VTT Materials Innovation Hub

Accelerating Finland's growth with materials development

beyond the obvious

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Introduction

Climate change and biodiversity loss have long posed global challenges to societies. In recent years, they have been compounded by geopolitical tensions and threats to the availability of critical raw materials. For Finland, an additional challenge is the prolonged stagnation in economic and productivity growth.

However, it is possible to respond to these challenges – and even turn them into drivers of sustainable growth. This expert report examines two key challenges and the opportunities they present for renewing Finnish industry.

Challenge 1:
The availability of critical raw materials is under threat
Uncertainty in the supply of raw materials is forcing industry to seek new solutions. This is particularly urgent in sectors in the middle of the green transition, such as battery and energy industries. There is a need not only for substitute materials but also for entirely new, purpose-designed material solutions.

Challenge 2:
The value of biomass-based products must be increased
The demand for sustainable materials is growing rapidly, and their development must be accelerated. The traditional 10–15-year timeline for developing bio-based materials is no longer sufficient. The EU must strengthen its resilience by rapidly replacing fossil-based materials with bio-based alternatives. At the same time, the scarcity of raw materials requires improved resource efficiency. Industries such as forestry must refine biomass and biogenic carbon dioxide into diverse, high-value products. Swift action is needed.

The common denominator of both challenges is the need to accelerate and enhance the development and production of entirely new materials. This requires new methods and tools that enable rapid progress from laboratory to industrial scale and profitable business.

The development path of new materials can be divided into three phases:

1. Design of new materials
2. Laboratory-scale manufacturing and testing
3. Scaling from pilot to industrial production

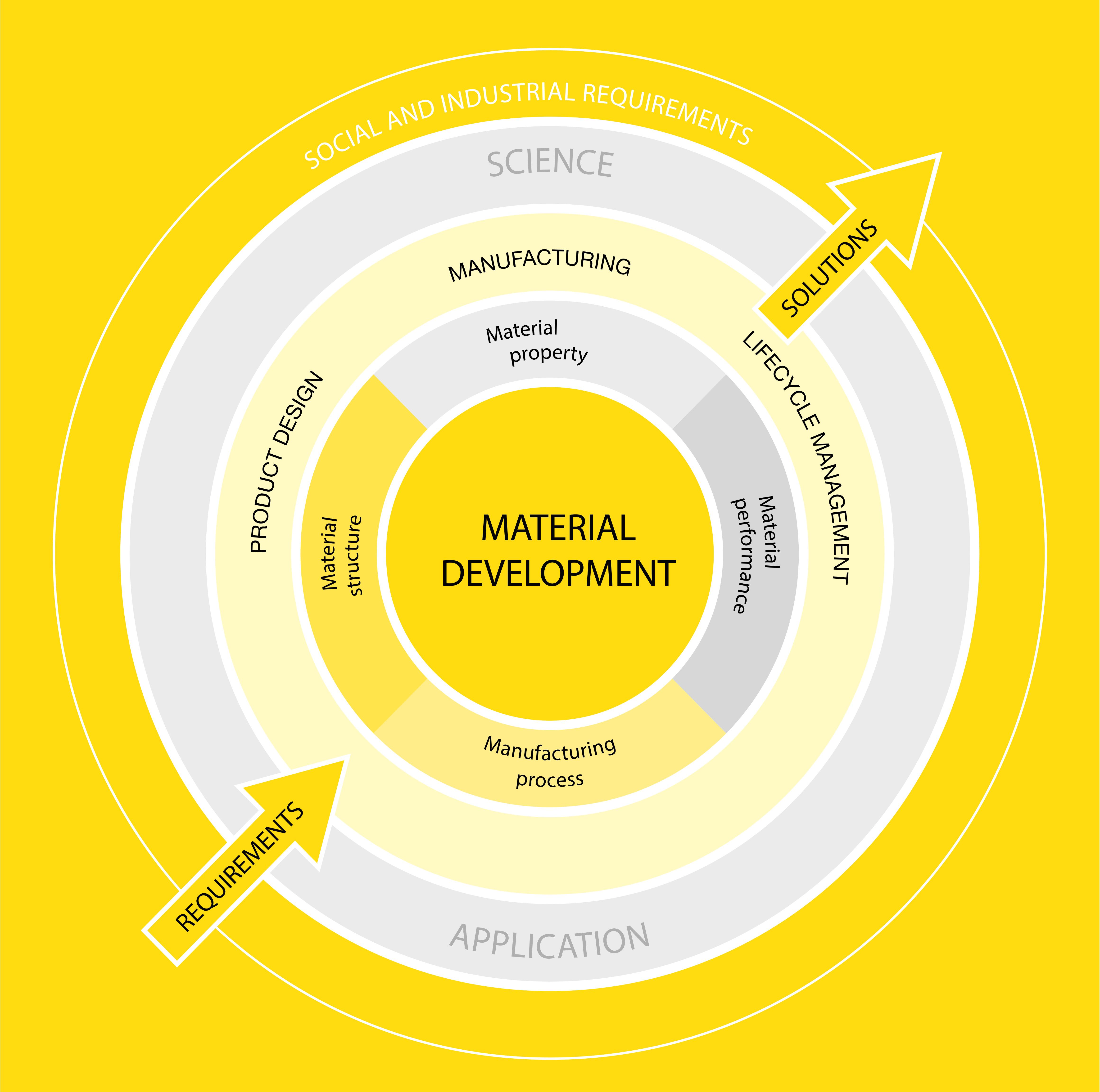
To support this development path, VTT has created the Materials Innovation Hub concept. We believe it allows Finland to seize the new opportunities presented by global challenges in the best possible way.

