKET: 2 Estimated years	TRL 4-7	TECHNO-ECONOMIC EVALUATION ✓	LCA ✓

VALUE FROM LIGNIN SIDE-STREAMS

LIGNIN IS the most important by-product from the lignocellulosic biorefineries, and a valuable renewable resource for the chemical industry. Annually 50–60 million tons of lignin is extracted from wood as a by-product of the pulping industry. Even more is expected to originate from 2nd generation bioethanol production in the future. The valorization of lignin will significantly improve the cost-competitiveness of the lignocellulosic biorefineries, and will create low-cost, sustainable raw materials for the chemical industry. To fully exploit the lignin side-streams, there is an urgent need to commercialize economically and sustainably viable lignin upgrading process technologies. VTT has developed and patented two competitive technologies (LigniOx, CatLignin) close to commercialization for the valorization of lignin, and is constantly developing also other lignin upgrading methods for material purposes. VTT is now looking for partners to co-develop these technologies towards industrial implementation and for product development. ➤

LigniOx – Lignin oxidation technology for versatile dispersants

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THE LIGNIOX technology is a simple and cost-competitive lignin functionalization method based on alkali-O_2 oxidation for production of versatile lignin-based surface active agents. Wide application possibilities in several end-uses with high market volumes can be found for anionic LigniOx lignins, e.g. as high-performance concrete plasticizers and versatile dispersants. The technical performance of LigniOx lignin in concrete plasticizers is better than with commercial lignosulphonate plasticizers, and comparable with synthetic superplasticizers at a higher dose. The results also show potential for replacement of synthetic dispersants, e.g. in paints. By adjustment of oxidation conditions, the lignin properties can be fine-tuned to a wide range on end-products. The method is also well applicable to lignins originating from different raw materials and processes. The oxidation is performed using low-cost, non-toxic bulk chemicals (NaOH, O_2) and can be easily integrated into lignocellulosic biorefineries. Especially by the integration into a kraft pulp mill right after lignin separation, both the operation and investment costs will be significantly reduced when the otherwise necessary acidic washing stage of kraft lignin can be omitted. The potential of the technology for production of concrete plasticizers and dispersants of inorganic particles (pigments, fillers) has been shown at laboratory scale.

TIME TO MARKET: 2-4 Estimated years	TRL 4-5	TECHNO-ECONOMIC EVALUATION ✓	LCA ✓

I am absolutely thrilled that VTT is developing outstanding technological solutions that may help the world to become a better place. If I can support commercialization of VTT solutions and creation of new business, I am happy.

- Vice President, Research Tiina Nakari-Setälä

CatLignin – Highly reactive lignin for phenolic resins

Further information: Tiina Liitiä, tiina.liitia@vtt.fi, +358407552387

In addition to the surface active agents, the lignin use in phenolic resins for wood adhesives is one of the end-uses of lignin with the most potential. For the resin producers lignin offers a low-cost, biobased, non-toxic raw material for a replacement for phenol. However, with the current commercial lignins, the phenol replacement levels are rather moderate (20–40%) due to the lower reactivity of lignin compared to phenol. To reach higher utilization degrees (50–100%) required for significant cost reduction in resin manufacturing, the reactivity of lignin needs to be improved.

VTT has developed and patented a simultaneous lignin separation and activation process that produces highly reactive catechol-rich lignin, CatLignin, enabling phenol replacement levels well above 50% without any additional activation treatment. As a result of this, the total resin manufacturing cost can be significantly lower than with the conventional phenol formulations or using any currently available commercial lignins. For pulp mills, the technology offers an entry with a lignin product to a growing high-value market and will potentially open up the door for multiple other high-value applications from lignin. The potential of the technology has been shown at laboratory scale for both softwood and hardwood kraft lignin, and the process has been scaled up in the VTT pilot.

Figure. The versatile application possibilities of CatLignin after the first target market of phenolic resins.

TIME TO MARKET: 2–4 Estimated years	TRL 4	TECHNO-ECONOMIC EVALUATION ✓	LCA ✗

THERMOPLASTIC CELLULOSE FOR PLASTIC REPLACEMENT

Further information: Jarmo Ropponen, jarmo.ropponen@vtt.fi, +358400215951

ON TOP OF the several current uses, cellulose would find use in bioplastic applications if it was thermoplastic, either intrinsically or due to functionalization. In order to achieve thermoplasticity, the solubility and mechanical properties of cellulose need to be tailored, without significantly affecting its natural performance.

VTT has developed a technology that decreases cellulose molar mass in a controlled manner and leads to cellulose with thermoplastic properties after chemical functionalization. The method is based on chemical treatment of cellulose in specific conditions, providing cellulose which can be further functionalized with significantly lower chemical amounts (Figure 1). The technology has been demonstrated with dissolved cellulose, kraft cellulose, as well as with recycled paper as raw material and the process requires only conventional process equipment. After functionalization, e.g. by esterification, cellulose possesses a thermoplastic behaviour, therefore it can be used in various similar processes and applications as fossil-based plastics is used. The cellulose can be pelletized and converted to final application with traditional equipment used in the plastic industry (Figure 2).

Thermoplastic cellulose offers 100% biobased thermoplastic for manufacturing plastic products with existing plastic converting equipment. The process steps are straightforward and can be up-scaled with business-as-usual engineering. With true industrial market prices of the starting cellulose, thermoplastic cellulose could have a competitive price at the industrial scale compared to existing biobased thermoplastic materials. The innovativeness of this thermoplastic cellulose solution lies partly in the ease of technology adoption; the route to thermoplastics uses existing raw material and equipment in all process steps. Further, a competitive cost level at industrial manufacturing volumes is expected. VTT is currently manufacturing the thermoplastic cellulose at the scale of 2 kg.

TIME TO MARKET: 2-5 Estimated years	TRL 4-5	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

Figure 1. Example of mechanically strong cellulose ester films.

Figure 2. Demonstrated application by injection moulding based on VTT's thermoplastic cellulose.

NOVEL BIO-BASED 3D PRINTING PASTES FOR DECORATIVE AND WOUND HEALING APPLICATIONS

Further information: Panu Lahtinen, panu.lahtinen@vtt.fi, +358405349794

3D PRINTING has started to evolve into a promising manufacturing technology in many industries and applications. 3D printing is nowadays widely used for example for rapid prototyping, moulds, personal fabrication in industrial, aerospace, consumer and pharmaceutical applications. It is a feasible manufacturing method for small objects, additions, complicated or tailored geometries and lightweight structures. It allows on-demand manufacturing with a relatively small amount of process steps. A number of materials are used for 3D printing including thermoplastics, metals, ceramics and food stuff. However, the selection of suitable biomaterials for 3D printing is still limited and there is a significant potential for more sustainable and biocompatible solutions for several applications.

A common challenge when 3D printing hydrogels is that the printed shapes tend to collapse due to low viscosity and solids content. Another challenge is related to post-processing and the curing process, which tend to form hard or fragile objects when excess water is removed. To increase the structural fidelity, hydrogels are often printed in combination with other materials. Cellulose nanofibrils (CNF) are an attractive ingredient for 3D printing due to their superior properties such as mechanical strength enhancing, rheology modification and biocompatibility. CNF is suitable for use as a component in printing pastes or as a substrate for printing functionality. CNF can be produced from a variety of biodegradable and renewable resources such as wood pulp, ago- and food residues.

VTT has developed new concepts and materials for printing bio-based hydrogels for applications like textiles, decorative elements, wound healing applications and prototypes. With different material combinations it is possible to print both elastic and rigid structures and they can be cured in ambient conditions or in elevated temperature. In addition, hydrophobic and absorption properties can be tailored. These materials are expected to be applied in decorative and technical solutions within a couple of years. They are also attractive alternatives for biomedical applications and tissue engineering.

TIME TO MARKET: 2-7 Estimated years	TRL 3-4	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

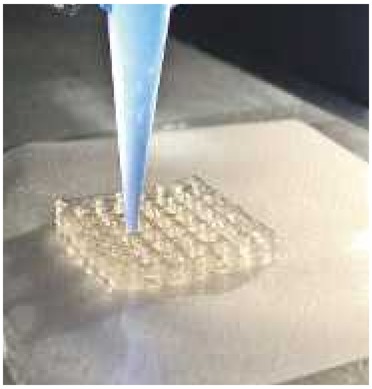


Figure. 3D printing of bio-based hydrogel on ultra-thin and flexible substrate including CNF.


Bioenergy
VTT

THERMOCHEMICAL CONVERSION

Further information: Esa Kurkela, esa.kurkela@vtt.fi, +358405026231

BIOENERGY

Smart use of biomass residues to replace fossil fuels and base chemicals combined with development of high-value-added products and production technologies as part of the circular economy is the key driving force for the thermochemical conversion (TC) research at VTT. The main challenges addressed in the TC research are:

- Decarbonization of the transport sector requires massive production of renewable fuels. Electric cars powered by renewable electricity can be the main solution for light-duty vehicles, while heavy-duty road transport and air traffic require renewable fuels. This should be based on the use of sustainably available biomass residues and waste-derived feedstock.
- Requirements to achieve as high overall biomass utilization efficiency in the new biofuel and biochemical value chains as is achieved in existing combined heat and power plants.
- Integration of bioenergy and biofuels production into the changing European energy mix, that is dominated by an increasing share of intermittently available solar and wind energy.
- The growing demand for introducing renewable feedstocks also into the chemical industry.

VTT HAS DEVELOPED gasification and pyrolysis technologies to TRL 4–5 using the new piloting platform, Bioruukki. The basic idea of VTT's process concepts is integration into energy-intensive industries or district heating power plants. This makes it possible to utilize by-products for generating heat and power and thus over 80% total energy efficiencies can be achieved. Pilot-scale development carried out at Bioruukki is paving the way for industrial follow-up demonstration projects. On the global level, biofuels produced from sustainably available residues may represent 10–15% of total energy demand of transport. This potential can be more than doubled by using hybrid renewable concepts studied by VTT. In these processes hydrogen produced by low-cost excess electricity is used to boost biofuel production.

In addition to the biofuels and bioenergy, the work has focused on the production of high-quality platform chemicals. Synthesis gas makes it possible to produce a wide variety of chemicals either via methanol, ammonia or Fischer-Tropsch conversion paths. A special focus of VTT's work has been the development of cost-effective conversion processes for producing BTX (Benzene, Toluene and Xylene). This seems to open interesting business opportunities in the production of chemicals in fields where there is already a strong consumer pull for green materials.

Gasification and pyrolysis technologies are presently used industrially for the production of heat and power. The new process concepts for transport fuel production developed at Bioruukki are expected to reach demonstration phase by 2018–2020 and thus, the first production plants would enter the European Biofuel market around 2023 with full market penetration after 2025. The development of solar-energy-assisted fuel production and the development of optimal processes for platform chemicals is continuing at Bioruukki, where a new flexible and containerized synthesis test facility began operation at the end of 2016. Bio-fuel demonstration projects are planned while also keeping in mind future needs for demonstrating novel production concepts for renewable chemicals. ⬢

RAPID DECARBONIZATION OF TRANSPORT BY BIOMASS GASIFICATION INTEGRATED INTO INDUSTRIAL AND DISTRICT HEATING POWER PLANTS

Further information: Esa Kurkela, esa.kurkela@vtt.fi, +358405026231

THE CO_2 emissions of the transport sector must be decreased by 40% by 2030. Electric cars powered by renewable electricity can be the main solution for light-duty vehicles, while heavy-duty road-transport and air traffic require renewable fuels. Our gasification development is targeting this market. If 5% of the European transport fuel market would be satisfied by the diesel and jet fuels produced with our technology, that would mean an annual production of 14 million tons of oil equivalent corresponding to 200–300 production plants and equipment sales of some 40 billion €.

In all gasification-based fuel production concepts part of the biomass energy is converted to by-product heat and synthesis off-gases. The energy efficiency from biomass to FT-wax may at best be of the order of 50–55%, while an additional 20–30% energy is available for generating heat and power. VTT's gasification-BTL process is designed for medium-scale production units, which will utilize 100–150 MW of biomass input and produce typically 30–50 ktoe of FT products and 15–40 MW heat for district heating or industrial use.

The gasification-BTL process is based on several innovative process simplifications. Gasification is carried out without a need for an expensive oxygen plant. Another key unit operation developed by VTT is the catalytic reforming of tars and hydrocarbon gases, which improves the syngas efficiency and makes it possible to operate the gasifier at low temperature, which is beneficial for the conversion efficiency. Simplified final gas clean-up followed by once-through synthesis can also be applied without decreasing the conversion efficiency. As a conclusion of these processes, modification the BTL plant can be economically down-scaled from 300–500 MW to below 150 MW. This makes it possible to integrate the production into the heat requirements of district heating systems of medium-size towns and many types of industries.

A pilot plant for the new BTL gasification route has been built and is operated at Bioruukki. Tests are carried out with various wood residues, straw and waste-derived feedstocks in the BTL2030 project (http://www.vtt.fi/sites/BTL2030/en). The road map for industrial plants is also created in co-operation with participating companies in the on-going project.

TIME TO MARKET: 5-10 Estimated years	TRL 5	TECHNO-ECONOMIC EVALUATION ✓	LCA ✗

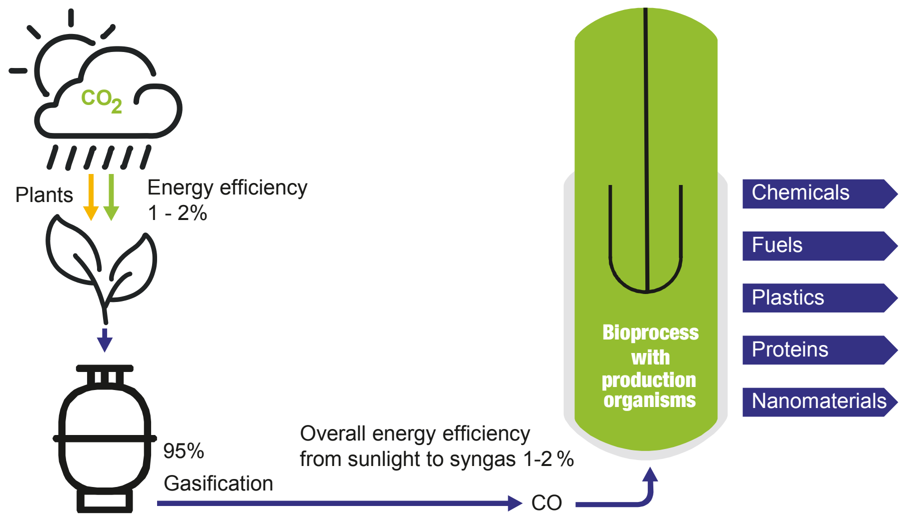
I aim at finding sustainable solutions to the globally mutual challenge of natural resources sufficiency.

