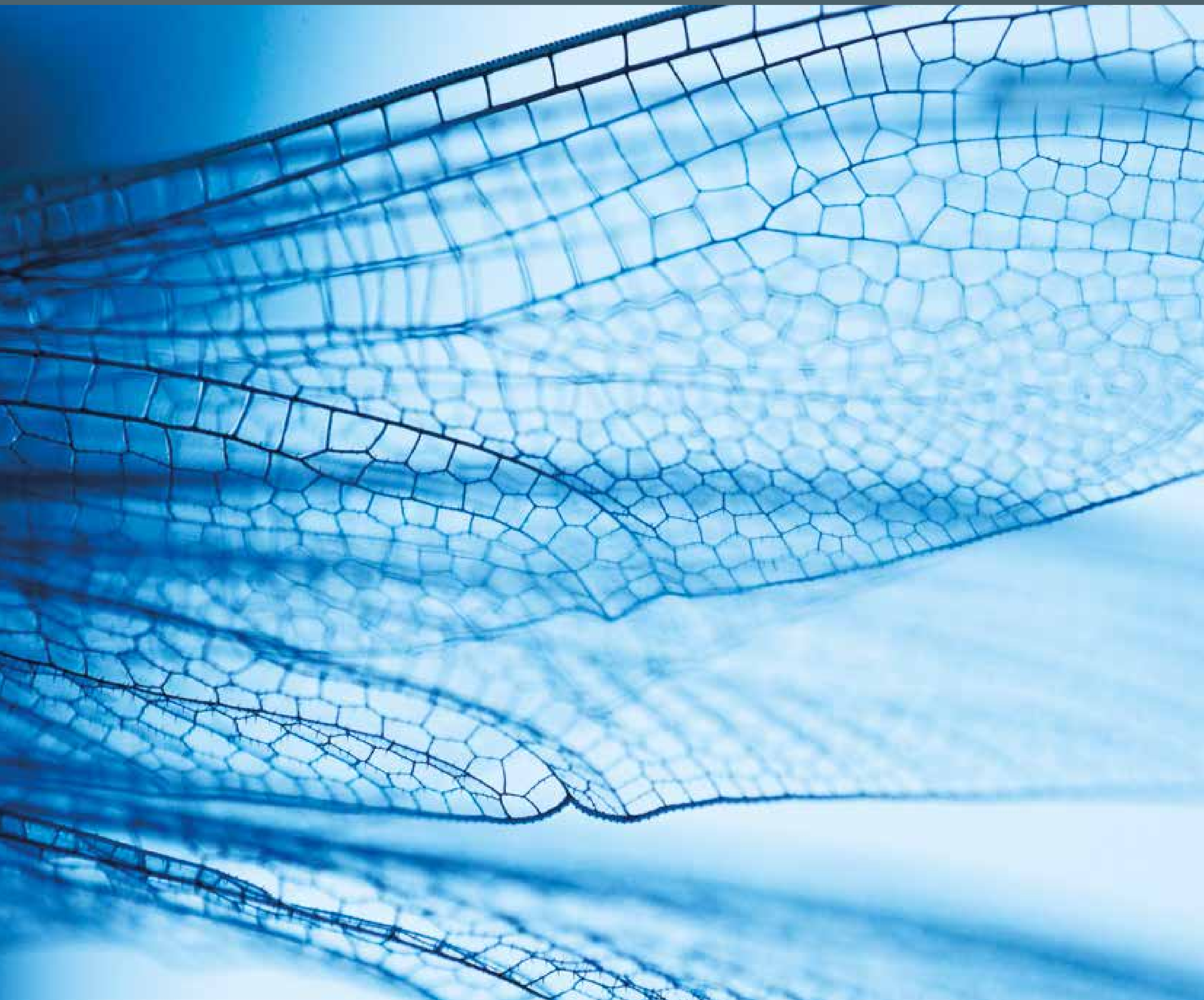
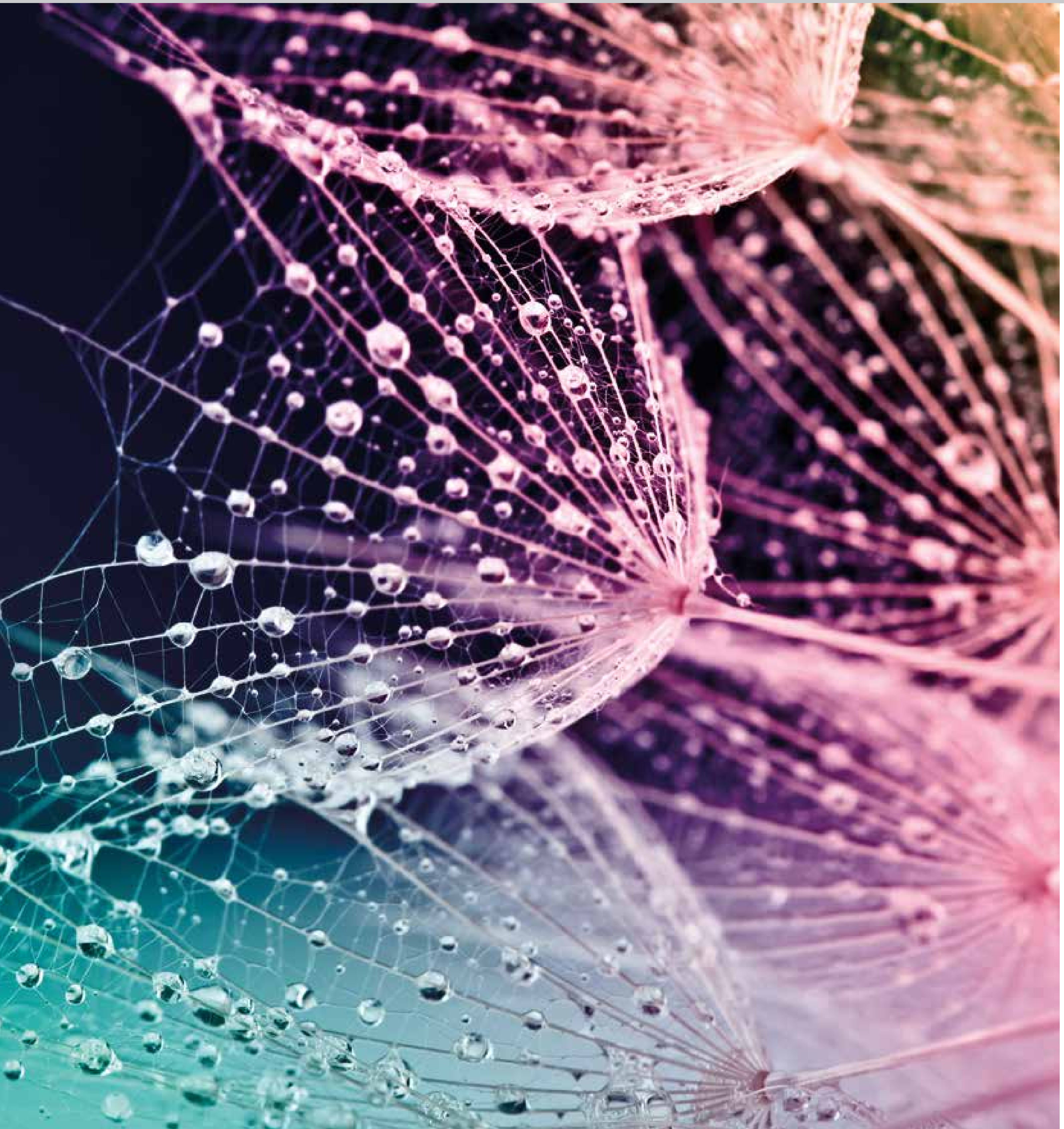
Fraunhofer