VTT Materials Innovation Hub – Response to the challenges of material development and production

Traditional materials research relies on theory, experience and experimental development. Using these methods, discovering entirely new material solutions is laborious, time-consuming and expensive. Reaching industrial scale and bringing new materials to market can take 15–20 years and require investments of hundreds of millions, or even billions, of euros.

Over the past decades, computational research has rapidly advanced and established itself as the third pillar of science, alongside theoretical and experimental research. Artificial intelligence (AI) has accelerated this development by opening up entirely new possibilities for designing and optimising materials and their production processes. In the future, quantum computing will bring yet another leap forward in research and development.

VTT is one of Europe's leading centres for computational materials research. The next step is to implement a platform for material design, development and production: the VTT Materials Innovation Hub.



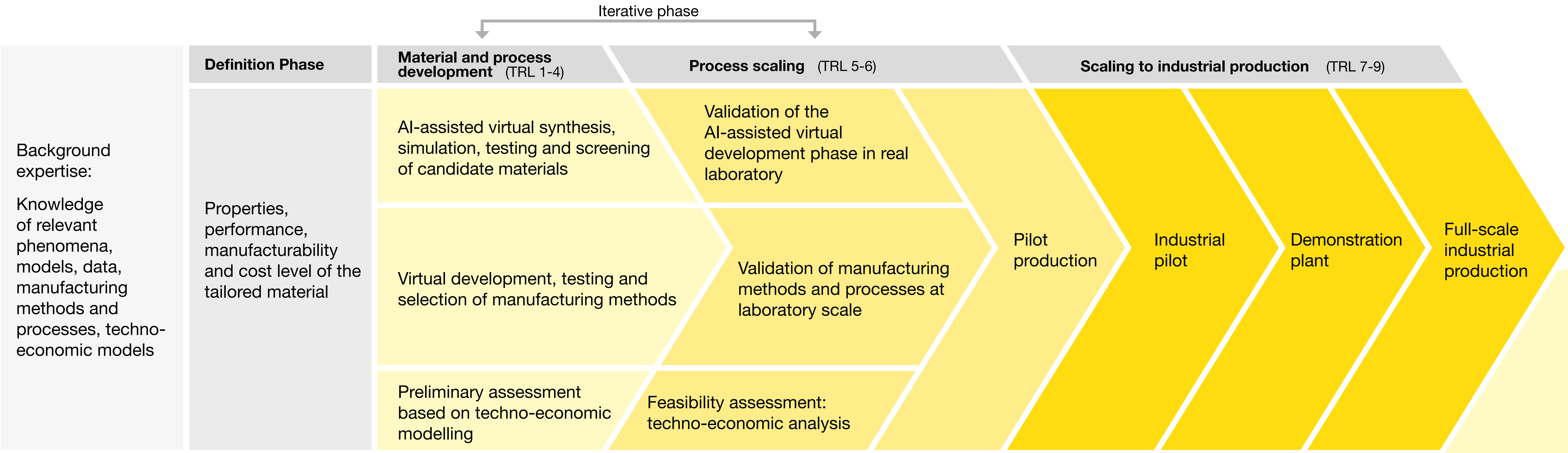
Harnessing computational power and AI for material design and production