\- Principal Scientist Raija Lantto

MICROBIAL ROUTE TO FUEL ETHANOL FROM SYNGAS

Further information: Juha-Pekka Pitkänen, juha-pekka.pitkanen@vtt.fi, +358403569758.

MOST INDUSTRIAL gases are combusted or even flared today. Steel mills, oil refineries, pulp mills and power plants produce yearly millions of tons of untapped raw material in Finland. The gas streams can be valorised with novel process concepts like gas fermentation. In gas fermentation, microorganisms work as catalysts to produce fuels such as ethanol, chemicals such as lactic acid and single-cell protein for the use as animal feed from the gases. One example is bacterium *Clostridium autoethanogenum*, which produces ethanol from carbon monoxide under anaerobic conditions. Carbon monoxide containing gas applicable as feed for the microbial fermentation is produced for example as a side product in submerged arc furnace during production of ferroalloys. Currently that gas is used on site for generation of heat and electricity, but with gas fermentation process it could be converted to fuel ethanol instead. Furthermore, plant-based biomass side streams and municipal waste can be gasified to produce syngas, which can be converted to fuel ethanol with *C. autoethanogenum*. At VTT development is at its early stage and currently aims at improving the growth and ethanol productivity of *C. autoethanogenum* on simulated syngas.



TIME TO MARKET: 6 Estimated years	TRL 3	TECHNO-ECONOMIC EVALUATION ✓	LCA ✗

The bioeconomy is a long-lasting sustainable solution to the main ecological challenges and the economy.

- Research professor at VTT

POWER-ASSISTED BIOFUELS FOR MAXIMAL RESOURCE EFFICIENCY

Further information: Ilkka Hannula, ilkka.hannula@vtt.fi, +358408380960

THE EUROPEAN UNION aims to reduce greenhouse gas emissions from transportation by 60% by 2050. This goal is highly ambitious, but can be achieved with a combination of efficiency improvements, electric vehicles and biofuels. For biofuels the tightening sustainability requirements favour so called advanced biofuels, which are alternative fuels produced from various waste and residue streams. As the availability of these resources is limited, so is the supply potential of advanced biofuels. However, it is possible to lift this limit by using electricity as an additional energy source in biofuels production.

By exploiting synergies between bioenergy and other low-carbon energy sources, VTT has developed and optimized hybrid process configurations that makes possible to more than double the output of biofuels from a given amount of residues. This will lead to a significant increase in both resource efficiency and supply potential of advanced biofuels. No additional technical hurdles will emerge as a result of such integration, but very low-cost and low-carbon electricity is needed to achieve attractive conditions for commercialization. A larger impact of power-assisted biofuels can therefore be expected only after Europe's power supply has been first adequately decarbonized. However, countries like Finland, Sweden, Norway and France that already have sufficiently low-carbon power systems are identified as attractive market areas.

TIME TO MARKET: 1-3 Estimated years	TRL 7-8	TECHNO-ECONOMIC EVALUATION ✓	LCA ✓

HIGH-QUALITY PLATFORM CHEMICALS FROM FINNISH BIOMASS

Further information: Matti Reinikainen, matti.reinikainen@vtt.fi, +358505634137

BTX (Benzene, Toluene and Xylene) is a mixture of basic platform chemicals that are used for the manufacturing of plastics, pharmaceuticals, fine and specialty chemicals, solvents, paints, fibres and resins. At the moment, BTX-hydrocarbons are based on fossil raw materials and chemical manufacturers are actively looking for drop-in replacements. Major drivers for the bio-based BTX are a shortage of aromatics due to the shale gas boom, the extreme price volatility of fossil oil-based BTX, and the trend towards more sustainable products. Strong consumer pull is already here for "green" materials.

VTT has developed and filed a new highly competitive process for the manufacture of "green" BTX-chemicals and olefins from biomass such as forest side streams or waste water sludges. Combining biomass gasification, Fischer-Tropsch synthesis and aromatization in a unique way has allowed us to prepare BTX in high purity and yields. The principle and product alternatives of the process are illustrated in Figure.

In the first synthesis step a product mixture rich in olefins is produced from synthesis gas over a promoted iron catalyst. In the second stage, the whole product from the first step reacts further to a mixture of aromatic hydrocarbons over a special zeolite-catalyst. A hydrocarbon product with an exceptionally good selectivity to aromatic hydrocarbons is formed. To our knowledge this is the first example of a process capable of producing BTX-components with such a high selectivity from biomass.

Extensive techno economic calculations were done for an industrial plant with a dry input of 1000 t/a. Accordingly, the estimated manufacturing price is in the range of the long-term average BTX market price, 1.4–1.5 €/kg.

The benefits over other biomass-based BTX processes are product purity (specialty chemical grade), high total yield from biomass to products, flexibility in raw material intake and products selection.

The technology has been demonstrated in laboratory scale and the good quality of bio-based BTX product has been further verified in higher-value applications such as paracetamol and ASA. In the next step the process will be scaled-up utilizing VTT's new Bioruukki-infrastructure for the manufacture of multi-kilogram samples to be tested by our customers.

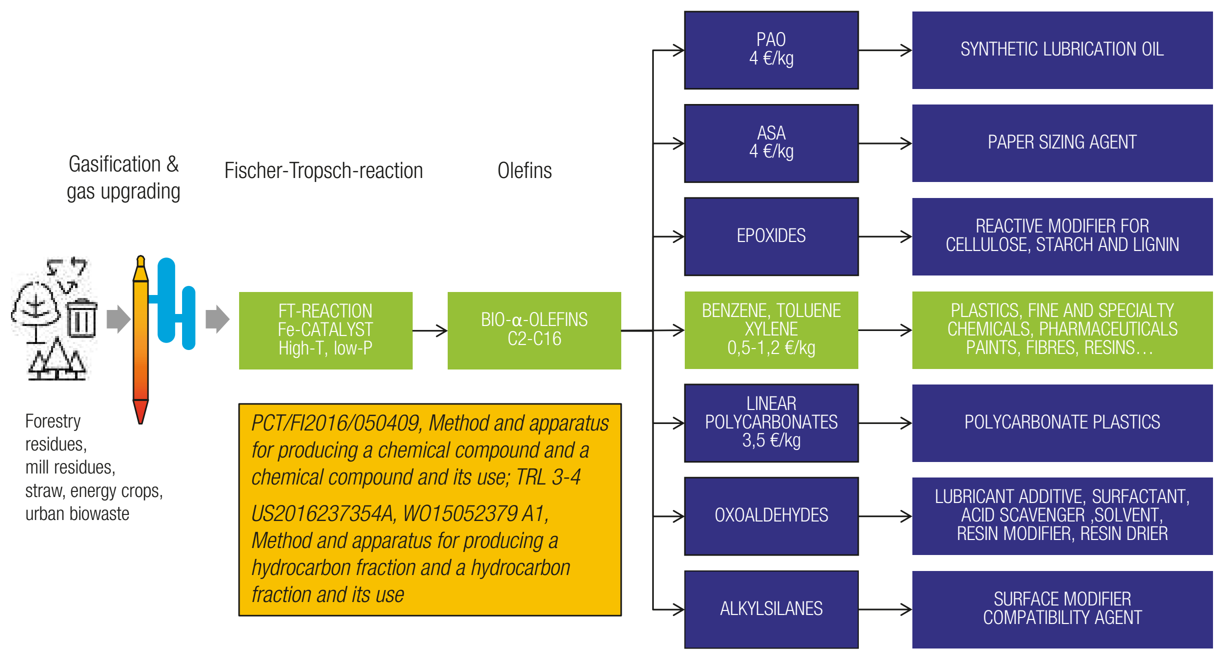


Figure. VTT has developed a new highly selective and competitive process for the manufacture of "green" BTX from biomass.

MORE POWER TO THE DEVELOPMENT OF THERMOCHEMICAL PROCESSES THROUGH CFD MODELLING

Further information: Lars Kjäldman, lars.kjaldman@vtt.fi, +358405938672

Combustion power plants have challenges to meet the new limits of emissions and to maintain good availability in operation with variable fuel mixtures and in load following conditions. Computational Fluid Dynamics (CFD) offers a powerful tool to investigate the furnace processes in various operating conditions. CFD has become a standard tool in the design of boiler retrofits and in troubleshooting tasks.

The alkali components of biofuel ash can cause slagging and fouling, and chlorides cause corrosion of heat transfer surfaces in the furnace. VTT has combined the modelling of the ash behaviour to CFD simulations of combustion. In this way, through simulation the trajectories of the fuel and ash particles and the behaviour of the ash in the furnace can be determined, i.e. where vaporization of ash components takes place, their reactions and condensation rates in the furnace, the melting stage of ash particles hitting heat transfer surfaces, and the location and probability of sticking of ash on the surfaces. By properly choosing air and fuel injections it is possible to influence the trajectories of the fuel and ash particles as well as the local furnace conditions, e.g. flame location, heat transfer distribution and local stoichiometric conditions, and in this way to minimize the risks for slagging and fouling and for corrosion. Combined CFD and ash chemistry simulations to bubbling fluidized bed (BFB) and pulverized fuel (coal mixed with wood) fired furnaces have been applied with good results. This method serves power companies and boiler manufacturers in the design of new boilers and of retrofits of existing boilers and in troubleshooting.

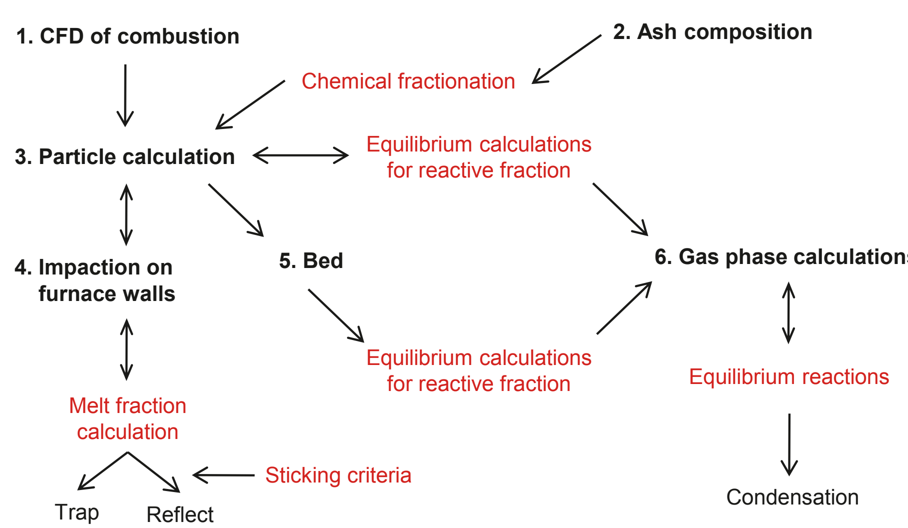
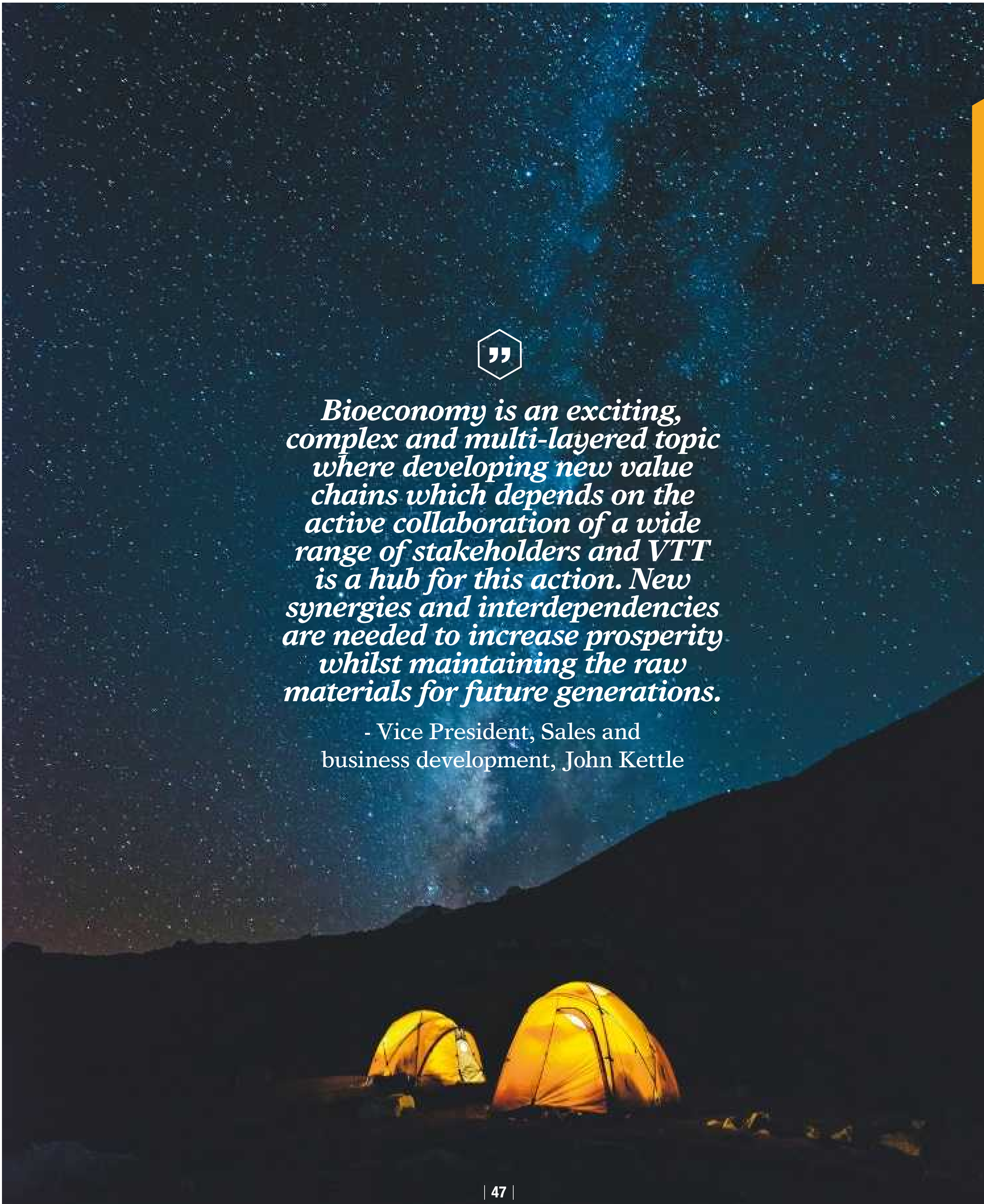


Figure. Combined CFD and ash behaviour modelling.