BIOLOGICAL TRANSFORMATION AND BIOECONOMY





> **"I THINK THE BIGGEST INNOVATIONS OF THE 21ST CENTURY WILL BE AT THE INTERSECTION OF BIOLOGY AND TECHNOLOGY. A NEW ERA IS BEGINNING."**

Steve Jobs

> "IT IS DIFFICULT TO IMAGINE ANY AREA OF OUR FUTURE LIFE THAT WILL NOT BE IMPACTED BY BIOLOGICAL TRANSFORMATION."

Into the future with biologization and digitalization!

German products, processes and equipment are competitive and, as such, in big demand throughout the world. As the country's leading application-oriented research organization, the Fraunhofer-Gesellschaft contributes toward this success in many areas of technology. Here, the question of sustainability is becoming increasingly important. Furthermore, the powerful growth of knowledge in the biosciences has spawned all manner of synergies in the fields of medicine, nutrition, energy and, in particular, digitalization, thereby creating a platform for exciting new innovations.

As the examples in this magazine show, the Fraunhofer-Gesellschaft is at the forefront of developments in the field of bioeconomy and is therefore paving the way for our country's continued economic success. Fraunhofer researchers draw inspiration from biological principles and from the material cycles in nature. The products developed in this way each respond to a major challenge of our times: the need for palatable, healthy food that is not based on environmentally harmful meat production; stem cell research to replace animal experimentation; the development of strong, durable materials from renewable sources; the growing of vegetables in an urban setting – to name but a few.

It is difficult to imagine any area of our future life that will not be impacted by biological transformation. I wish everyone at the Fraunhofer-Gesellschaft continuing success in this crucial field.

Yours,

Prof. Dr. Wiltrud Treffenfeldt
DOW Europe, Chief Technology Officer Europe, Middle East, Africa & India
Member of the Senate of the Fraunhofer-Gesellschaft

"AT FRAUNHOFER, BIOLOGICAL TRANSFORMATION GOES HAND IN HAND WITH DIGITAL TRANSFORMATION."

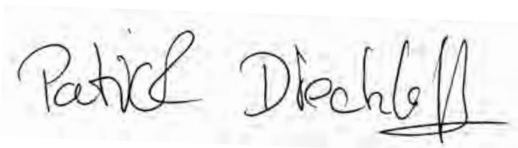
In Germany, there is a tradition of drawing inspiration and innovation from nature. Back in the 1990s, the federal government identified biotech as a key technology for the future. In 2007, under German presidency, the Council of the European Union issued a road map for a more sustainable future: "En route to the knowledge-based bioeconomy". And with its national research strategy "Bioeconomy 2030", the federal government has placed the biosciences at the very heart of its high-tech agenda.

Meanwhile, the Fraunhofer-Gesellschaft is now looking to amalgamate digital change (connectivity) with biological change (sustainability). This yields the concept of biological transformation: a process that describes the increasing technological utilization of principles, structures and materials derived from living nature with the goal of establishing sustainable systems of value creation. Biological transformation is a diverse process. It includes, for example, as one of the essential pillars of a future bioeconomy, the use of renewable raw and residual materials as a replacement for basic materials derived from fossil fuels.