The goal of the VTT Materials Innovation Hub is to develop new material solutions in as little as one-tenth of the time required by traditional methods. At the heart of the concept lies the data needed for AI-driven computation: its smooth and unrestricted flow between different functions, and the new knowledge and insights generated from it.

In the concept, data is generated through both experimental and computational methods and collected from pilot and production environments. It is processed and analysed using the most suitable methods and tools for the application in question, and the next development steps are guided by the new knowledge derived from it. The processes for generating, handling and managing data and ultimately using it in AI-assisted material development and production are to be automated. Experimental activities are also automated as far as possible.

This automation across is a second key element that enables significant efficiency gains. New knowledge can be generated, and machines, equipment and information systems can be utilised around the clock.

In addition to speeding up development, AI-assisted material innovation enables the creation of unprecedented designer materials with tailored properties. The pharmaceutical industry has led the way in this development, using AI from the design and synthesis of active compounds to virtual testing. VTT Materials Innovation Hubs brings similar advances to the development and production of structural and high-performance materials.



TRL = Technology Readiness Level

The development of manufacturing processes and production is part of the VTT Materials Innovation Hub concept

The concept is not limited to material design; it also includes test environments and methods that support scaling the production of developed materials from laboratory level to industrial scale. At VTT, available test environments include facilities for developing fibre-based products, producing recycled plastics and conducting biotechnical manufacturing.

Scaling to industrial scale is a major decision for any company and requires a techno-economic analysis. The test environments and their equipment mentioned above represent a step towards full-scale industrial production. In addition, VTT is developing methods and tools for conducting techno-economic analyses to evaluate the feasibility and profitability of new materials and manufacturing processes.

The core of the VTT Materials Innovation Hub concept

1. AI- and data-driven experimental activity, simulation and production process development are integrated into an automated and robotised laboratory, forming a network of digital twins.
2. Data, information management, platforms, interfaces, autonomous laboratory, high-performance computing, quality control.
3. Researchers capable of advancing research to a techno-economic readiness level from which companies can continue scaling the results to industrial scale.

Biomaterials

e.g. biomass-, fibre- or microbe-based materials and biosynthetically produced compounds

Structural materials

e.g. metallic and metal-ceramic materials for extreme conditions, such as fusion reactors

Functional materials

e.g. semiconductors and battery materials

Recycled materials

e.g. metals from electronic waste, recovered materials from textile and plastic waste and construction and industrial waste

VTT Materials Innovation Hub – What and why?