TIME TO MARKET: 1 Estimated years	TRL 6	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗



Bioeconomy is an exciting, complex and multi-layered topic where developing new value chains which depends on the active collaboration of a wide range of stakeholders and VTT is a hub for this action. New synergies and interdependencies are needed to increase prosperity whilst maintaining the raw materials for future generations.

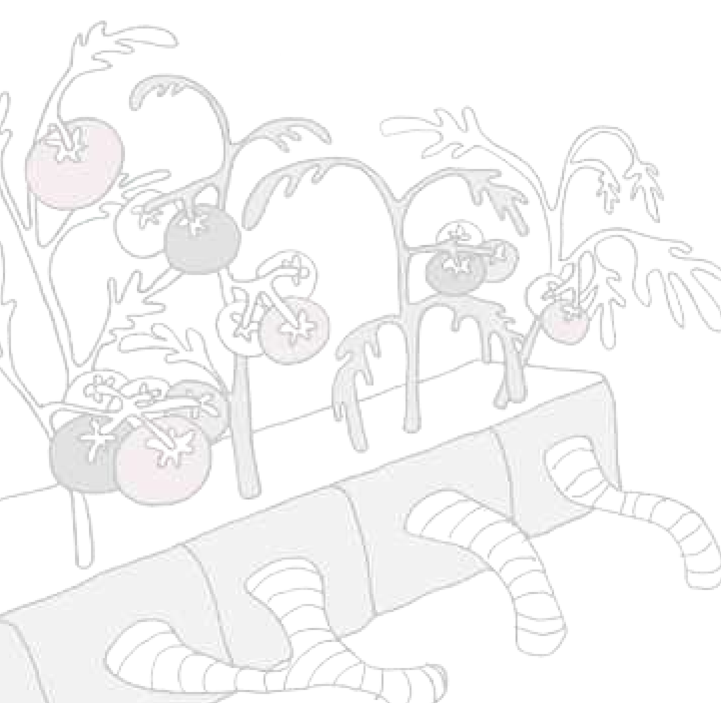
- Vice President, Sales and business development, John Kettle

Let’s have a look at the year 2047 and meet Helmi and her family, the Andersons and Jonas “Brad” Salmi! They were introduced in the "People in the Bioeconomy 2044” report which was published by VTT in 2014.

LIFE IN 2047:
INSECT PROTEIN AND CLOTHES FROM CELLULOSE

Text: Pekka Pekkala Photos: Jutta Suksi

It is 2047, and a group of friends is gathering for a Sunday brunch on the outskirts of Helsinki. The Anderson family is hosting, and they are getting busy preparing the meal. It is mostly cooked from semi-personalized food products. This way all the participants can share the same meal but in a personalized way: portions will look the same with or without lactose, gluten or dairy products. The home bioreactor, a bioreactor that enables anyone to grow plant cells for food at home, has been busy all week growing berry and birch cultures for the meal.



THE ANDERSON family children, Lisa and Sam, love the worm-based snacks with Asian-style sauces. Their mother, Vilma, must keep an eye on the already prepared dishes, otherwise Lisa and Sam would eat most of them before the guests arrive.

Vilma is in her forties and wearing a new blue dress that she just manufactured from a pile of old jeans in the neighborhood recycling center. The recycled cotton feels silky and smooth since all the polyester fibers are gone, thanks to the new machinery at the recycling center that separates fibers with precision.

Her husband, Philip, is at the door, welcoming the first guests, Igor and his wife, Helmi, with their children, Avena and Linum. Igor is bringing some roach with him, a fresh catch from the local lake. He and his wife own a business, the modern-day version of an eco-friendly vitamin and cosmetics shop. As a 34-year-old, city-bred but eco-minded woman, Helmi has grown her various organic businesses into profitable ones. She has brought her favorite kitchen appliance with her: a small carry-on device that extracts the protein from insects. The device produces protein powder for food, oil for feed and, for French cosmetic factories, the chitin extract is a high-value pharmaceutical ingredient.

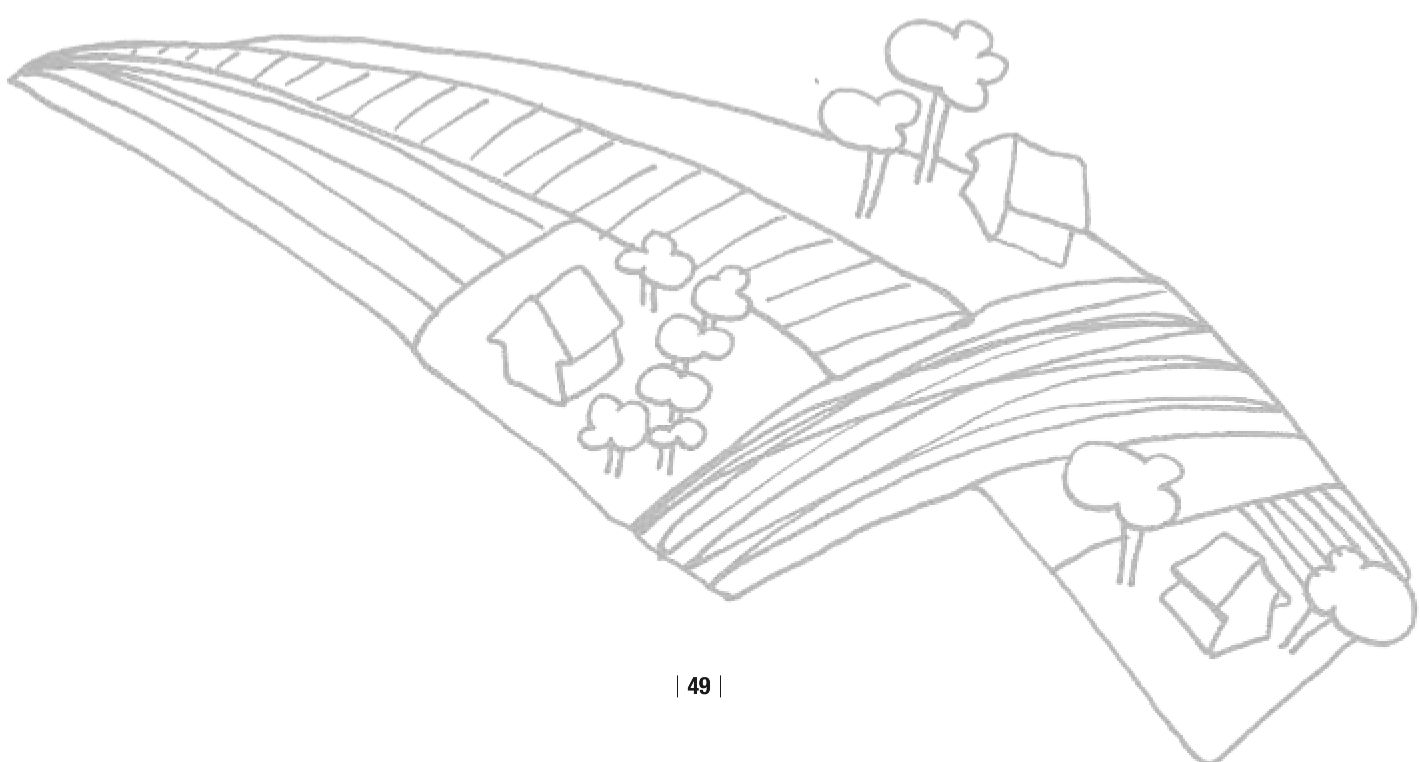
Lisa and Sam have heard about the device but never seen one live. After a few minutes, they have taken over the machine and started dividing the mealworms and crickets, preparing some dipping sauces for the snacks. Helmi tells them that she bought the device from Australia, where the abundance of crickets has made the insectractor-type devices a huge hit. Avena and Linum want to try it too, but Helmi says that they are too young to use the device themselves.

"Oh I love your dress! Did you make that at the new recycling co-op center? It looks like silk," gushes Helmi after seeing what Vilma is wearing.

Vilma notices Helmi's new bag. "That must be the new nonwoven material from cellulose you make at home? You must show me how to make things like that with the foam-forming home kit!"

Helmi has recently started manufacturing things from cellulose and is ready to move one step further: making her own clothes from the flax they grow. Igor says it would make their family almost 100% self-sustainable. The robots are doing most of the manual labor at their farm; everything is recycled and power comes from renewable sources and is stored in liquid form for the colder periods when the demand is higher.

The doorbell rings and in walks Jonas "Brad" Salmi. He is a serial entrepreneur and his latest business is a biorefinery that utilizes pig manure as raw material. After a microbial fermentation, feed protein and oil for transport fuel is formed. He brings a selection of herbs in biodegradable pots that have all the necessary sensors printed in them. Philip is excited to see the digipots live and starts placing them next to the kitchen window. The plants will literally take care of themselves, ordering nutrients and watering from the miniature drone that carries out multiple tasks at the Anderson home.



SMART BIOMASS FRACTIONATION

Further information: Anna-Stiina Jääskeläinen, anna-stiina.jaaskelainen@vtt.fi, +358405753430

The biobased economy relies on the utilization of a wide range of different biomasses as feedstocks for energy, chemical, material and even food and feed applications. It can be foreseen that the availability of native high-quality biomass will be limited in the future.

THE WORLDWIDE biomass production is ca. 100 billion tons (calculated as carbon) per year, of which ca. 13 billion tons (dry) is the annual growth of wood-based biomass. This equals ca. 6 billion tons of biomass carbon, which is comparable to annual worldwide oil production (ca. 4.4 billion tons). It is therefore obvious that recovery and valorization of biomasses from different sources is a pre-requirement. The great variety of the structure and chemical composition of the biomass feedstocks has evolved stimulating pressure to modify existing processes and to develop totally new process concepts to obtain raw materials or intermediates for future biorefineries.

Biomass fractionation includes chemical, mechanical and enzymatic processing to separate the components. Due to the enormous variations in biomass composition and structure, the processes need to be designed for the particular raw material. Proteins are present mostly in biomasses from industrial food and feed side streams or from aquaculture or urban waste. Recovery and upgrading of the protein fraction to intermediates for the food or feed industry is of utmost importance to satisfy the global need for proteins. Biomasses with substantial amounts of lower-value protein (e.g. keratin from hairs, horns, feathers) could be valorized in technical applications.

Lignocellulosic feedstocks originate mostly from agriculture and forestry. They are composed of cellulose, hemicelluloses, lignin and varying amounts of small molecular extractives and inorganic substances. Due to the complex and interlinked structures of these biopolymers in plant cell walls, their separation alters the structure and properties of the polymeric components. Traditionally, wood fractionation is performed by chemical pulping processes, in which lignin is dissolved while the cellulose and hemicelluloses are recovered as chemical pulp fibres. In the existing pulping processes, lignin is most commonly incinerated to produce bioenergy, but lignin is also a valuable intermediate feedstock for material applications. Lignin recovery technologies, LignoBoost and LignoForce, have been installed in kraft pulp mills to produce lignin-based raw materials suitable for high-value applications. Additional lignin refining processes can improve the purity and homogeneity of the product. CatLignin technology, developed at VTT is an example of a novel procedure to recover and produce lignin with remarkably higher reactivity and thus improved applicability for instance formaldehyde resins.

Fractionation of biomass into smaller particles by mechanical means is a high-yield solution from the raw material efficiency perspective. During mechanical refining typically only a few mass per cents of biomass are lost into dissolved substances, unless chemi-mechanical means are applied for obtaining some specific quality or efficiency targets at the cost of yield. Mechanically refined fibres, flakes and fines can be used in novel fibre products, like advanced packaging materials, wood-plastic composites and insulation boards. The finest fibrils, cellulosic nanofibrils, have potential in several of other applications in pharmaceuticals, cosmetics, materials, viscosity modifiers, etc. The novel characteristics and uses of the particles require updates to traditional fibre processing equipment, as well as novel processing innovations. The solutions are typically hybrid technologies combining mechanical, chemical and enzymatic processing means.

Ionic liquids and Deep Eutectic Solvents (DES) are solvents, which could open up a totally novel fractionation processes for biomass. DESs are biodegradable, low-volatile and cost-effective. They can be composed by mixing a natural hydrogen bond donor with a natural hydrogen bond acceptor, which have high melting points (generally above 100°C), but form low-volatile liquids at room temperature upon mixing. We have successfully applied these solvents for fractionation of proteins and are developing DES-based methods for lignin removal. ⬢

NEW GENERATION OF GREEN SOLVENTS TO EXTRACT VALUE-ADDED PRODUCTS FROM BIOMASS

Further information: Sari Asikainen, Sari.Asikainen@vtt.fi, +358 40 5184740

DEEP EUTECTIC solvents (DESs), also often described as low melting mixtures, are a new generation of green solvents that have shown potential in biomass valorization. DESs are promising alternatives for conventional solvents in lignocellulosic or protein-enriched biomass fractionation or chemical modification of polysaccharides and other polymers.