Part of this process involves applying the findings of molecular biology to the development of new and individual forms of therapy. Similarly, the principles of nature can help us understand and control complexity – essential for the creation of self-organizing manufacturing systems or self-contained digital ecosystems.

Yet it would be wrong to claim that biological transformation is sustainable per se. Its role is to contribute toward achieving the sustainable development goals of the United Nations. And let us not forget that the examples presented here are but a selection – colorful and diverse, just like their inspiration – nature. That so many others could have been added to this list – car tires made from dandelion rubber, for example, or butadiene fermented from renewable raw materials – merely serves to demonstrate the scope and continuity of our engagement in this field. In other words, this overview presented here is merely the beginning. We hereby invite you to join us on our journey of biological transformation!

Yours,



Dr. Patrick Dieckhoff
Head of Science Policy of the Fraunhofer-Gesellschaft
Coordinator for Biological Transformation

BIOLOGICAL TRANSFORMATION

Anyone walking barefoot near an anthill is well advised to carry on moving. The all-female soldier ants are quick to attack. At the slightest provocation, they will swarm out to defend their citadel against an all-powerful enemy. Their prompt reaction shows that the seeming chaos is but apparent. As a collective, the colony is in complete control. Both organizationally and physically, ants could teach us humans a thing or two: how to walk upside down on smooth surfaces, for example, or how to avoid traffic jams on congested roads. Despite their huge numbers, they live in harmony with nature all over the world. Humans can learn a lot from nature.

Bionics has given us Velcro and zipper fasteners, supersmooth surfaces with the lotus effect and camera lenses based on the compound eye of an insect. Nature is a constant source of inspiration. More than half of all pharmaceutical ingredients have their origin in natural substances. Advances in biotechnology mean that bacteria, fungi and plants now play a key role in the chemical industry. Drones are piloted according to principles derived from the workings of a bee's brain. Indeed, wherever we turn, the use of the principles and materials of nature is on the increase. Out of the multitude of individual examples, a recognizable trend is emerging: a growing convergence of nature and technology, with the aim of establishing a sustainable economy. Here, experts talk of biological transformation. By this, they mean that the utilization and combination of knowledge from the life sciences across all areas of technology is now promoting the establishment of sustainable economic systems such as a bioeconomy.

As a field of inquiry and activity, biological transformation is driven by our growing understanding of biological principles and processes. This knowledge, in turn, has been made possible by ever more powerful information technology. It was the availability of immense computing capacity that first enabled scientists to sequence the human genome – and, since then, many other genomes. Out of a jumble of letters, scientists have been able to develop new diagnostic procedures and individualized therapies. Analysis of huge datasets has helped disclose unknown global patterns. With the help of GPS navigation, we have been able to follow the migration of animals right around the world. These findings have revealed connections between habitats that were once considered as entirely distinct. Some of the findings have proved less palatable: global studies on the consequences of climate change (deforestation, glacier retreat, desertification etc.) have revealed its true dimensions and impact on ecosystems. At the other end of the scale, computer-controlled microscopes have shone a light on minuscule structures at the molecular level, thereby leading to the development of nanoscopic substances and materials. Computer-based ("in silico") simulations help reduce our use of animal testing. Meanwhile, we are now able to create digital ecosystems. And one day, we may well conceive of DNA as a highly efficient data memory or neuronal interface. In other words, digital transformation first enabled biological transformation. They go hand in hand and can even reinforce one another.

From today's perspective, we can identify three different phases of biological transformation. Each emerged at a different time; each makes use of different principles, structures and materials; and each continues to this day. In the beginning, there was bionics, which analyzed structures and processes from nature in order to apply them to technical problems. The first ever German bionics patent – a "dispersion mechanism" based on the seed capsule of the opium poppy – was registered in 1920. Yet that was only the start. During the first half of the 20th century, health care benefited from numerous developments in pharmaceutical drugs and diagnostics – from antibiotics to blood glucose test strips – based on active ingredients that come more or less unchanged from nature. The next milestone came in the 1970s, when Stanley Cohen and Herbert Boyer pioneered the replication of DNA in foreign cells. Their discovery gave rise to biotechnology: the application of technology to living organisms. Today, biological organisms are used to produce a whole range of substances: bacteria, fungi, and other microorganisms are efficient producers of vitamins, specialty chemicals, biofuels and humanized implants. What's more, detergents are now as effective at 30 °C as they once were at 90 °C. That saves energy.

The application of biological principles has led to radical changes in a whole range of business sectors, including pharmaceuticals, the consumer goods industry, food production and agriculture. This process is expected to intensify in the future, as biology and IT increasingly converge. Today, advances in artificial intelligence and machine learning are already giving rise to what are known as social machines along with innovative logistics, robust manufacturing systems and self-optimizing machines.

Digital transformation and biological transformation are complementary strategies: the former aims primarily at interconnectivity and efficiency, the latter at sustainable development. Each is necessary, but neither is in itself sufficient. They must therefore be thought out and pursued in combination. Unlike digitalization, which is now largely accepted as a necessity, the process of biological transformation is still in need of political support. In fact, biological transformation can help achieve the sustainable development goals set out by the United Nations (SDGs), which serve as a reliable benchmark against which to measure sustainability.