- A highly **refined research, development and production process for materials** that leverages physics-based simulation, artificial intelligence, experimental research and data, as well as automation of workflows and data processing.
- **Reduces the time required for materials research and development** to as little as one-tenth of what it would be using traditional experimental methods.
- **Applicable across a wide range of use cases**, including raw material refinement, recycling, biomaterials, fibre-based solutions, manufacturing, production and lifecycle and circularity management of materials.
- Enables **tailored and optimised material solutions** and takes into account e.g. properties, manufacturability, lifecycle, costs and environmental impacts.
- **Supports innovation of entirely new materials** with properties previously unattainable. Potential applications include space technology and fusion reactors.
- Provides a solid foundation for developing manufacturing processes for materials, offering **test environments from laboratory-scale pilots to small-scale industrial pilots.**
- Includes the **Self-Driving Labs (SDL) concept for experimental research and development**, where key elements are automation of experimental activities, data generation and process intelligence based on data analysis. Examples of systems used include AI-assisted AMANDA and GNoME.
- **Supports techno-economic analyses** that are essential for preparing companies' investment decisions.

Solutions to the availability of critical raw materials

Key clients of materials research include the metal refining industry as well as the mechanical engineering and metal product industries. Together, their export value is approximately €28 billion, accounting for 39% of Finland's total exports (2024). This sector is therefore vital to the Finnish economy.

Global geopolitics has brought to the forefront the competition for raw material resources and their availability. In practice, there are three ways to address the challenges of raw material availability:

1. Increase the production of raw materials
2. Improve the recycling and reuse of materials and raw materials
3. Replace critical raw material components with alternative material solutions

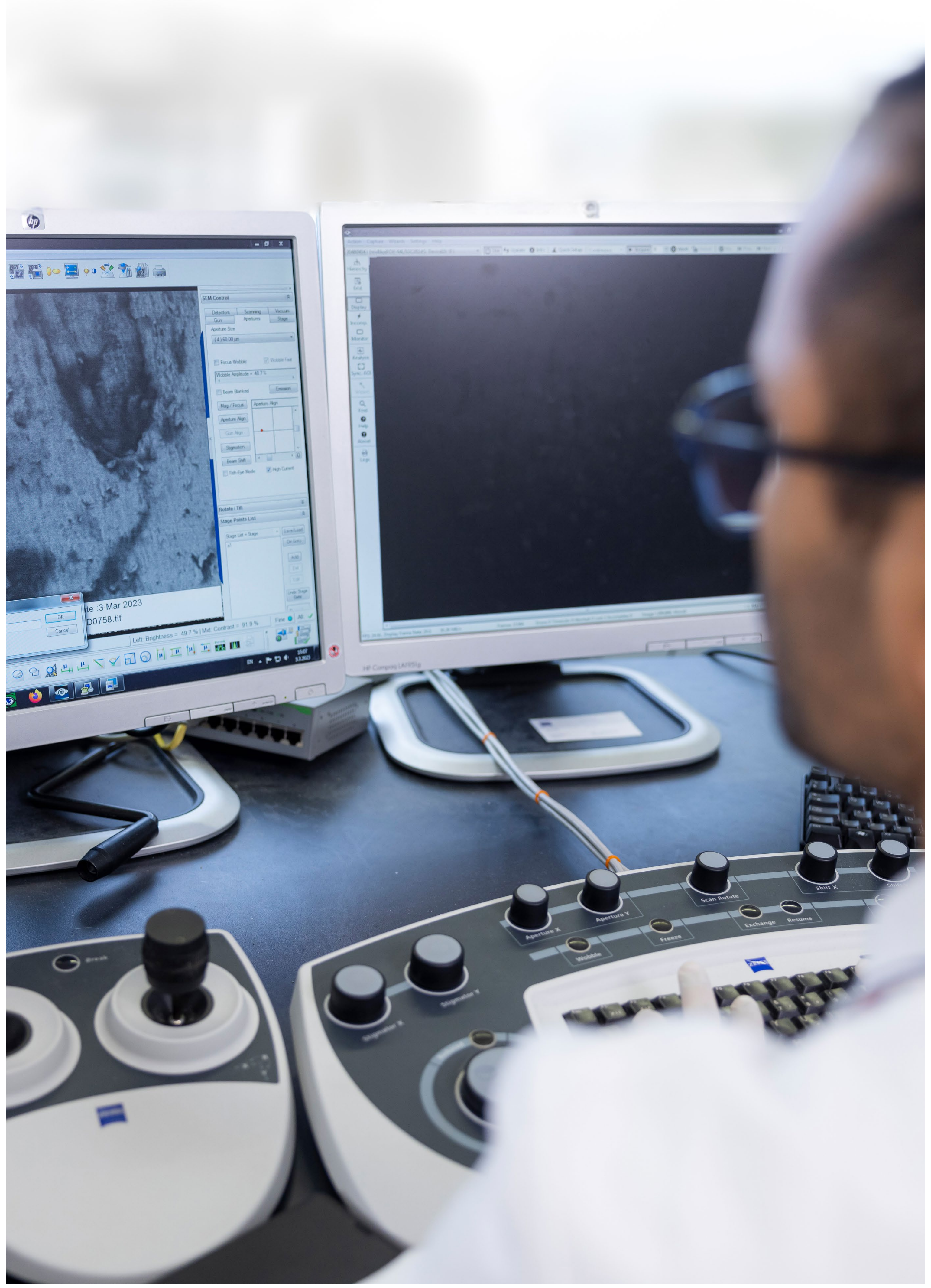
Materials research can particularly influence the latter two.