DESs are promising media to recover protein-enriched fractions from plant biomasses. We have shown that food-grade DESs can extract proteins with high yield and less degradation than other solvents, which is important in terms of process economy and protein quality. DES fractionation thus provides technology to recover protein for food and feed applications from non-conventional plant biomasses.

VTT is actively developing lignocellulosic fractionation by DESs aiming for effective delignification without significant modification of lignin or hemicellulose structures and to produce cellulosic fibres with tailor-made properties. VTT has developed novel DESs for wood fractionation, and the research is actively going on in a large EU project in which industry is strongly committed. The research is in the early phase and the optimal DESs for selective delignification of wood are yet to be found. The pulping conditions and the process to isolate fibres, lignin and hemicelluloses has to be developed. In order to be a techno-economically feasible process, DES needs to be recycled in an energy-efficient manner while maintaining its physico-chemical and dissolving properties. In the best case mild pulping process producing fibres, high-quality lignin and hemicellulose fractions are realized.

TIME TO MARKET: 5-15 Estimated years	TRL 2	TECHNO-ECONOMIC EVALUATION ✓	LCA ✗

INNOVATIVE WOOD GRINDING TECHNOLOGY ENABLES NEW FUNCTIONALITIES FOR NOVEL FIBRE PRODUCTS

Further information: Jari Sirviö, jari.sirvio@vtt.fi, +358400548143

NOVEL FIBRE products are expected to contain as much bio-components as possible, instead of mineral fillers or oil-based polymers. Both conventional paper board packages and novel insulation applications require lightweight, but still strong fibre-based materials. Such materials benefit from rigid fibres fixed together by strength-agents.

VTT has modified the well-known wood grinding process into a process that generates well-bonding fine particles directly from moist wood logs in one process step. The novel grinding technology is rather simple: the surface of the novel grinding stone is serrated in order to prevent separation of intact fibres from the wood matrix. Instead, the grinding stone penetrates into the fibre wall in an angle that forces disintegration of the fibre wall into fibrils and flakes.

Wood grinding mills can implement the technology during the regular grinding stone replacements. The method is very efficient with respect to raw material; basically the wood can be utilized with up to 97% yield. The quality of the fines particles can be adjusted by the grinding stone characteristics and grinding conditions. The fines produced are in micrometre-scale and they can form porous structures also by themselves. Therefore, they can be used in multiple applications as strength-enhancers, bio-based fillers, structural and functional modifiers, etc.

New grinding technology has been tested in semi-pilot scale using hardwood and softwood species and applying different grinding stone configurations. The basic relations between grinding stone peripheral speed, wood feeding rate and force, specific energy consumption and fines quality have been clarified. The technology is ready to be up-scaled. VTT is looking forward to finding industrial partners to co-develop this towards commercial applications.

TIME TO MARKET: 3-5 Estimated years	TRL 5	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

GRASS SILAGE AS A SOURCE FOR PROTEIN AND CHEMICAL PRODUCTION

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FINLAND IS nearly self-sufficient in animal protein, but imports about 85% of the plant protein needed in livestock feeding. There is a national effort to improve self-sufficiency and supply security related to plant protein sources. Rural communities are looking for new investors who would base their operations on local raw materials and processing. Centralizing dairy production has left closed facilities, with new production potential. Surplus agricultural land is also available for primary production. The opportunity to process silage, a raw material with year-round availability with existing harvesting and storage infrastructure, into added value products has become attractive. Thus, companies in the value chain (co-operatives, chemical and machinery manufactures, feed and dairy industry and local communities) show great interest in developing technologies to process silage into innovative feed products.

In collaboration with Luke technologies, VTT has developed a technology for silage to produce microbial protein from its sugars, and to stabilize the liquid products by lactic acid bacteria. The value chains based on farm-scale and centralized process have been analysed and techno-economics of integrated concepts will be evaluated. The work is ongoing with basic fractionating techniques optimized and the value chains related to local and centralized concepts preliminary characterized. Technologies under development are expected to be commercialized by companies participating in the current project.

TIME TO MARKET: 4-6 Estimated years	TRL 3-4	TECHNO-ECONOMIC EVALUATION ✓	LCA ✗

FERMENTABLE SUGARS FROM LIGNOCELLULOSIC BIOMASS

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The main driver for the development of biorefinery processes for lignocellulosic sugar production globally is the increasing demand for renewable fuels in the transportation sector. In the short and medium term significant amounts of renewable fuels are needed to meet the many policy targets, for instance the EU renewable directive for transportation fuels. Many scenarios suggest a gradual increase in biochemical productions as well. The Deloitte study (2014) expects 6.5% annual growth of non-alcoholic biochemicals by 2020, the largest growth being in organic acids and polymer precursors.

THE FERMENTING industry currently uses technical sugars from hydrolysed wheat and corn starch as well as sucrose for bioethanol and chemical production. However, lignocellulosics are considered more sustainable raw materials for fuel and chemical production because they do not violate the food chain and because the higher net greenhouse gas and energy savings. Cellulose should be used for added-value wood and fibre products, sugars can be produced from lower value fractions, side- and waste streams. Recent efforts have thus been directed towards the use of sustainable raw materials for sugar production such as residues from agriculture, forestry and industrial and municipal wastes and side streams. Although production of lignocellulosic ethanol is currently being commercialized, the technologies are still hindered by technical and economical obstacles and the production is governmentally subsided. The conversion of biomass to platform sugars is hampered by the complex and recalcitrant structure of lignocellulose as well as the limited performance of the hydrolytic enzymes in saccharification.

Despite of the vast development of the lignocellulolytic enzymes more efficient enzymes and enzyme cocktails are still needed, as well as more efficient enzyme production systems. We have discovered novel enzymes from environmental samples, culture collections or from metagenomic libraries and utilized the increasing genomic data in public and proprietary databases. Enzyme properties have also been improved by protein engineering. We have also analysed the limiting factors in hydrolysis, especially the role of hemicellulose and lignin and the hydrolysis in high consistency. Molecular-level mechanistic studies have paved way for development of more efficient enzymes. Just recently VTT, in cooperation with the Finnish industry and Tekes, started FiDiPro collaboration with Associate Professor Kiyo Igarashi and the University of Tokyo. This work allows molecular-level mechanistic studies of cellulases with the world-leading scientist. We have also developed the enzyme production systems, especially using the fungus *Trichoderma reesei*. The recent development of protease deletion strains and strains with modified cellulase regulation pathways has made it possible to substantially increase protein production in *Trichoderma* and make the strains compelling also for on-site enzyme production.

To overcome the challenges in the enzymatic biomass conversion, the development of improved pretreatment technologies is essential for different kinds of biomass raw materials. In the second generation biorefineries utilization of all major components of lignocellulose for value-added products is of utmost importance. We believe that the future pretreatment methods rely on fractionation of the main components, in a quality which allows their further use for added-value products. VTT has developed a promising alkaline oxidation technology for lignocellulosic biomass. It is a simple cooking technology using sodium carbonate and molecular oxygen. The enzyme demand for the saccharification of the produced cellulose fraction is radically lower in comparison to the state-of-the-art pretreatment methods. In addition, the method produces separate lignin and hemicellulose fractions. ⬢

FUTURE BIOREFINERY CONCEPT OFFERS FLEXIBLE PRODUCT PORTFOLIOS

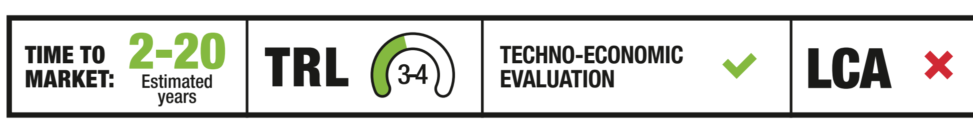
Further information: Jari Sirviö, jari.sirvio@vtt.fi, +358400548143

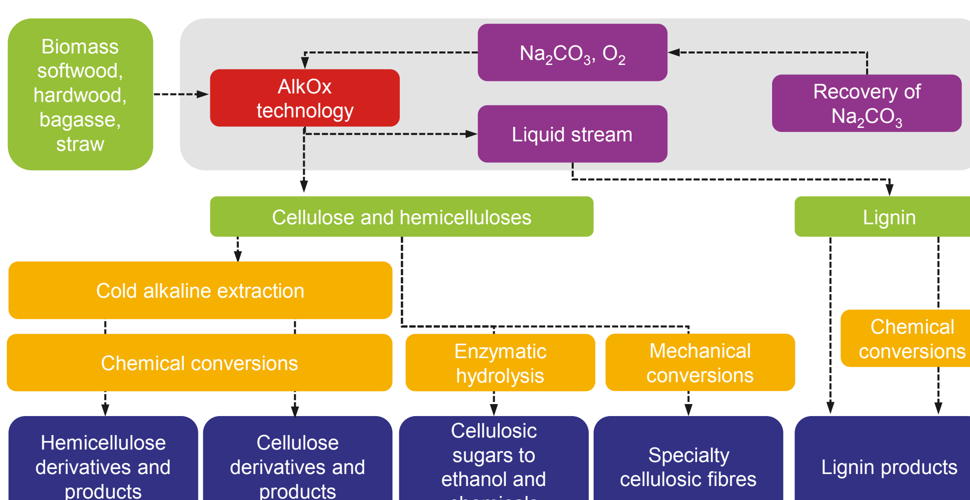
Future biorefineries should be flexible with respect to raw materials and product portfolios, and it should be possible to integrate them into current production facilities. Flexibility of raw materials offers freedom of biorefinery geographical location and the operational margins arising from the availability and price of raw materials. Flexibility on product portfolios enables maximization of the value of production under a changing business environment. Integrability into current production facilities promotes efficiency both in logistics and investment costs.

VTT has developed a new biorefinery concept for achieving the above targets. The AlkOx concept is capable of processing various raw materials including hardwood and softwood species, annual plants and agricultural residues like wheat straw. Different main components of lignocellulosic raw materials (cellulose, hemicelluloses and lignin) can be separated from each other and processed into a variety of intermediate products, to be used either in existing or novel products. The new concept can be integrated, e.g. into a kraft pulp mill.

The cellulose fraction can be further processed into bio-fuels or bio-chemicals, or to specialty pulps like nanocellulose or dissolving pulp. Hemicelluloses are expected to be suitable for producing technical sugars, transparent films or bio-plastics. Industrial uses in several adhesive or dispersion applications are expected to be developed for lignin with unique characteristics.

The flexibility and the integrability of the biorefinery concept have been tested within several R&D projects. The preliminary techno-economic evaluations have provided promising results and addressed the critical issues to be further studied and developed before commercial applications.





NEW SUPERB FUNGAL STRAINS FOR EFFICIENT ENZYME PRODUCTION

Further information; Markku Saloheimo, markku.saloheimo@vtt.fi, +358207225820

TRICHODERMA REESEI is one of the most important enzyme production systems used in the industry. It has exceptional properties in being able to produce enzymes in levels exceeding 100 g/l. Native and recombinant enzymes produced in *T. reesei* are applied in a number of industrial sectors including the textile, food, feed and pulp and paper fields. In particular, this fungus has a central role in production of the lignocellulose saccharification enzymes used in production of biofuels and chemicals in second-generation biorefineries.

VTT has been a forerunner globally in development of *T. reesei* as a potent enzyme production system for several decades. VTT's prior work has shown that the native proteases produced by this host form a major barrier for efficient production of recombinant enzymes and proteins. The protease spectrum of T. reesei has been characterized and a series of protease deletion strains have been constructed where the level of extracellular protease activity is greatly (at least 30-fold) reduced from the non-engineered strain. In the most advanced strain constructed 11 protease genes have been disrupted. To our knowledge not even the leading enzyme companies have proceeded equally far in this development. VTT is working currently with these valuable strains in several projects funded from public sources and by companies from the enzyme and biorefinery industries. This work has shown that it is now possible to produce recombinant enzymes at industrially relevant levels that would not be achievable with non-engineered strains. The first production strain licencing and technology transfer agreements based on this technology are expected to be executed within the next year.

TIME TO MARKET: 2-4 Estimated years	TRL 5	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

I want to build a cleaner and a better world.

- Senior Scientist at VTT

ENZYME TOOLBOX FOR EFFICIENT UTILIZATION OF BIOMASS

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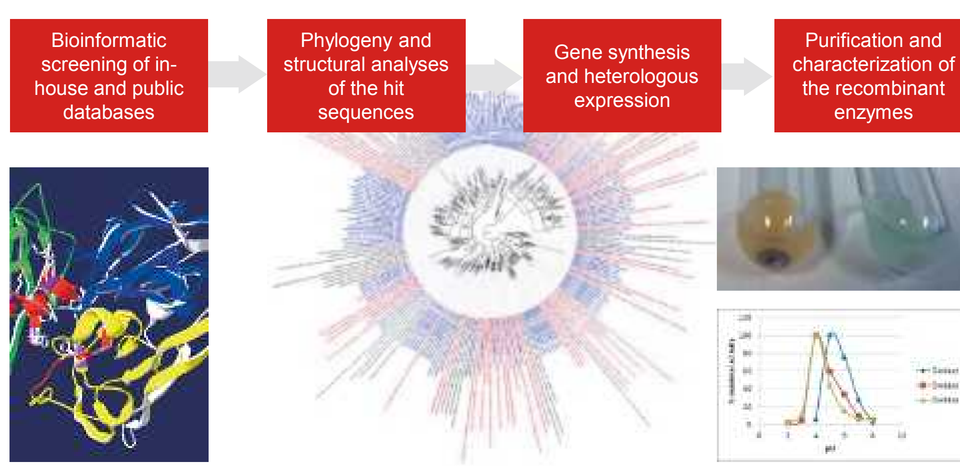
VTT's enzyme toolbox includes both enzyme discovery and protein engineering methods to obtain improved enzymes and tailored enzyme mixtures for sustainable biomass utilization. The enzyme properties of importance are, e.g. catalytic rate, thermostability, and substrate and product specificities under the desired process conditions.