Conclusion

Biological transformation is based on knowledge gleaned from the life sciences. Germany is a leading player in the fields of environmental technology and resource efficiency. In essence, the German term Industrie 4.0 was coined to define a digitally supported strategy that promotes greater connectivity and efficiency – not an agenda for greater sustainability. This is where biological transformation comes in – a process that describes the increasing technological utilization of materials and principles from nature to establish a sustainable economy.

Thanks to extensive ongoing funding, Germany occupies a strong position in the life sciences. Biological transformation refers to a process based on a whole range of scientific disciplines, which is now promoting the establishment of sustainable economic systems such as a bioeconomy. In other words, biological transformation is an innovation process that describes the application of scientific results and, potentially, systemic change. As such, it forms a bridge between science and research, on the one hand, and an economic system, such as a bioeconomy, on the other. It therefore constitutes an interdisciplinary task for science, politics and society.

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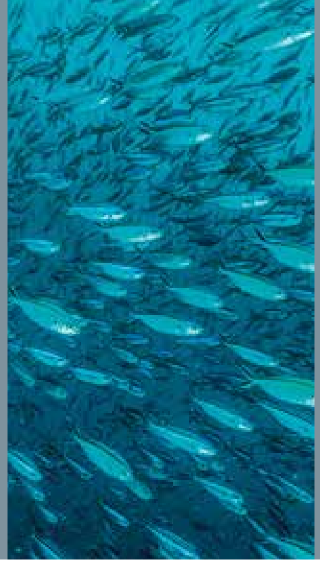
THE CONTRIBUTION OF BIOLOGICAL TRANSFORMATION TO THE SUSTAINABLE DEVELOPMENT GOALS* OF THE UNITED NATIONS



SDG 2

Zero hunger

A synergy of technology-based approaches (smart agriculture, the latest plant-breeding methods) with biology-based approaches (microbiome research and agricultural biodiversity, for example) will help increase agriculture's efficiency, resiliency and environmental compatibility (reduced use of fertilizer). Research into alternative protein sources to replace meat, for example, will also enable the progressive replacement of greenhouse gas-intensive animal products.

SDG 3

Good health and well-being

Examples of biologically inspired therapies and diagnostics include biopharmaceutical products, regenerative medicine, biofunctionalized materials for medical purposes, tissue engineering and microbiome-based research. In addition, biological transformation will enable the development of cell-based testing procedures, thereby reducing animal experimentation. At the same time, machine learning and advanced computer simulation can enhance our understanding of complex biochemical processes in cells and organisms, thereby accelerating the development of new active ingredients for pharmaceutical drugs.

SDG 9

Industry, innovation and infrastructure

The adaptation of biological principles can play a key role in making technological systems and infrastructure more resilient. This applies not only to construction and other materials (such as self-healing materials) but also to entire infrastructure (for example, in the area of mobility or energy supply), which could then be designed on the basis of resilient ecosystems. In addition, the use of natural resources is a prerequisite for freeing industry around the world from its dependence on materials based on fossil fuels.

SDG 12

Responsible consumption and production

The replacement of fossil fuels by renewable biological materials and chemicals, and the establishment of closed-loop material cycles, will make a significant contribution towards reducing business and industry's carbon footprint. Using biological processes and biomimetics can help make manufacturing processes more efficient and thereby reduce their consumption of raw materials. Similarly, the application of biological principles (such as swarm intelligence as a digital process) can reduce logistical requirements and a buildup of industry at particularly impacted locations.

SDG 6

Clean water and sanitation

Biological processes play a well-established role in wastewater treatment. For example, microorganisms help break down dissolved pollutants and other waste materials in wastewater or even convert them into usable raw materials. Biosensors and molecular biotechnology are used in environmental analysis to accurately determine pollution levels in water. Similarly, bio-electrochemical and biomimetic membrane systems enable energy-efficient water treatment. In agriculture, precisely controlled irrigation systems inspired by biological principles help ensure water is used more efficiently.

SDG 7 und SDG 13

Affordable, clean energy and climate action

The sustainable use, as a source of energy, of biomass or – in line with a cascading use – its derivative products can help replace fossil fuels. Bioenergy can contribute to a varying degree – depending on the region – toward providing a sustainable source of fuel, heat and electricity. Meanwhile, modeled on plants and microorganisms, catalytic processes are now being developed to produce basic chemicals from carbon dioxide with a view to establishing a "closed carbon cycle economy".

* (SDGs)

BIOLOGICAL TRANSFORMATION – ITS APPLICATION IN THE ECONOMY

It is a reasonable assumption that biological transformation will have a global impact on trade, supply chains, individual sectors of the economy, industrial locations and employment. In some cases, it will give rise to completely new ways of doing business. In enabling new tools, new materials and new raw materials (the utilization of CO_2 with biotech methods, plus waste and residual materials, for instance) as well as new manufacturing methods, machinery, robotic systems and digital ecosystems, the process of biological transformation will stimulate a host of business sectors.