In recyclability, a key factor is the alloying of materials, which affects their processing during recycling. Examples include battery materials and high-grade steels for demanding applications. In alternative material solutions, the goal is to replace components of functional materials, such as permanent magnets, that are particularly scarce.

Both paths require deep material expertise and careful design. This ensures that the functional properties of materials still meet their intended use. Such understanding also enables meaningful trade-offs that consider performance, availability and cost.

In practice, VTT Materials Innovation Hub transforms the process of replacing raw materials by enabling the systematic identification of substitutes. Traditionally, finding alternative materials has relied on trial and error: producing test batches and evaluating whether they are good enough for the intended application. This approach typically yields only a few dozen candidate materials, which is insufficient when the goal is to discover a new material and bring it to industrial application. Traditional methods have not significantly advanced material substitution from either a technical or business perspective.

VTT Materials Innovation Hub supports the replacement of strategic and critical raw materials in a fundamentally different way. It combines AI, modelling, simulation, material synthesis and processing and testing from laboratory scale to industrial piloting. The process uses various tools and workflows that enable the efficient and controlled development and evaluation of substitute materials.



Put simply, the use of AI fundamentally changes the scale of material development. Instead of testing a few dozen experimental candidates, it becomes possible to computationally evaluate billions of alternatives already in the early stages of development. VTT Materials Innovation Hub's piloting capabilities enable the testing and validation of hundreds of materials for each application case.

Thanks to these capabilities, the VTT Materials Innovation Hub offers a systematic way to develop new substitute materials and solutions, which can also be widely applied across other areas of material development.

Examples of raw material substitution

- **Superalloys** such as tungsten-, rhenium- and tantalum-based materials are extremely high-performance and are being targeted for substitution with so-called refractory and high-entropy alloys.
- One development direction for light metal alloys is the creation of new **aluminium-based alloys** that can replace, for example, titanium, beryllium and magnesium.
- In energy storage, a key development direction is the **shift to new material chemistries**, such as sodium-, magnesium- and calcium-based solutions, as well as cobalt-free active materials.
- In catalysis research, solutions are being developed that utilise **base metals like nickel, molybdenum and iron** instead of rare and expensive precious metals.
- For rare earth elements (REEs), ongoing research focuses on new **magnetic materials** and new materials for solar cells.
- In semiconductors, many of the aforementioned elements are critical and there is a growing need to find more environmentally sustainable alternatives.