Enzyme screening makes use of nature's huge diversity as a source of better biocatalysts. Novel enzymes can be accessed through microbial culture collections (i.e. VTT Culture Collection) or environmental samples, as demonstrated by identification of novel fungal cellobiohydrolases. However, since the vast majority of the microbes cannot yet be cultured under laboratory conditions, novel methods that allow direct access to all the microbial genomes existing in a given environmental sample have been developed during recent years. These, so-called metagenomic or metatranscriptomic techniques, have been successfully applied at VTT leading to identification of thermostable cellulases and xylanases that are active and stable at ≥ 60 °C. As the sequencing of the genetic code of single, isolated micro-organisms is nowadays relatively cheap, this has led to a rapid increase in genomic data in public (e.g. http://genome.jgi.doe.gov/) and proprietary databases (e.g. VTT in-house databases). The available genomic data in combination with computational tools (bioinformatics) has also been utilized at VTT for searching for new enzymes for lignocellulose hydrolysis and lignin modification.

Optimal enzymes for application purposes, besides enzyme discovery, can be obtained through protein engineering. As an example, cellulase enzyme variants (cellobiohydrolases) with improved thermostability and activity have been made using various protein engineering methods. Interestingly, the improved thermostability also rendered the enzymes more resistant to lignin inhibition.



ADVANCED APPROACHES FOR ENZYMATIC BIOMASS UTILIZATION AND MODIFICATION

Further information: Anu Koivula, anu.koivula@vtt.fi, +358407207158

FINLAND has a long and profound history in producing industrial enzymes (Roal, DSM, Dupont) and in enzymology research, especially enzymes acting on lignocellulosic materials. Moreover, Finland has a strong industry in utilization of biomass (UPM, MetsäFibre, St1, to name some companies). In future biorefineries it is of utmost importance that our biomass resources are used in a sustainable way and for added-value products. Potential new applications for biomass-derived components are foreseen, e.g. within chemical, food, automotive, construction and medical industries.

VTT has been one of the leading institutes in the enzymatic hydrolysis and modification of lignocellulosics research for decades, and the basic tools and knowledge are available. To ensure this leading position and competitiveness of the Finnish industry, VTT has, in cooperaton with Associate Professor Kiyohiko Igarashi (University of Tokyo, Japan), recently obtained a four-year Tekes project under the FiDiPro programme (Finland Distinguished Professor programme: https://www.tekes.fi/en/whats-going-on/news-from-tekes/tekes-funds-eight-new-fidipro-professors-or-fellows/), where the overall aim is to create a more profound understanding on the mechanisms of the lignocellulose active enzymes at a molecular level. Prof. Igarashi has a strong understanding of various enzyme types and chemo-enzymatic reactions for polymeric and monomeric carbohydrate molecules. He has pioneered the single-molecule visualization of cellulolytic enzymes in real-time, and has also an excellent publication record in the field. With the FiDiPro project, research will be strengthened particularly in the areas of bioinformatics & computational biology, enzyme discovery, enzymatic mechanisms and applications in the total hydrolysis of lignocellulosics, and in modification of lignocellulose & cellulose fibres. The FiDiPro project will also include mobility between VTT and the University of Tokyo, as well as collaboration with other Finnish research organizations, such as the University of Helsinki, Aalto University and the University of Eastern Finland.

Performing research which has an impact on the future is the source of my motivation.

- Reseach Manager at VTT

SYNTHETIC BIOLOGY IS REVOLUTIONIZING BIOTECHNOLOGY

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Synthetic biology is a new rapidly developing field, which makes engineering biological systems significantly faster, cheaper and more predictable than is currently possible. It is enabled by the possibility to synthesize large pieces of DNA in a test tube. These can be transferred to living cells and the cells will use this synthetic DNA code to express new properties, which are not present naturally in the organism.

IN THE NEAR FUTURE, scientists will increasingly use the enormous biological and genomic information present in databases and design, using computer programs, new combinations of desired functionalities or even functions that do not exist in nature. Large numbers of engineered cells can be built in an automated fashion using synthetic biology tools (e.g. the genome editing method CRISPR), and robots will be programmed to cultivate the cells and select the best ones for our needs.

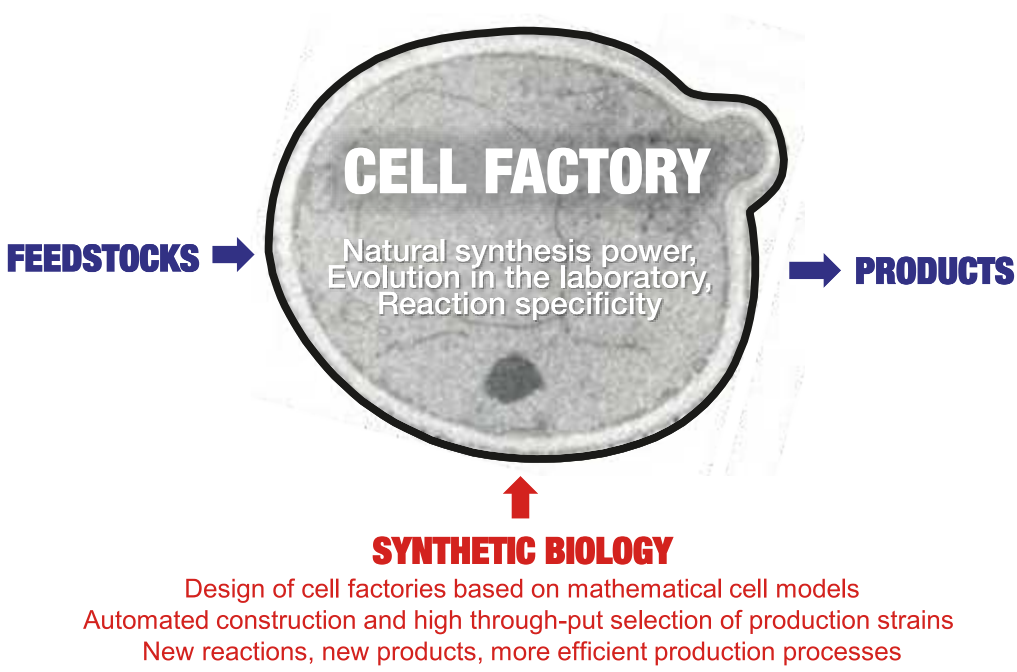
Synthetic biology is revolutionizing industrial biotechnology, the use of living cells or enzymes in industrial production. Gene technology was developed in the 1980'ies and enabled the production of human insulin with baker's yeast, and efficient production of antibiotics and powerful industrial enzymes with moulds. The development work has until recently, however, been largely trial-and-error, making it time-consuming and costly. Through synthetic biology technologies microbial engineering will become precise and 10-fold faster by 2020.

Biotechnology – powered by synthetic biology – is a technology platform enabling solutions for almost any industrial sector, i.e. energy, chemical, forest, food, feed, pharma and IT. Using biological principles and the diverse chemistry of cells – biochemistry – almost any chemical can now in principle be produced using biotechnology, also those currently produced from fossil resources using petrochemistry. Many chemical and energy companies are considering synthetic biology since it has the prospect of providing new products, less costly and more sustainable and energy-efficient processes. These large-scale products can range from biofuels such as bioethanol and butanol to platform chemicals used in production of bioplastics such as organic acids for manufacture of PLA or biopolyesters.

A great benefit of synthetic biotechnology is that it is well-suited for the bio- and circular economy. Microbes can utilize organic waste fractions as raw materials, such as straw, wood chips and municipal waste, and turn them into the desired product once they have first been engineered to do so. Furthermore, microbes can use just CO_2 as a carbon source and light for energy, as plants do. The production processes are contained in large bioreactors and no organisms are released to nature. Synthetic biology has a paramount role in making microbial utilization of various renewable raw materials more efficient and can provide true breakthroughs and disruptive technologies in our transition from a fossil society towards a sustainable biobased one.

Nature is an excellent engineer. It provides unique functionalities for us to learn from and utilize. Unlike any other technology, biotechnology provides an intrinsic synthesis power which can be boosted by evolution technologies. Various material structures exist (such as cellulose, silk, nacre and natural polyesters) that can be produced by microbial cell factories, and these inspire us to develop new strong or conductive biomaterials. We can also learn from nature how to make light or energy.

VTT is strongly involved in developing synthetic biology and is coordinating a large strategic opening project funded by Tekes called "Living Factories: Synthetic Biology for a Sustainable Bioeconomy". The goal is to develop a synthetic biology tool and automation platform for rapid generation of cell factories, and this way lower the barrier for Finnish industry to adopt biotechnology. We also develop microbes that can utilize C1 carbon sources (CO_2, methanol, methane) or produce more efficiently useful higher-value chemicals. Our mission is to give the Finnish industry a competitive edge and provide a technology platform that can have a significant impact on diversifying the bioeconomy. ⬢



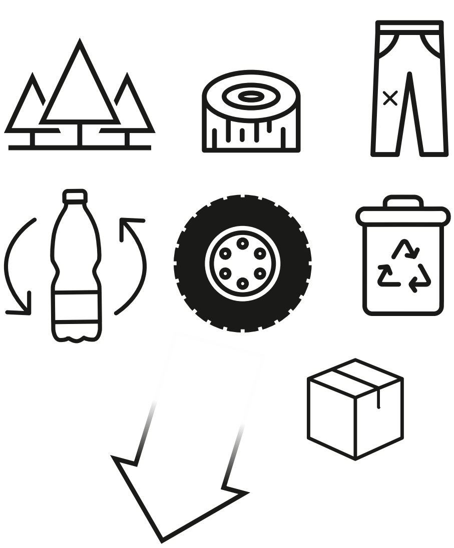
BIORUUKKI PILOT CENTRE:

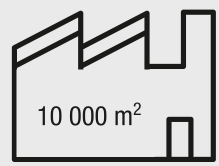
Value from integration

WILL MY GREAT IDEAS WORK?

New business opportunities in bioeconomy and circular economy demand cross-disciplinary knowhow, piloting and demonstration facilities for a fast track to market.

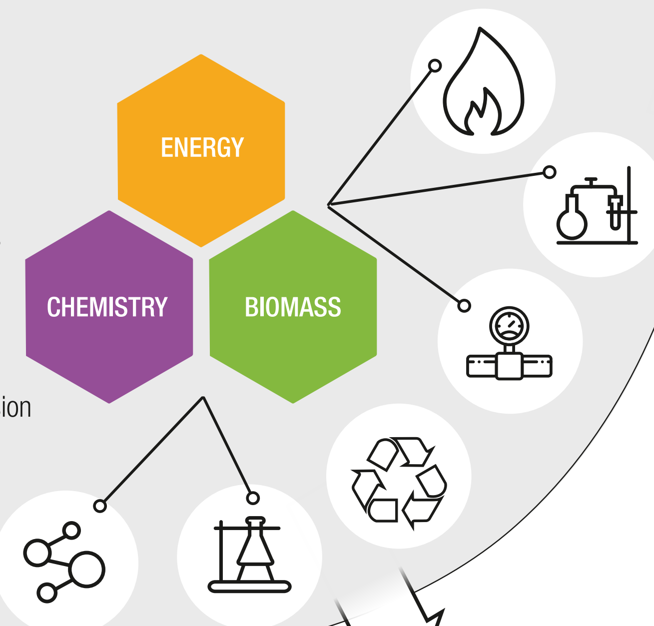
Piloting provides techno economic data for an industrial scale biorefinery investment decision.





BIORUUKKI PILOT CENTRE

Unique innovation and demonstration platform



- Thermochemical conversion
- Biomass processing
- Green chemistry
- Energy storage

QUESTIONS TO BE ANSWERED:

- Will my idea work?
- Will it be economically viable?

ACCELERATES GLOBAL MARKET LAUNCHES OF YOUR INNOVATIONS

BIOCHEMICALS

FUELS

PROVIDES DATA TO LOWER TECHNICAL AND ECONOMIC RISK

MATERIALS:

Textile & composite fibres, nanocellulose

BIORUUKKI PILOT CENTRE – VTT'S INNOVATION ACCELERATOR LOWERS CUSTOMER RISK

Further information: Ilkka Hiltunen, ilkka.hiltunen@vtt.fi, +358400226730

VTT has a long history of creating and developing new process concepts in close cooperation with industrial partners to create and develop new process concepts – from the initial idea, through the laboratory phase and to industrial pilot demonstrations. With Bioruukki, VTT can help companies to accelerate their global market launches.

The flexible research and pilot project infrastructure in the 10,000 m^2 Bioruukki facilities offers a world-class platform for scale-up and demonstrations, as well as for small-scale manufacturing. It is possible to make use of Bioruukki's process equipment for your pilot programme to avoid the set-up costs of in-house pilots. VTT's considerable body of existing knowledge as well as 500 experts are at your disposal. Bioruukki is seamlessly connected to other VTT pilots in biotechnology and biomaterials.

The development path and commercialization require typically substantial R&D work, money and time. Experimental pilot production is often needed to speed up the development and to lower technological and market uncertainty to the acceptable level for large investments. A major challenge is that the uncertainty is notably reduced only after the piloting, but already the investments in pilot facilities and operations can be too high. This means that many good innovations may not pass the "valley of death".

VTT's open access shared pilot facilities providing scale-up research and services offer a cost-effective route to piloting. The costs of pilot investments are shared and high utilization rates enable effective operation. The scale-up professionals and state-of-the-art pilot equipment complement companies' R&D resources. ⬢


Menu
Usage Now
Dual Fuel
HIGH
132 gm
Co2kg
47 kg

DIGITAL BIOECONOMY

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While we are examining the paths towards bioeconomy transformation in Finland, digitalization changes the whole global economic environment rapidly and systematically. Important drivers for digitalization are the enabling technologies, such as sensors, smart connected devices, wireless networks, cloud service platforms and data flow solutions, and easy access to computing power. The outstanding scalability of digital solutions, large volume supply of devices and competition between global platform providers keep the capital expenditure costs low and make technologies accessible to anyone. Devices, sensors and functions can be distributed everywhere, which makes it possible to control the useful data in real-time and to build services utilizing the data.