In the German economy, for example, the machinery and plant engineering sector will play a key role in driving biological transformation, determining its scope and speed. As a key supplier to industry, the engineering sector will define the structures and standards that determine the application of biological principles within the field of technology. These principles include redundancy, resilience and material cycles, the transfer of which to the manufacturing environment has major, as yet unexploited, potential. Given their use of biotechnological production processes and biological therapies, the chemical and pharmaceutical industries are already well advanced along the path of biological transformation. It is evident that the most successful companies in this field are those that are able to tap specialized know-how, whether internally or externally. Crucial, too, is the acquisition of knowledge and experience in handling organisms and biological products. It will be equally important for companies to forge new and unusual alliances and to cooperate with experts specializing in a whole variety of disciplines and processes. Similarly, the need to manage the complexity resulting from an increasing digitalization of manufacturing processes (Industrie 4.0) will yield new approaches.

Exploiting the potential of biological transformation involves substantial challenges. For a start, there is the need to maintain cost competitiveness (relative to, for example, products based on fossil fuels) and to connect different sectors. Similarly, there is the challenge of overcoming of path dependencies and of reaching a social consensus on the central goals of biological transformation and the political and economic action this will require. To take advantage of the opportunities in this new market, it will take substantial innovation along with a raft of accompanying measures. These include a needs analysis, market analysis, identification of business models, impact assessments, networking activities and social dialogue.

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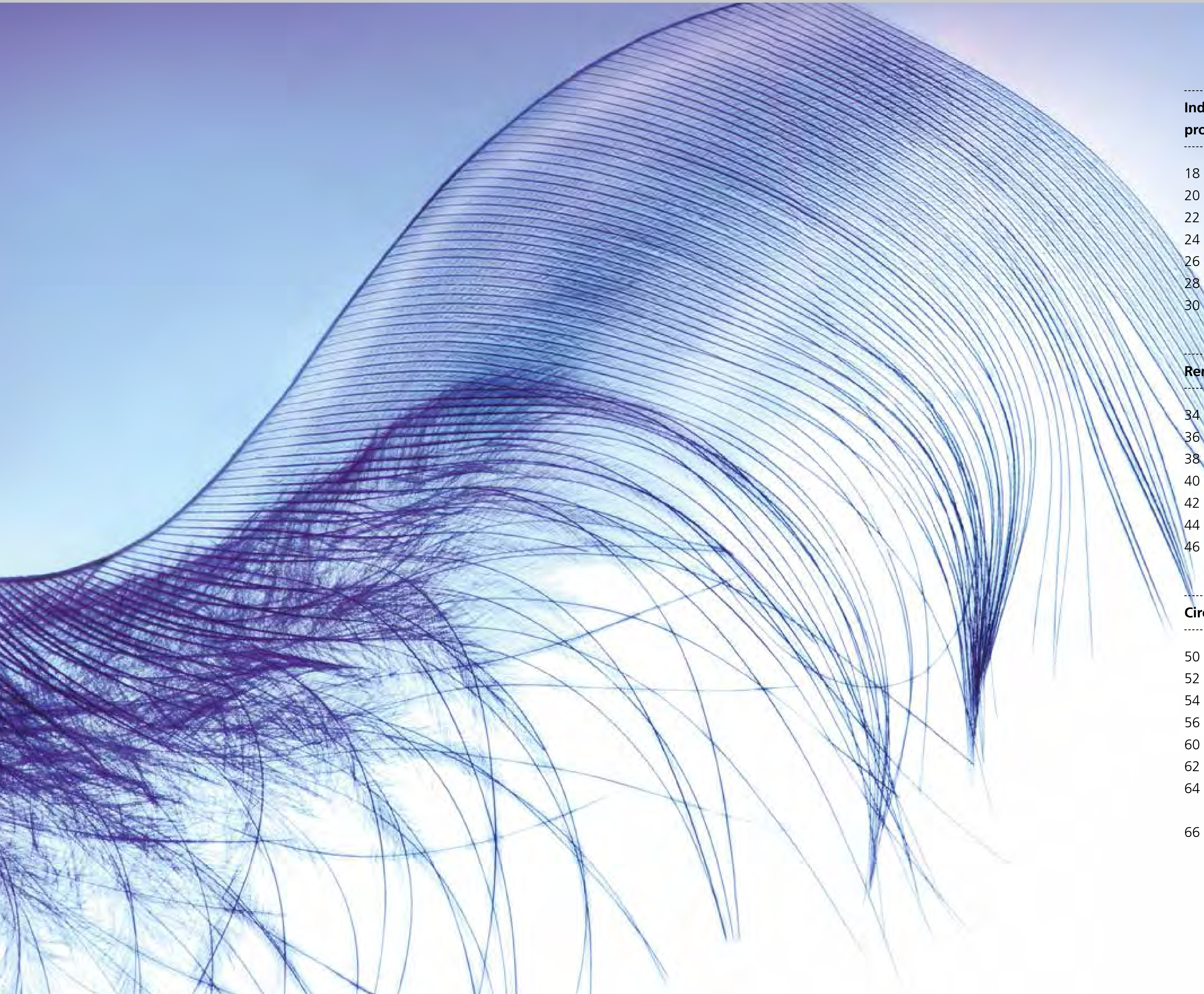