Added value from new forest-based products

In Finland, the majority of bio-based products originate from the forest industry. This sector carries high expectations both economically and in terms of sustainable environmental development.

The forest industry accounts for approximately 15.9% of Finland's goods exports, equating to €12.1 billion (Finnish Customs Statistics 2023). As such, it holds significant importance for the national economy.

The VTT Materials Innovation Hub also offers solutions to the material development needs of the forest industry. Key tools are already in use, such as VTT ProperTune®, which enables the optimisation of multiple, overlapping requirements for each material. We are also developing tools that support the development and control of manufacturing processes, as well as material identification and analytics. VTT Materials Innovation Hub also covers solutions for managing the entire product lifecycle from design to manufacturing and use.

Bio-based materials are produced from renewable biological sources, and their value is created through refinement. Biotechnology can improve the properties and recyclability of materials. This supports the sustainable renewal of industry and more efficient use of raw materials.

Increasing the value of biomass requires a higher degree of refinement, which can be achieved through better planning and innovation. At the same time, material expertise improves, and value can also be generated through the sale of related services.

Examples of high-value bio-based products

- A key challenge in using biomass, such as wood, is its dual role: it serves both as a raw material for products and as a source of energy. While energy production offers efficiency, in the future, biomass should be directed toward more valuable products. Cellulose-based materials like nanocellulose and regenerated cellulose enable the creation of new products that can replace plastics and composites.
- **The biorefinery concept** addresses the challenges of energy use by utilising valuable components from side streams and generating more added value than through energy sales alone. Traditional by-products include tall oil and turpentine, which are used in the production of detergents, paints, solvents and rubbers, as well as raw materials for biofuels. Newer processes also recover sulphuric acid and methanol, along with high-value components such as betulin and pectin. These are further refined into new chemicals and materials, expanding the range of value-added products.
- Several alternatives to plastic have been developed for food packaging, including **paper and board products** with mono-material or bio-based barrier layers, **moulded fibre products** (e.g. foam-formed packaging) and **flexible packaging** made from alternative film materials (e.g. VTT's transparent cellulose film).
- **Bio-based textiles** represent a higher-value and longer-lifespan product category compared to packaging.
- Water purification technology based on **cellulose films** offers a complete solution, including not only the membranes but also separation equipment and intelligent monitoring and control technologies for process management.
- New **wood-based construction materials** improve living comfort and indoor air quality while enhancing both new builds and renovations. At the same time, they sequester carbon over the long term.
- **Bio-based battery carbon** could serve as a foundation for domestic cell and battery production. However, this requires close collaboration with battery chemical producers and recycling sector stakeholders.
- Pulp mills offer a significant source of **biogenic carbon dioxide**, which could be utilised as a raw material for e-fuels, chemicals and polymer materials.

Synthetic biology as a foundation for new industry and sustainable growth

Synthetic biology, the convergence of engineering and biology, is predicted to revolutionise industry in this century. It enables the design and construction of new biological systems or subsystems, such as enzymes, gene circuits and novel organisms.

In practice, synthetic biology builds on foundational knowledge in genetic engineering, molecular biology and biochemistry, and leverages advances in these fields to optimise biological systems beyond their natural capabilities. Cells or their components can perform new functions and produce valuable products from sustainable raw materials such as agricultural and forestry side streams or even carbon dioxide.