DATA IS THE KEY to creating valuable information. The more data that are available, the better; the more *accurate* the data are, is even better. That is, in order to benefit from the data, the quality of data needs to be taken into account. Typically, efficient utilization of data enables productivity increases by process optimization, creation of new service offerings or creation of new business models that can disrupt the existing value chains. When the value of data is truly understood, there is also a stronger need to pay attention to data ownership, privacy and security issues.

Digitalization affects all industrial branches. A clear sign of digital transformation is that new global service platforms are entering the market and challenging the existing market entirely, e.g., how Uber has challenged taxi services or AirBnB accommodation services. Would similar disruption be possible in the bioeconomy? Are there also possibilities for creating such disruptive platform services for the bioeconomy? At VTT, we believe that it is possible and we are helping Finnish industry and companies to realize these visions.

Potential industrial beneficiaries of digitalization can be, for example, agricultural food production and plant growth monitoring, animal production and animal health monitoring, sorting and logistics efficiency and in controlling distributed and localized processes.

Roadmap to digitalized bioeconomy

As a part of the Bioeconomy programme, in cooperation with Natural Resources Institute Finland (Luke), VTT developed a roadmap towards a digitalized bioeconomy. The starting point of the roadmapping was to deepen the understanding of the two evolving phenomena, digitalization and bioeconomy, and their interaction. The goal was to identify the branches of the bioeconomy that can benefit from digitalization, and create ideas on digital applications and solutions, which promote bioeconomy. The roadmapping project was carried out as a bottom-up co-creation process, in which more than 30 researchers from VTT and Luke participated.

There were three key targets identified for digitalization in the bioeconomy. The first one is to increase the efficiency of existing production processes. This requires digital solutions for ➤

the management of big raw material streams, improved logistics, and tailored solutions for specific uses. Secondly, digitalization enables the development of new bio-based products and services, business models, as well as other operational models for bioeconomy actors. The third target is to increase transparency and openness in various bioeconomy-related operations and actions.

To achieve these goals, we identified three main action pathways towards a digitalized bioeconomy:

1. Efficient management of raw-material streams. This path is about gaining more value from raw-material by more efficient and optimal use of different raw material fractions for different uses. Digital applications can be developed for matching the right quality of raw-material to a certain end use, smart logistics and agile operations.
2. Data-based business models and decision-making tools for the bioeconomy. The availability and use of data was identified as a key element of the digitalization of the bioeconomy. This pathway is about gaining more value from existing data and utilization of novel data generation methods to increase the amount of data to be used for the purposes of decision-making in companies, governance and among consumers. Digital solutions can increase transparency and enable anticipatory decision-making.
3. Network-based business models and collaborative governance of natural resources. The third pathway deals with the development of digital platforms that enable the networking of bioeconomy actors and new business models for collaborative governance of natural resources. In other words, it is about gaining more value from cooperation networks.

Role of sensors

Advanced sensors can be used as a source of more accurate data or obtaining data from a place not currently accessible. Therefore, advanced sensors can be very important value-creating tools and business differentiators for the data-driven business. Supplying sensors as a part of data-driven services can also be a path to easier access or even to ownership of data.

Many times, the advanced sensor is also a significant opportunity to obtain intellectual property protection for the data-driven business and that way reduce investment risks. VTT has a significant patent portfolio (over 350 patent families), out of which as many as 41% belong to sensors, measurement techniques and their integration. VTT licenses, transfers and creates spin-off companies through IPR for the benefit of Finnish industry.

In the bioeconomy branch, VTT's sensor and monitoring technologies have already created new data-driven business opportunities as illustrated in Figure 2 and described in the following case examples.

Role of services

New digital technologies, including efficient use of data, can create opportunities for new services or other offerings to customers. In general, digitalization drives the servitization of companies. At the same time also user expectations towards services provided to them are changing, whether the users are employees in a company, citizens, or consumers. Technological advancements and digitalization have changed the role and power of users and customers, who now have access to vast amounts of information and the ability to experiment, share, and interact with one another.

Advanced sensor systems enable efficient collection of data in different forms, but when utilizing the data for creating a new service offering it is necessary to put the customer in central focus. Understanding customer needs is a key factor for successful service design. This is also required for strategic decisions within companies. Clear service strategies help companies to redefine their current and future position in the market and the actions necessary to reach their goals, and also how to effectively manage and price the new costs inherent in the service business. ⬢

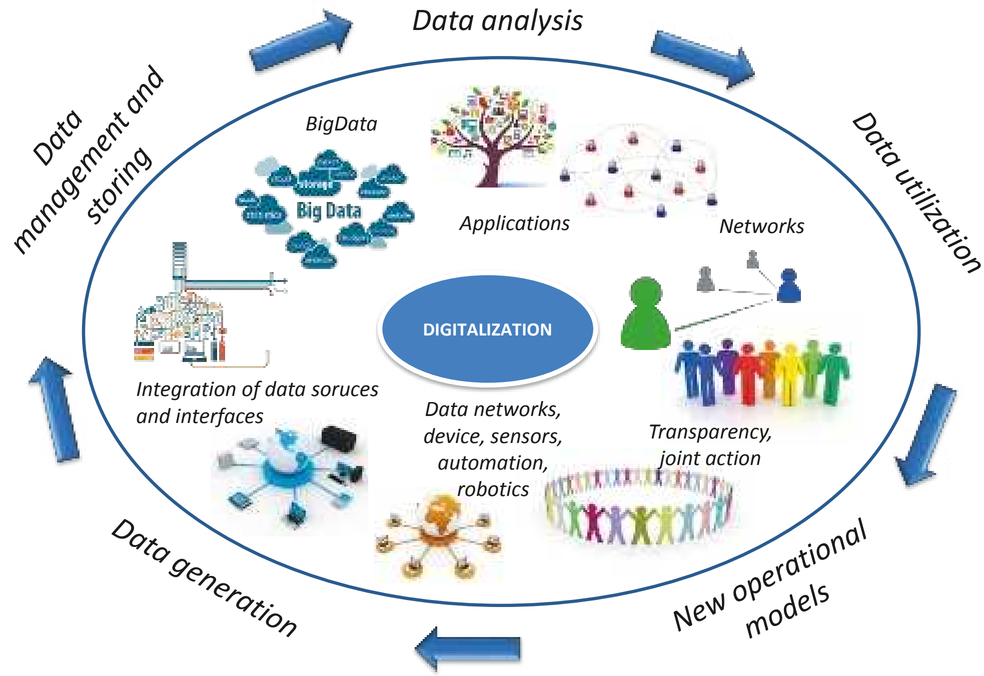


Figure 1. Digitalization cycle as defined in the context of the Digibio Project. Data is the core business enabler and technologies enable access to data.

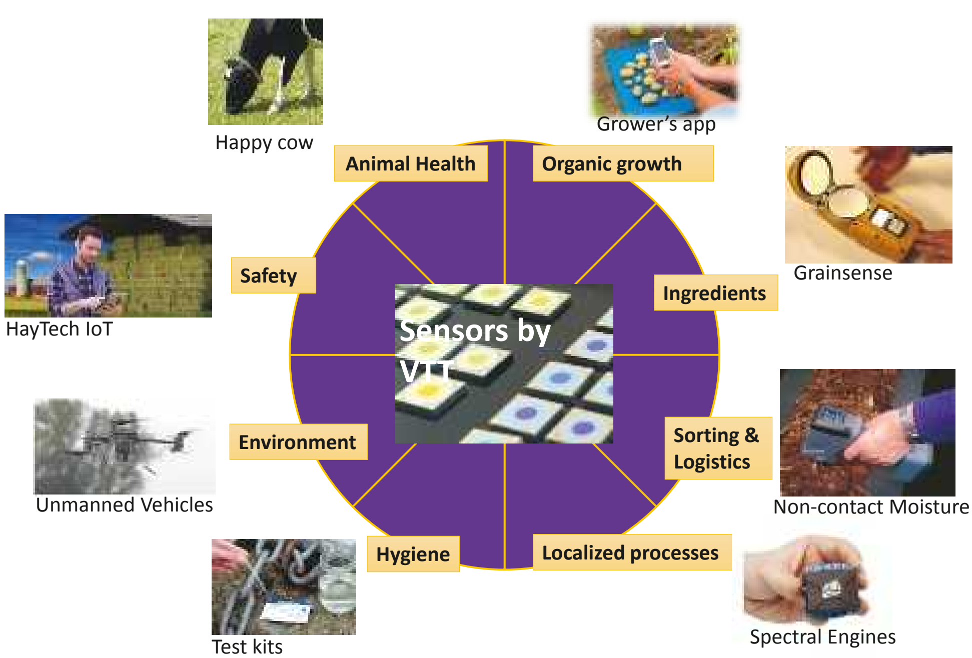


Figure 2. Examples of applications of VTT sensor technologies in a distributed and hyperconnected digital bioeconomy.

INTERACTIVE FLOWER POT

Further information: Maria Smolander, maria.smolander@vtt.fi, +358407029933

IN ORDER TO ensure adaptation of new applications enable by printed electronics, it is important to take consumer insight into consideration early on. VTT's Owela is a platform for co-innovation and co-development of novel applications for consumer products in cooperation with the consumers. To better understand how printed electronics could serve consumers, examples of novel printed electronics applications, especially related to disposable, even partially biodegradable products, were presented to the participants at Owela. The participants developed these ideas further and innovated new ones. The participants were especially interested in the novel solutions for gardening and wearables and gave positive feedback. As an outcome of the ideation phase with the consumers, a concept demo on an interactive flower pot was developed. The concept is a flower pot with a built-in moisture sensor. The pot is made of biodegradable materials and a moisture sensor is embedded in the soil. The sensor will communicate with a mobile phone and the phone records the measurement data into a cloud server which can map the measurement results against, e.g. daily weather reports. Various cloud-based services and social media interaction could potentially be built in the system and a biodegradable flower pot would send a tweet when you need to water the plant.

TIME TO MARKET: 3 Estimated years	TRL 2	TECHNO-ECONOMIC EVALUATION ✖	LCA ✖

OPTICAL SPECTROMETERS FOR DISTRIBUTED USE

Furher information: Mikko Utriainen, mikko.utriainen@vtt.fi, +358407537415

IMPORTANT BUSINESS opportunities in digital era rely on availability of data anywhere and anytime. The technology trend is towards small-sized, low-cost and distributed and connected sensors and devices that respond to that promise.

A novelty-rich approach and vision of VTT are miniaturized optical spectrometers that can be outsourced from laboratories to quantify chemical and biochemical ingredients. The value proposition is to provide, by means of spectrometry development expertise, more accurate data in the point-of-use and/or to measure things that cannot be measured cost-effectively today.

Utilizing VTT's core technologies like Fabry-Perot Interferometers *(http://www.vttresearch.com/Impulse/Pages/Fabry-Perot-Interferometer-technologies.aspx)* and other technical design expertise, like optical interface design in sampling, calibration, LEDs as light sources, optical detectors, etc., VTT has demonstrated many solutions for optical spectrometers in distributed use in the bioeconomy.

Hand-held devices have applications especially in sorting and logistics. For example, VTT's spin-off, GrainSense Oy, have commercialized the hand-held device to measure protein, moisture, oil, and carbohydrate content of cereal grains and other crops in the field. Furthermore, VTT's hand-held non-contact moisture meter prototype uses three wavelengths in the near-infrared region and can be used for moisture control on-site for biomass.

Miniaturized imaging spectrometers can be used, e.g. in plant and forest growth monitoring as a payload in unmanned aerial or ground vehicles. The same optical instrumentation principles with application-specific modifications can be employed also in localizaed process monitoring. Examples where low-cost spectrometers can be useful are control and monitoring, e.g. in localized biogas and bioethanol processes, small waste water utilities and milking stations at farms.

TIME TO MARKET: 3 Estimated years	TRL 3-5	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

SATELLITE IMAGE PREDICTIONS OF FOREST VARIABLES HELP COMPUTATION OF CARBON BALANCE OF BOREAL FOREST

Further information: Tuomas Häme, tuomas.hame@vtt.fi, +358405870631

FORESTS ARE facing conflicting user expectations. On one hand the bioeconomy requires intensifying utilization of wood as raw material and on the other hand forest conservation is demanded to improve carbon storage and biodiversity.

Satellite image observations that are available from any global location offer a way to obtain objective and up-to-date information on forest resources. Satellite image predictions can be input to carbon flux models to estimate carbon balance in the form of raster maps. VTT is on the international frontline in developing methods for forest characteristics estimation from satellite data.

VTT has expertise in utilizing all types of satellite-based imagery. In addition, we have a very good level of forestry expertise including knowledge of statistical methods. Our international network includes partners from the forest industry and international research partners.

Several of our methods and software products are already in operational and commercial use. Presently, we are coordinating development of a platform that offers a computing infrastructure and software as well as an opportunity for the global marketing of the services.

TIME TO MARKET: 0-3 Estimated years	TRL 5-8	TECHNO-ECONOMIC EVALUATION ✗	LCA ✗

Sustainable chemicals and materials will replace petroleum-based materials increasingly in the future. This will give new companies and countries a possibility to gain market share. At VTT we create new technology for the Finnish industry so that they can save the world and make a profit.