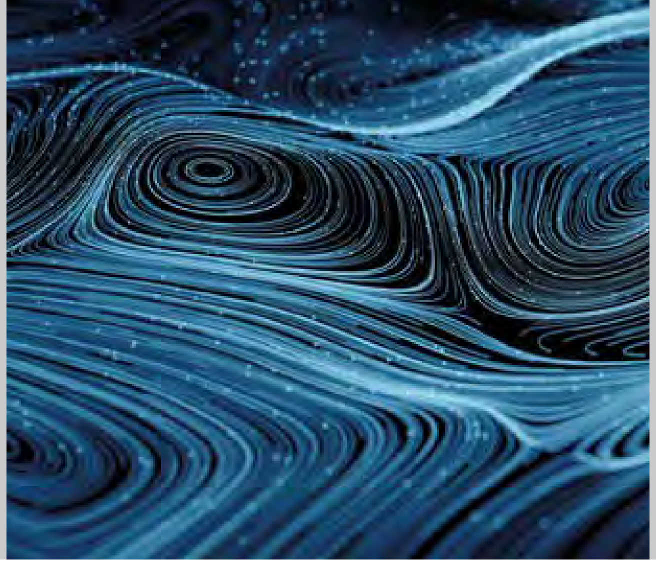
Industrialization, Innovation, Infrastructure – production processes inspired by nature

Renewable resources to ensure health and nutrition

Circular economy – sustainable consumption and climate protection

INDUSTRIALIZATION, INNOVATION, INFRASTRUCTURE – PRODUCTION PROCESSES INSPIRED BY NATURE

With raw materials becoming ever scarcer, green spaces disappearing under built structures, and the need to protect natural resources such as air, water and ecosystems growing increasingly urgent, it is time to rethink industrial production. Sooner rather than later, we will have to accustom ourselves to harvesting food and pharmaceutical ingredients from the walls of houses, abandoning animal testing altogether and manufacturing products in ultra-efficient ways.



COMPLEXITY AND BALANCE – DIGITAL ECOSYSTEMS

The squirrel living in the woods has no alternative: it has to interact with the other forest creatures – all the birds and hares and deer, to name just a few. After all, it lives in a natural ecosystem. Likewise, interaction and connected living are becoming increasingly important in industry and society, whether in the software sector or in our cities. But how can we optimize these digital ecosystems? And what requirements must they fulfill? To answer these and similar questions about digital ecosystems, we transfer approaches from natural ecosystems to artificial ones.

Natural ecosystem is a term most people are familiar with. It refers to a community of organisms of different species and their inanimate environment. Whether the ecosystem is marshland, desert, or ocean, the organisms living within it interact with one another. They come into contact with each other, mutually help each other (like bees and plants do), act as parasites on each other (like mistletoe) and eat each other. When it comes to the boundary conditions that prevail in an ecosystem, the inhabitants can influence them only to a limited degree: in a desert the ecosystem stays dry; in a marsh it stays wet. If the wind blows the seeds of a dryness-loving desert plant into a marsh, they will find unsuitable growing conditions there and will not germinate.

Digital ecosystem? A definition ...

So far, so good. But what is behind the expression "digital ecosystem"? Digital ecosystems can be defined as heterogeneous systems made up of interacting players and their environment. There are many examples. In pure software ecosystems, for instance, IT systems interact with people. Many different organizations and companies are thronging the market for software development and web services – and they are all in contact with each other via networks. Often a platform such as the Apple App Store forms the basis for such networks; other times it is a common market. If technical systems are also players, then we speak of "smart ecosystems". Just like the individual beings in a natural ecosystem, the players in a digital one seek to achieve certain goals (see graphic on the right). To this end, they must interact with other players in the digital ecosystem while also observing fixed boundary conditions they can scarcely influence.

Example: Smart grid

An example makes this definition easier to grasp: smart grids. These systems help households feed excess energy – such as that produced by solar panels – into the grid or take the energy they need from the grid. In general, the idea is to sell energy profitably and purchase it at low rates. Energy producers can actively intervene by means such as pricing. On windless days, wind generators do not supply any energy. The price of energy surges and encourages households to feed electricity into the grid or at least to consume less of it. For reasons of grid stability, however, there are also limits to this influence. For example, there is a fixed upper limit to the amount of electricity that can be carried through high-voltage power lines.

Digital ecosystems in the economy

Digital ecosystems are playing an increasingly important role in our economy, as systems that used to be separate are now being connected. In this way, we can see digital ecosystems emerging in many sectors, such as manufacturing (Industrie 4.0), medicine and the transport industry. Mastering the challenges that arise from digital ecosystems is thus crucial for

	NATURAL ECOSYSTEM	DIGITAL ECOSYSTEMS	
		Software ecosystem	Smart ecosystem[1]
Subjects	– Living organisms	– Organizations	– Organizations
Objects		– IT-systems	– IT systems – Technical systems
Value	– Potential for viable offspring	– Potential to earn money directly and indirectly and to survive as an organization	– Potential to earn money directly and indirectly and to survive as an organization
Resources	– Organisms	– Manpower – Capital – Data – Source code (software)	– Manpower – Capital – Source code (software) – Machines and other physical entities – Data (including digital twin of physical entities)
Environment	– Physical (nature)	– Digital	– Physical (nature and technology) – Digital

1 *"Smart ecosystems" are software ecosystems that bring together formerly isolated solutions into an integrated overall solution.*

many areas of the economy and of life. Interdisciplinarity in particular is tough to master. Classic software development methods and mechanical engineering design techniques are no longer sufficient; what is needed now are development methods for overall systems. On top of this, the issues involved are more complex. For example, security assessments for digital ecosystems need to evaluate how security, safety and privacy mutually influence each other. In addition, many questions can no longer be answered during development, but only once systems are running, because they change autonomously.