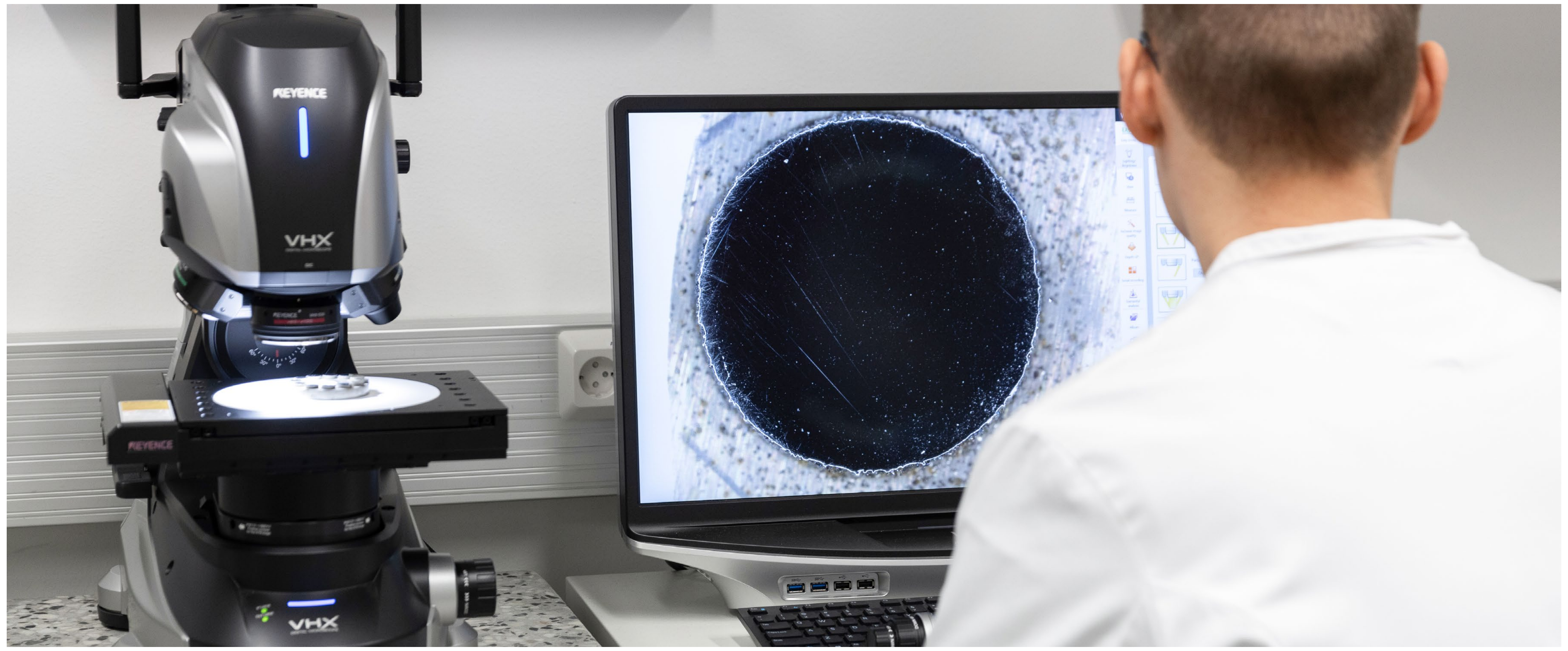
Synthetic biology thus offers solutions to both Finnish industrial renewal challenges discussed earlier. It promotes innovation across a wide range of industries, creating new opportunities for economic growth and sustainability.

In the circular economy of the future, where waste is minimised and materials are reused, synthetic biology plays a central role. Engineered microorganisms can convert waste into valuable resources and accelerate the closing of material loops, as they are capable of utilising compounds from side streams even at low concentrations among other substances.

Additionally, synthetic biology is advancing carbon capture and utilisation technologies, where engineered microorganisms can capture carbon dioxide from the atmosphere and convert it into useful products such as biomaterials and food proteins. These innovations have the potential to reduce greenhouse gas emissions and mitigate the effects of climate change.

Biomanufacturing already uses synthetic biology to produce valuable compounds with microorganisms. This approach is applied in the production of chemicals, bioplastics, biofuels, pharmaceuticals and food proteins. By using renewable resources and environmentally friendly biological processes, biomanufacturing offers a sustainable alternative to traditional chemical synthesis. Synthetic biology enables more efficient use of resources by optimising biological processes and opens the door to new products with enhanced properties.