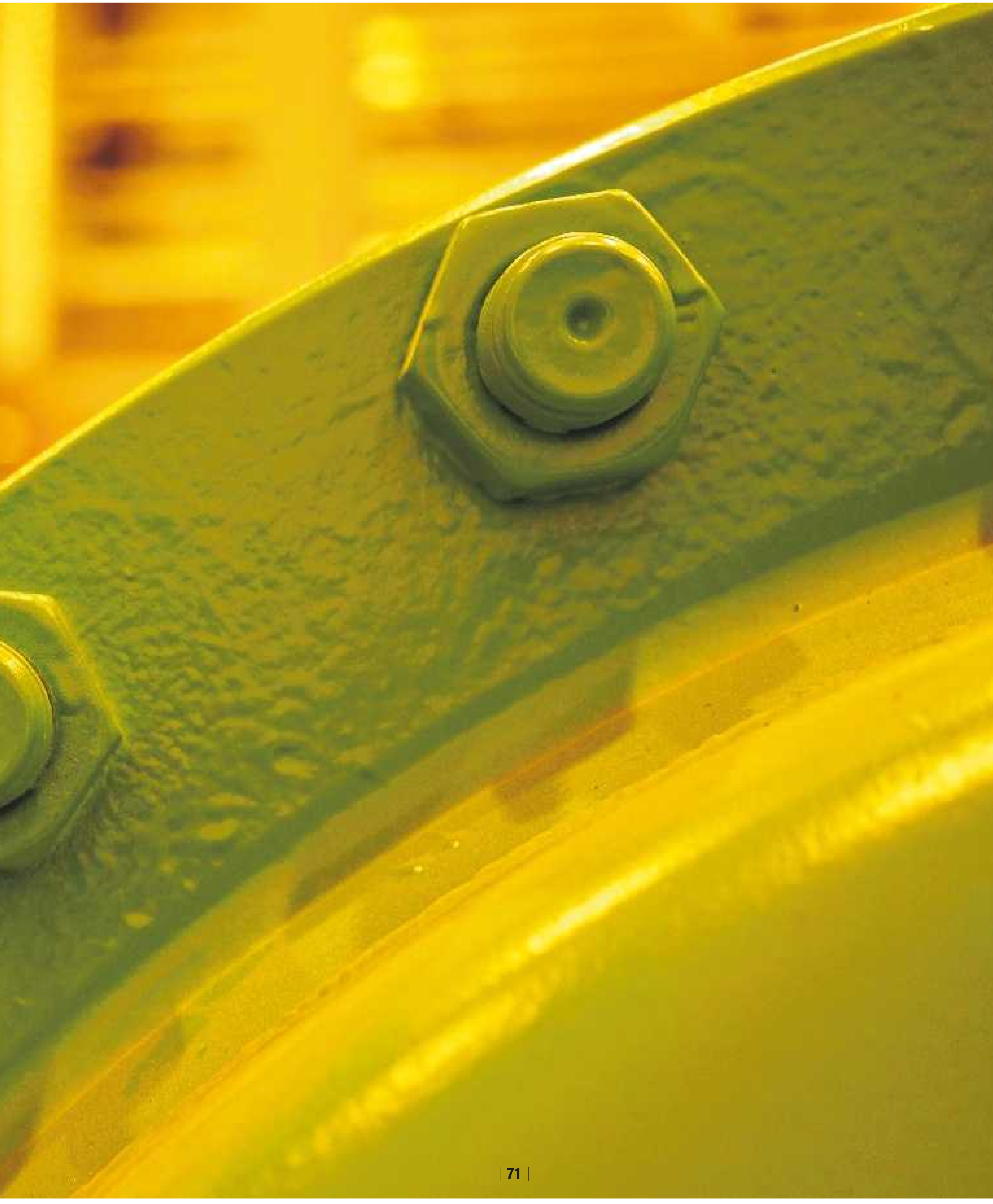
- Principal Scientist Juha Linnekoski

Bioeconomy will bring us unique properties of biomaterials, positive environmental effects.

- Senior Scientist at VTT

A love for chemistry and discovery. Developing new ways to move away from oil dependency.

- Senior Scientist David Thomas



QUO VADIS BIOECONOMY – SOME QUESTIONS ABOUT THE FUTURE BIOECONOMY IN FINLAND

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INTRODUCTION

Finland aims to be a strong global actor in the bioeconomy; similarly VTT wants to strengthen its role in as a key player in the emerging bioeconomy regime. Could we better identify the potentials of the Finnish bioeconomy by creating alternative (national) future scenarios? VTT has foresight and technology competences, and experience in creating holistic, but plausible and reachable future bioeconomy lenses in cooperation with different stakeholders. In the following section the VTT-level process on bioeconomy and the future potentials studied for South Australia are shortly discussed. Would it be time for Finland to do a proper national study on a reachable and plausible bioeconomy?

VTT'S BIOECONOMY SCENARIOS

A scenario process is a systematic, participatory, holistic, future intelligence gathering and medium-to-long-term vision building process. Scenario building was used as a tool at VTT to explore bioeconomy futures. As a result, complementary scenarios for opening discussions on bioeconomy perspectives, steering strategic decisions and actions towards the bioeconomy were produced.

The scenario process accelerated several VTT-level actions; digitalization of the bioeconomy and advanced manufacturing in the bioeconomy. The work continues by identification and strengthening of the competence base in the emerging circular bioeconomy (see also a policy brief published on circular economy by VTT 2016). The scenarios on high-value bioworks, biogarage and bioeconomy for the circular economy could act as lenses to scale-up within the national bioeconomy context. It is essential to vision and co-create reachable and plausible bioeconomy futures based on quantitative and qualitative foresight. This should include not only techno-economic perspectives, but also socio-cultural and ethical perspectives. The bioeconomy concept enables:

- recognizing complexity
- recognizing phenomena-driven policy, new ways of getting out of the silos of industry and governance (see high-value bioworks scenario)
- recognizing new social dynamics needs for responsive and adaptive programming, just like user aspects and recognizing new stakeholders, such as bottom-up-driven business and engagement (see biogarage scenario)
- understanding international or global (policy) interdependencies requires multilevel thinking,
- co-evolution of technologies, economy and society (see bioeconomy for circular economy scenario)
- re-understanding of regions; centralized or de-centralized bioeconomy and the challenges vs potentials

In the bioeconomy there are several fields of potential industrial convergence where there is need for interlinking service providers as well as platforms for collaboration and piloting (see Figure).

Could VTT be the Finnish Bioeconomy booster by utilizing the exceptional excellence not only in raw materials and technologies, but also in business, innovations and foresight? The bioeconomy is not only about natural resources and technologies, it is about the complex, future potentials especially on the trajectories of societies, industries, businesses and consumers. However, the work is not yet done.

FUTURE POTENTIALS

VTT is exceptional by having the technology and foresight expertise both in the same house. This unique capacity and excellence has created many forward-looking bioeconomy activities outside of Finland (see e.g. South Australian Cellulosic Fibre Value Chain Technology Roadmap http://www.iea-bioenergy.task42-biorefineries.com/upload_mm/e/2/4/9f556bef-f608-4f1b-a54e-1c9ce3b6753f_966_vtt_final_stage1_report.pdf). In Finland the potential for a regional-level bioeconomy transition by using VTT's capacity has not yet been used systematically or in a way that the impacts would be as evident as in this example case. Recommendations made in the South Australian roadmap process have been taken as the basis for the renewal of the region, and, e.g., new R&D mechanisms have been launched. How is it possible to use the key findings from Australia and reflect the results in Finnish Bioeconomy renewal?

According to our study, the key challenge in South Australia (SA) was not the low level of technology adaptation, but the lack of communication and co-operation among the operators. The lack of connections in the local industrial system hindered regional renewal. Although Finland is recognized as a strong player in the bioeconomy, new opportunities are also needed here.

During the SA project, one could observe a rise in the level of awareness among the regional operators (media as well). Finland needs to develop a holistic bioeconomy strategic and technology roadmap considering the understanding of current societal, industrial, consumer needs and aims, but also the technology readiness level of current and future technologies. What is reachable and what is plausible from the short-, mid- and long-term perspective? What is the scope of the Finnish bioeconomy; using new radical technological innovations and building a future leadership role developing higher value-added production in the bioeconomy?

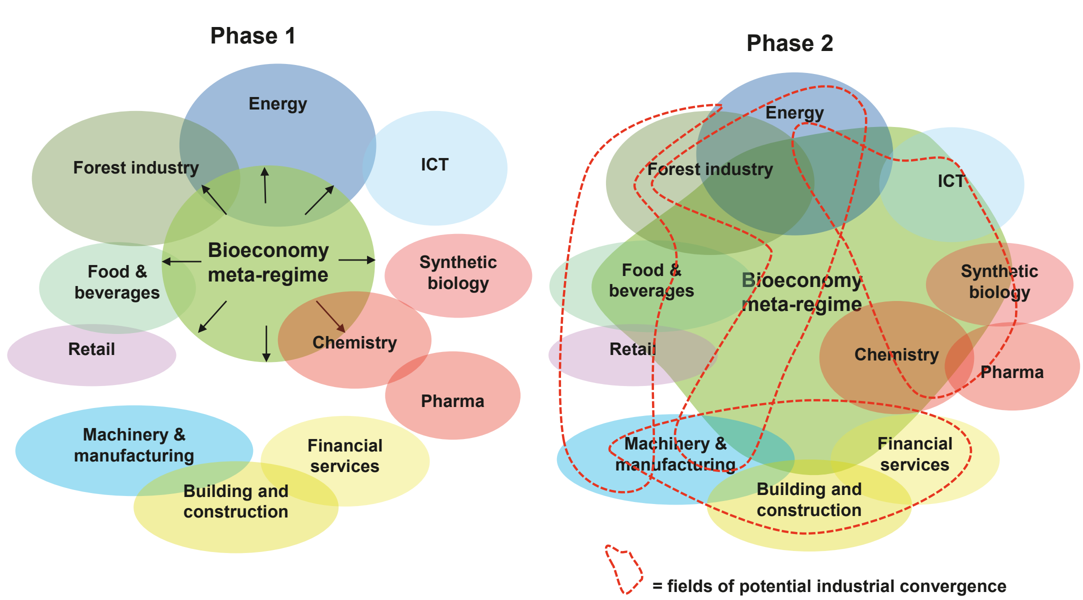
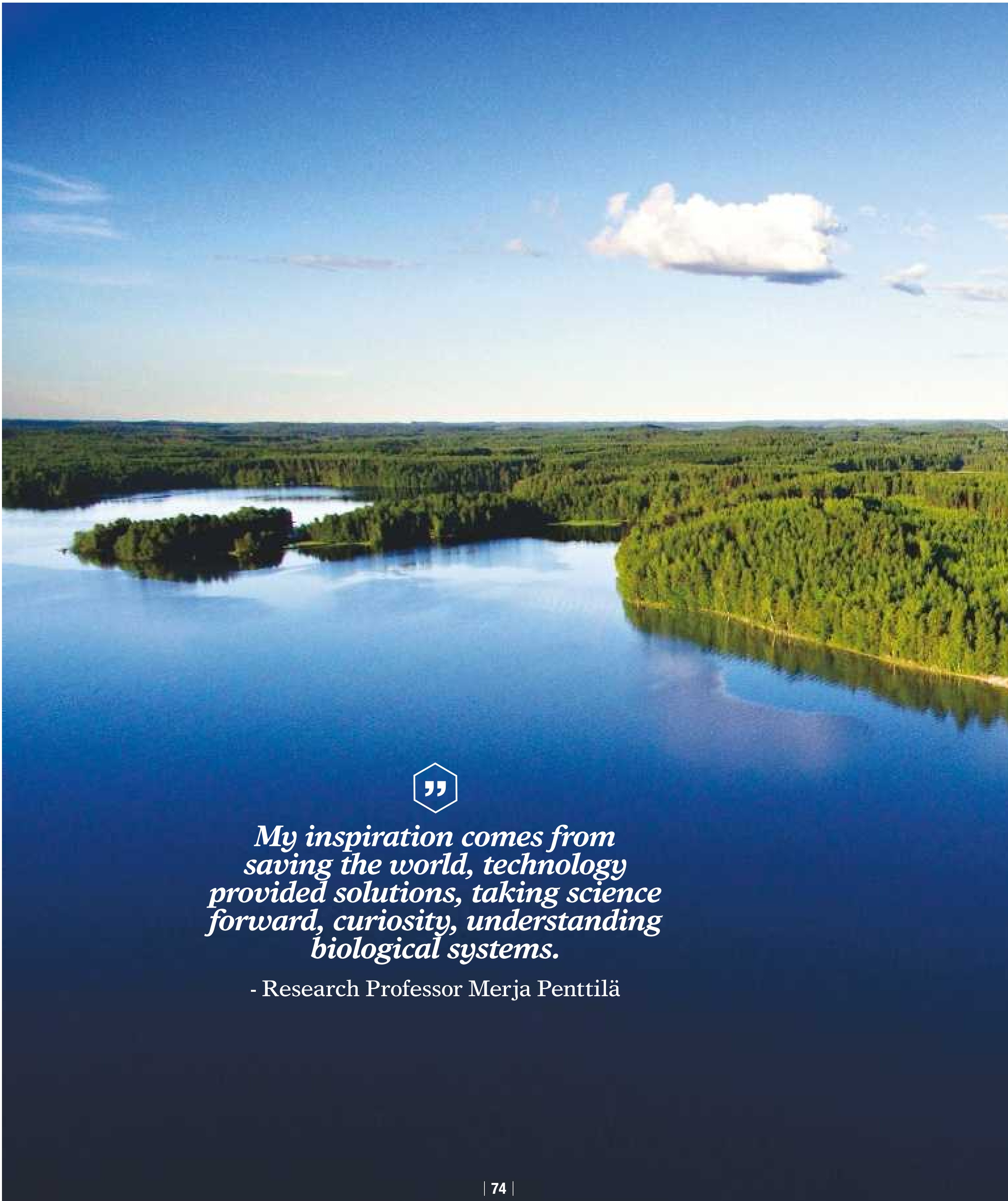


Figure. Inside out: the spreading of the bioeconomy as a new meta-regime.



My inspiration comes from saving the world, technology provided solutions, taking science forward, curiosity, understanding biological systems.

- Research Professor Merja Penttilä

APPENDIX 1:

VTT researchers' PhD theses related to the Bioeconomy Transformation programme

Akhgari Nazarlou, Amir Behzad 2015:
Alkaloids of in vitro cultures of Rhazya stricta. VTT Science 93.

Al-Qararah, Ahmad M. 2015:
Aqueous foam as the carrier phase in the deposition of fibre networks. Research Report 7/2015. University of Jyväskylä.

Arola, Suvi 2015:
Biochemical modification and functionalization of nanocellulose surface. VTT Science 102.