Taking inspiration from nature: From anthills to swarm intelligence

So as to better understand digital ecosystems and be able to optimize them, the principles of natural ecosystems are adapted to the technical ones, which has the effect of biologically transforming them. What that means in practical terms is illustrated by two research projects being undertaken at the Fraunhofer Institute for Experimental Software Engineering IESE. At the institute, researchers are combining numerous IT systems. The idea is that once combined, the systems will deliver more benefits than the sum of the individual components, leading to an optimization of business processes. This is similar to an anthill, where the combined capability of the colony far exceeds what the individual ants could achieve cumulatively. Another project is investigating the use of crowdsourcing: What requirements does a digital ecosystem need to fulfill? In this case, the intelligence of everyone involved comes together to give the ecosystem the optimal shape and structure. However, such instances of "swarm intelligence" can be as damaging as they are beneficial, and therefore their effects on the digital world have to be researched and adapted. Digital ecosystems throw up many questions that are difficult to answer. Nevertheless, understanding them better is still very much worthwhile, as the results have all kinds of benefits and uses.

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ULTRA-EFFICIENT MANUFACTURING IN THE FACTORY OF THE FUTURE

In many regions of the world, the competition for land on which to live, work and produce food is intensifying. At the same time, many raw materials – biotic and abiotic – are becoming scarcer. Both trends call for a rethink in how we go about industrial manufacturing. Against this background, the Ultra-Efficient Factory – a new approach from the Fraunhofer Institute for Manufacturing Engineering and Automation IPA – serves as a model for future manufacturing. The goal is to have highly efficient local production that consumes a minimum of materials and energy in an environment people find pleasant to live in. A circular flow of materials and energy delivers them back to the start again for a new round of production.

The adaptable, zero-emissions factory of the future safeguards an intact ecological and social environment and is cleverly integrated into its urban setting. In addition to increasing digitalization, biological transformation is also an important requirement for ultra-efficient production. Increasing the proportion of biobased materials available locally is another important goal. This is to be achieved through the application of bionic principles in product design – specifically through bionic structures, functions and surfaces coupled with innovative manufacturing technologies, such as additive methods or selective coating technologies with biogenic material components. As a result, transport costs fall while material efficiency and resilience to turbulence in the globally distributed value chain increase.