Material modelling and biofoundries are at the core of biosynthetic material development



Combining material modelling with synthetic biology, as envisioned in the concept, opens new possibilities for material development. It helps researchers understand and predict material behaviour and performance under various conditions and accelerates the development of production processes. This is especially valuable when the number of new material candidates exceeds what can be experimentally produced and studied in a reasonable timeframe.

In practice, material modelling gives researchers access to a vast range of biosynthetic materials, such as thousands of new proteins or biopolyester structures and combinations, without the need for laborious and costly experimental research. For example, only a few dozen types of polyhydroxyalkanoate (PHA) polyesters produced by bacteria have been thoroughly studied, even though hundreds of thousands of variants are known. PHAs are particularly interesting biomaterials due to their biodegradability and plastic-like properties.

Synthetic biology provides the tools to design and produce materials with excellent performance and unique properties. These materials may resemble traditional plastics or possess entirely new features, such as self-healing, controlled biodegradability, or the extraordinary strength of spider silk.

In the future, biosynthetic materials can be developed up to ten times faster using AI-assisted development platforms. Alongside material modelling, the biofoundry, a development core that combines modelling, AI and automation, significantly accelerates the design and production of biosynthetic materials.

Biofoundries integrate synthetic biology, automation and computational tools for designing, building and optimising biological systems. In the long term, they will transform the bioeconomy by enabling the production of materials from diverse raw materials such as biomass and carbon dioxide. VTT is developing the equipment, processes, microbial strains and data management required for bioproduction as part of the U.S. National Science Foundation's (NSF) Global Centers programme. The goal is to evolve the biofoundry concept so that future bioproduction operates reliably and in a standardised manner, just like any other form of manufacturing.

However, the predictability of biotechnical processes and ensuring the scalability of bioproduction remain major challenges. To reach its full potential, bioproduction must advance technologically and increase its level of digitalisation. Standardised data storage and good data management practices provide the structure needed to systematically capture metadata and deepen the understanding of biological phenomena.

AI has already brought unprecedented insights into biological questions, such as the crystal structures of enzymes and other proteins. Integrating AI with synthetic biology accelerates the design and optimisation of biological systems. AI algorithms can analyse vast amounts of data, predict outcomes and suggest modifications to improve efficiency and performance. This synergy enhances the development of new bioprocesses and materials.

In the future, quantum computers are also expected to become key tools in biotechnology. Quantum mechanics can be applied to understanding complex biomolecules and quantum biology – a field that studies biological processes through quantum theory – is emerging as a new scientific discipline.

Summary

We are facing two major challenges: geopolitical uncertainty threatens the availability of critical raw materials and industry urgently needs ways to shorten the transition from laboratory to industrial deployment to increase the value of biomass. Both challenges have a significant impact on the development of Finland's economy.

Fortunately, there is also a solution: advanced materials research and the utilisation of new technologies. This requires investment in new, sustainable and cost-effective processing technologies. At the same time, it opens up opportunities to strengthen Finland's industrial base and increase added value through new materials, products and production methods.

As a multi-level platform for material design, development and production the VTT Materials Innovation Hub brings unprecedented speed and precision to material innovation. With the concept, the development of new designer materials can be achieved in a fraction of the time previously required, and these materials can be rapidly scaled from pilot to industrial production.

VTT Materials Innovation Hub enables the sustainable use of renewable biological raw materials in a raw-material-neutral way, accelerating development. It also supports investment in breakthrough technologies, such as cost-effective and sustainable processing methods. These may include not only biotechnology but also chemical or mechanical modifications of raw materials to commercialise new bio-based materials.

Now is the time to turn words into action! We invite innovative companies to take advantage of the opportunities offered by VTT Materials Innovation Hub and to build new, competitive and sustainable material solutions in collaboration with VTT and leading universities in Finland and internationally.

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