Asikainen, Sari 2015:
Applicability of fractionation of softwood and hardwood kraft pulp and utilisation of the fractions. VTT Science 73.

Bromann, Kirsi 2016:
Production of terpenes in Aspergillus nidulans. Engineering of the secondary metabolite gene cluster. VTT Science 126

Gabryelczyk, Bartosz 2015:
Diamond-like carbon binding peptides - evolutionary selection, characterization, and engineering. VTT Science 77.

Grunér, Mathias S. 2015:
Molecular interactions of hydrophobin proteins with their surroundings. VTT Science 114

Grönqvist, Stina 2014:
Action of laccase on mechanical softwood pulps. VTT Science 60.

Hannula, Ilkka 2015:
Synthetic fuels and light olefins from biomass residues, carbon dioxide and electricity. Performance and cost analysis. VTT Science 107.

Holopainen-Mantila, Ulla 2015:
Composition and structure of barley (Hordeum vulgare L.) grain in relation to end uses. VTT Science 78.

Hotti, Hannu 2016:
The killer of Socrates exposed - Coniine in the plant kingdom. VTT Science 135.

Häkkinen, Mari 2014:
Transcriptional analysis of Trichoderma reesei under conditions inducing cellulase and hemicellulase production, and identification of factors influencing protein production. VTT Science 65.

Kalliola Anna 2015:
Chemical and enzymatic oxidation using molecular oxygen as a means to valorize technical lignins for material applications. VTT Science 99.

Kangas, Petteri 2015:
Modelling the super-equilibria in thermal biomass conversion. Applications and limitations of the constrained free energy method. VTT Science 92.

Kemppainen, Katariina 2015:
Production of sugars, ethanol and tannin from spruce bark and recovered fibres. VTT Science 76.

Kouko, Jarmo 2014:
Effects of heating, drying and straining on the relaxation and tensile properties of wet paper. Research Report No. 12/2014. University of Jyväskylä.

Kuivanen, Joosu 2015:
Metabolic engineering of the fungal D-galacturonate pathway. VTT Science 106.

Ma, Hairan 2015:
Role of chemical and enzymatic modifications of milk proteins on emulsion stability/properties. Approaches for more stable protein emulsions. VTT Science 103.

Malho, Jani-Markus 2015:
Bioinspired materials. Non-covalent modification of nanofibrillated cellulose and chitin via genetically engineered proteins and multilayered graphene. VTT Science 81.

Manjaly Anthonykutty, Jinto 2015:
Hydrotreating of tall oils on a sulfided NiMo catalyst for the production of base-chemicals in steam crackers. VTT Science 83.

Niemi, Piritta 2016:
Enzymatic fractionation of brewer's spent grain and bioconversion of lignin-rich fractions in a colon model in vitro. VTT Science 124.

Nygård, Yvonne 2014:
Production of D-xylonate and organic acid tolerance in yeast. VTT Science 58.

Paasikallio, Ville 2016:
Bio-oil production via catalytic fast pyrolysis of woody biomass. VTT Science 137.

Purkamo, Lotta 2015:
Microbial ecology and functionality in deep Fennoscandian crystalline bedrock biosphere. VTT Science 116.

Reuter, Lauri 2016:
Plant cell factories. Production of hydrophobin fusion proteins in plant cell cultures. VTT Science 144.

Santala, Outi 2014:
Impact of water content on enzymatic modification of wheat bran. VTT Science 59.

Vishtal, Alexey 2015:
Formability of paper and its improvement. VTT Science 94.

Wahlström, Ronny 2014:
Enzymatic hydrolysis of cellulose in aqueous ionic liquids. VTT Science 52.

APPENDIX 2:

The most relevant VTT-coordinated, EU-funded projects related to the Bioeconomy Transformation programme

Research Infrastructure for Circular Forest Bioeconomy
Acronyme: ERIFORE • 1/16–1/18 • tot vol. 2 631 k€ • site: erifore.eu/
Reports: cordis.europa.eu/project/rcn/200673_en.html

Protein Mining of Cereal side-streams Exploring Novel Technological Concepts
Acronyme: PROMINENT • 7/15–6/18 • tot vol. 3 104 k€ • site: www.prominent-protein.eu/project/
Reports: cordis.europa.eu/project/rcn/197316_en.html

Mobile and Flexible Industrial Processing of Biomass
Acronyme: MOBILE FLIP • 1/15–12/18 • tot vol. 9 699 k€ • site: www.mobileflip.eu/

Tools for Resource-EFficient use of recycled FIBRE materials
Acronyme: REFFIBRE • 11/13–10/16 • tot vol. 3 937 k€ • site: reffibre.eu/about

Industrial Production Processes for Nanoreinforced Composite Structures
Acronyme: INCOM • 9/13–8/17 • tot vol. 4 957 k€ • site: www.incomproject.eu/

Enabling Intelligent GMES Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems
Acronyme: NORTH STATE • 9/13–1/17 • tot vol. 2 601 k€ • site: www.northstatefp7.eu/index.html

Added value from high protein & high oil industrial co-streams
Acronyme: APROPOS • 1/12– 12/14 • tot vol. 3 880 k€ • Reports: cordis.europa.eu/result/rcn/169145_en.html

BIO knowLEDGe Extractor and Modeller for Protein Production
Acronyme: BIOLEDGE • 10/11–9/15 • tot vol. 3 912 k€ • Reports: cordis.europa.eu/result/rcn/188633_en.html

Science based remote sensing services to support REDD and sustainable forest management in tropical region
Acronyme: ReCover • 11/10–12/13 • tot vol. 3 598 k€ • site: www.vtt.fi/sites/recover/en
Reports: cordis.europa.eu/result/rcn/90424_en.html

Added-value from chemicals and polymers by new integrated separation, fractionation and upgrading technologies
Acronyme: AFORE • 9/09–8/3 • tot vol. 10 747 k€ • Reports: cordis.europa.eu/result/rcn/90656_en.html

Novel high-performance enzymes and micro-organisms for conversion of lignocellulosic biomass to bioethanol
Acronyme: NEMO • 5/09–4/13 • tot vol. 8 099 k€ • site: nemo.vtt.fi
Reports: cordis.europa.eu/result/rcn/85940_en.html

APPENDIX 3:

Roadmaps related to the Bioeconomy Transformation programme

- **Ahlqvist, Toni et al. 2013:**
  South Australian Cellulosic Value Chain Technology Roadmap Stage 1. Assessment of the present state and future potential of forest industry in Mt Gambier region, South Australia. VTT Customer Report VTT-CR-02233-13. http://www.dmitre.sa.gov.au/files/966_vtt_final_stage1_report.pdf
- **Ahlqvist, Toni et al. 2013:**
  Stage 2. Future options for the cellulosic fibre value chain in the Green Triangle, South Australia: strategic technology roadmaps, business cases and policy recommendations.
  VTT Customer Report VTT-CR-04761-13. http://www.vtt.fi/inf/julkaisut/muut/2013/VTT-CR-04761-13.pdf
- **Heikkilä, Pirjo 2016:**
  Bio-based carbon materials road-map.
  VTT Research Report VTT-R-00181-16. http://www.vtt.fi/inf/julkaisut/muut/2016/VTT-R-00181-16.pdf
- **Hytönen, Eemeli et al. 2014:** Algal energy roadmap in India. Opportunities for Finnish industries and SMEs.
  VTT Technology 158. http://www.vtt.fi/inf/pdf/technology/2014/T158.pdf
- **Kaukovirta-Norja, Anu et al. 2015:** Roadmap for improving protein self-sufficiency of Finland.
  (In Finnish.) http://www.vtt.fi/inf/pdf/visions/2015/V6.pdf
- **Leinonen, Anna et al. 2017:** Digitalisaatiosta vauhtia biotalouteen – Tiekartta biomassavirtojen joustavaan hyödyntämiseen. Forthcoming, in Finnish.
- **Poutanen, Kaisa et al. 2017:** Food economy 4.0. VTT Visions 10. http://www.vtt.fi/inf/pdf/visions/2017/V10.pdf

APPENDIX 4:

Tekes' large strategic research opening projects and Academy of Finland Centre of Excellence related to the Bioeconomy Transformation programme

DWOC

DWoC (Design Driven Value Chains in the World of Cellulose) is a multidisciplinary research collaboration project funded by Tekes – the Finnish Funding Agency for Innovation, focused on finding new and innovative applications for cellulosic materials. The partners in the project are VTT Technical Research Centre of Finland Ltd, Aalto University, Tampere University of Technology and the University of Vaasa. DWoC project combines design thinking and design-driven prototyping with a strong competence in technology development.

The goal is to make Finland the source of value-added cellulosic products and business concepts and to accelerate the transformation of the current large-scale forest industry into a dynamic ecosystem for the bioeconomy containing both large and small-scale businesses.

Date: 1.6.2013–31.3.2018 • **Volume €:** VTT 4,76 M€ / 5 years; partners in total 11 M€ / 5 years • **Financier:** Tekes • **Partners:** VTT, Aalto University, Tampere University of Technology, the University of Vaasa • **WWW:** cellulosefromfinland.fi/design-driven-value-chains-in-the-world-of-cellulose/

DESIGN DRIVEN VALUE CHAINS IN THE WORLD OF CELLULOSE DWoC

LIVING FACTORIES – SYNTHETIC BIOLOGY FOR A SUSTAINABLE BIOECONOMY (LIF)

The mission of the "Living Factories (LiF): Synthetic Biology for a sustainable Bioeconomy" programme is to realise the potential of the breakthrough technology of synthetic biology (synbio) and enable its exploitation by Finnish industry, thus promoting sustainable bioeconomy in Finland. Particularly we will:

- Develop genome engineering and automation tools and concepts that will make the generation of high performance Living Factories (cell factories) cheap, predictable and fast. This will lower the barrier to invest in the biotechnology sector.
- Establish novel cellular chemistries "from C1 to Cn". This will enable new products in chemical and energy industry sectors, which are difficult to make using current biotechnology or chemistry.
- Create synthetic Living factories that are most carbon and energy efficient, and can compete with petrochemistry. This will allow highly sustainable, competitive and efficient production processes.
- Establish an international and dynamic business-research-education environment based on synthetic biology. This will support courageous new generation of experts with novel business ideas.

Date: 1.8.2014–31.12.2016 • **Volume €:** VTT: 3 761 684 Aalto University: 1 248 928 University of Turku: 639 389 • **Financiers:** Tekes, VTT • Partners: VTT Technical Research Centre of Finland Ltd (VTT), Aalto University (Aalto), University of Turku (UTU), Innomedica • **WWW:** vtt.fi/sites/livingfactories/en

HYBER

The aim of this Centre of Excellence is to create fundamental understanding on how self-assembled multicomponent materials of the future can be designed and produced by using biological starting materials, based on plant cell wall structures and designed biological macromolecules.

Date: 2014–2019 • **Volume €:** 1.19 M€ (2014–2016) • **Financier:** Academy of Finland • **Partners:** Academy Professor Olli Ikkala (Aalto University), Professor Markus Linder (Aalto University), Professor Janne Laine (Aalto University) • **WWW:** hyber.aalto.fi/fi/

THE FINNISH CENTRE OF EXCELLENCE IN WHITE BIOTECHNOLOGY – GREEN CHEMISTRY

The aim of the programme was to create scientific understanding and develop technologies that would enable the construction of efficient microbes and processes for the production of chemicals from plant biomass sugars. The goals were to identify new product possibilities from major biomass fractions, to create tools for obtaining higher yields and rates of production, and in particular to combine biotechnology and green chemistry know-how at VTT. The major achievements were:

- Examining broad range enzymatic conversion reactions for the hemicellulose derived sugars xylose, arabinose and galacturonic acid
- Establishing efficient microbial production processes for production of organic acids and their derivatives from these biomass sugars such as xylonic, galactaric and glycolic acid
- Chemical conversion of the acids to polymer precursors. Further work included conversion to the polymer precursors muconic and furandicarboxylic acid, and polymerisation of glycolic acid to PGA.
- Development of tools for genome level metabolic modelling, bioinformatics and single cell level analytics to address productivity and cellular stress reactions in bioprocesses

Date: 2008–2013 • **Volume €:** VTT 4500 k€; Academy of Finland 2600 k€ Coordinated by Research Professor Merja Penttilä, VTT

EXTERNAL MEMBERS OF PROGRAMME ADVISORY BOARD

***Mika Aalto**, Head of Division; Ministry of Economic Affairs and Employment*
***Heli Arantola**, Senior Vice President, Strategy & Renewal; Fazer*
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***Jari Vehmaanperä**, Global R&D Director; Roal Ltd*

TERMS AND LEGENDS

Basic Technology Research	**TRL 1.** Basic principles observed reported
Research to prove Feasibility	**TRL 2.** Technology concept and/or application formulated
	TRL 3. Analytical and experimental critical function of concept
Technology Development	**TRL 4.** Technology validated in laboratory environment
Technology Demonstration	**TRL 5.** Technology validated in relevant environment
	TRL 6. Technology demonstrated in relevant environment
System/Subsystem Development	**TRL 7.** System prototype demonstration in operational environment
System Test, Launch and Operations	**TRL 8.** Actual system completed and qualified
	TRL 9. Actual system proven in operational environment

TECHNO-ECONOMIC EVALUATION Economic evaluation is the process of systematic identification, measurement and valuation of the inputs and outcomes of two alternative activities, and the subsequent comparative analysis of these. The purpose of economic evaluation is to identify the best course of action, based on the evidence available. It is most commonly employed in the context of health economics and health technology assessment.

IN PROCESS | **YES** | **NO**

LCA Life-cycle assessment (LCA, also known as life-cycle analysis, ecobalance, and cradle-to-grave analysis) is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling.

Mankins, J.: Technology readiness levels. 6th of April 1995, White paper by NASA.

MAKING OF BIOECONOMY TRANSFORMATION

EDITED BY: Kristiina Kruus & Terhi Hakala
ISBN 978-951-38-8503-8
PUBLISHER: VTT Technical Research Centre of Finland Ltd
P.O. Box 1000 FI-02044 VTT, Finland Tel. +358 20 722 111