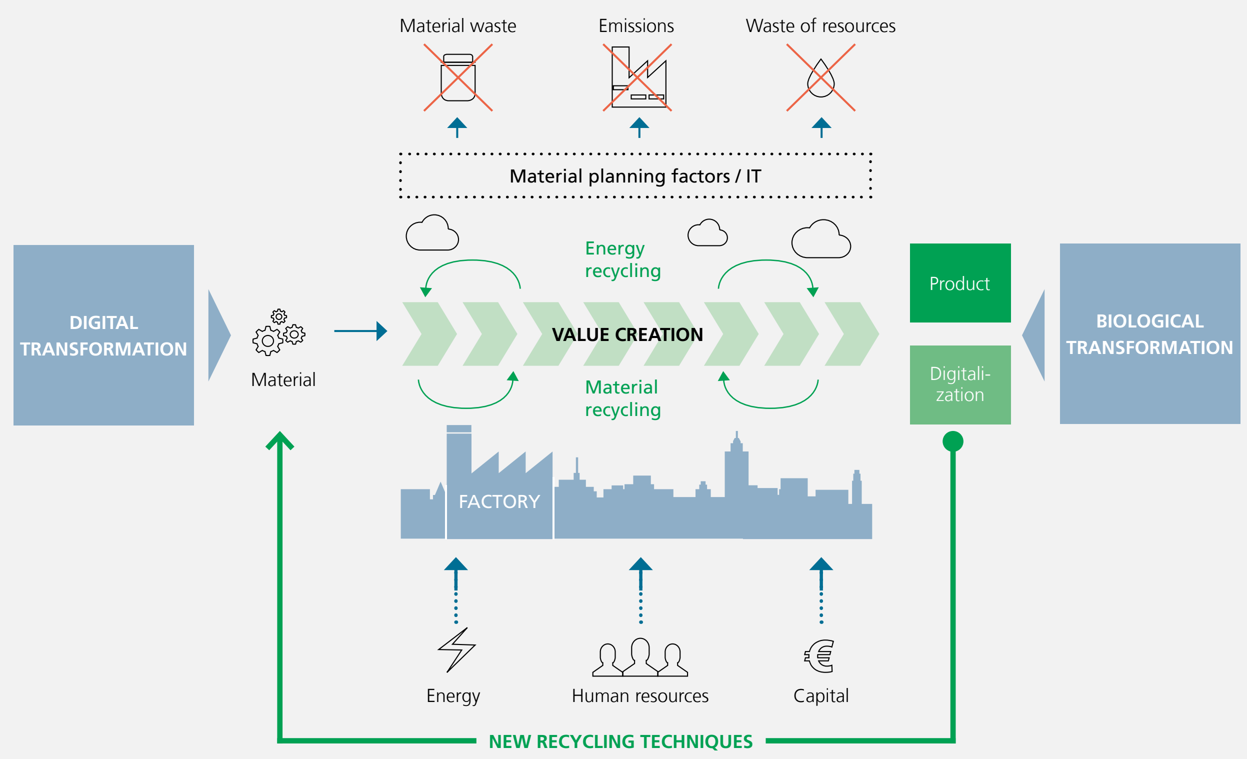
Using instead of consuming

The concept of the Ultra-Efficient Factory developed by Fraunhofer IPA is part of an energy system that is based primarily on renewable, fluctuating energy sources. Consequently, the focus is on maximizing energy flexibility as well as energy efficiency. In addition to drawing energy from traditional distribution grids, the goal is to adapt local energy generation, distribution and storage to the local geographical and material circumstances. In achieving this, there will be a role for the use of regional biological waste products as energy – i.e. biogas or biobased capacitor/fuel cell combinations – and also for a decentralized biobased energy supply from bacteria or photosynthesis at the low performance end of the scale, for powering distributed sensors for instance. Furthermore, people's needs are an important consideration in the Ultra-Efficient Factory. Technical and organizational measures based primarily on bionic principles take into account the biological needs of people in an optimal manner. Considering the physiology, health and well-being of employees is very much part of this. Innovative approaches use algorithms inspired by natural processes – such as swarm intelligence, evolution algorithms and neuronal networks – to optimize the organization of production systems. In addition to process-integrated biobased approaches, end-of-pipe solutions are also pursued in order to reduce emissions and waste and minimize environmental harm. This includes biological filter mechanisms in the form of bacteria and plants, for example, and the active use of waste and emissions in intelligent rooftop greenhouses. Production "waste" is reused in biorefineries.

Better environmental impact and new communication systems

Some of these technologies are already substantially improving environmental impacts in sectors such as food production and the process industry. Before they are ready for blanket integration into manufacturing industry, however, the existing technologies need to be further tested and adapted. Biobased management of material cycles also makes it possible to develop solutions for bonding potentially

Ultra-Efficient Factory – The future of production



dangerous substances, such as utilizing organic waste or using CO_2 as a raw material.

In addition, there is huge potential in the fusing of nano- and biotechnology in the production environment. This would involve biological or biobased material communicating with technical components. On this basis, we could develop a smart communication system that would, for example, facilitate interaction between Industrie-4.0-enabled manufacturing technologies and recyclates – that is, recyclable plastics. This would be particularly useful when dealing with recyclates with unknown chemical compositions and which are therefore difficult to recycle. In the concept of the Ultra-Efficient Factory, manufacturing is in a symbiotic relationship to its environment. This means that commuting and travel times and the environmental impact are all reduced, and that the factory is integrated aesthetically into the urban environment.

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OPTIMIZING INSTEAD OF MAXIMIZING – SAYING GOODBYE TO LINEAR THINKING

Biological transformation and digitalization determine each other. They can be understood as converging and mutually reinforcing processes which are transforming human activity in its core together with all aspects of sustainability. Biological transformation is ushering in a new way of thinking: connectivity instead of linearity; optimization instead of maximization. In short, if biological transformation and digitalization go hand in hand, this creates a Whole in Aristotle's sense of the term, which is more than the sum of its parts.

Linear thinking and the blinkered striving to maximize the results of human activity are endangering the ecosystems of our planet. If we observe the global effects of human activity and how they impact on nature and the environment, it becomes clear that many fundamental problems – on scales ranging from the supra-regional to the global – are man-made. By linear thinking and single-minded output optimization, humans have triggered massive climate changes that are threatening our very existence. Moreover, the rise of lifestyle diseases, the outbreak of epidemics, and global species extinction are the result of linear instead of connected thinking.

Single-minded optimization causes many problems

There are many examples of this blinkered focus on optimization, such as when farmers use monoculture to maximize their yield and end up overexploiting and destroying fertile land. Biodiversity is shrinking dramatically, and drinking water is becoming scarcer because it is being taken from non-renewable sources or else being contaminated with nitrates. Excessive livestock farming causes the emission of greenhouse gases, and virgin land is being broken for agricultural cultivation. Another example is the maximization of production and of consumption, which damages the climate, pollutes the air with harmful emissions such as carbon dioxide, particulates, nitrous gases, etc., and leads to the pollution, overfishing and acidification of the world's oceans. Palm oil plantations, biofuels, etc. lead to overexploitation of the world's forests. Excessive livestock farming and meat consumption also threaten our climate. Meanwhile, urban development and megacities go one step further, as they consume non-renewable resources such as sand and metals, pave over land surface and destroy ecosystems such as moors and marshland.

If we look back over broad swaths of human history, we see that linear thinking was mostly sufficient – the complexity was manageable. Supra-regional consequences were either rare or not recognized as such – the impact of people on their environment was too small. That said, historians are continually finding examples to contradict this picture of the past. For example, when our ancestors killed off the huge herds of aurochs that once roamed our continent, forests grew on what had been open pasture-land. Another example is when the Romans deforested the Mediterranean area, causing supra-regional climate change. However, the impact of human interventions today is greater by several orders of magnitude. Thanks to high-performance technology, the time periods it takes before changes take effect are radically shortened. In some cases, they can only be measured through the use of digital technology, in particular the analysis of large volumes of data – what we call "big data".

Nature is an integrally connected whole

In contrast to linear humans, nature organizes itself as an integrated and connected system. It evens things out, correcting imbalances through negative feedback, fault tolerances and hierarchically structured connectivity in intricate, overlapping control loops. One of the principles of nature is multifunctional optimization, which means that organisms or organs are always adapted, or optimized, to multiple boundary conditions simultaneously. Accordingly, each of these physiological capacities remains below the maximum level in favor of a global optimum that ensures the survival capability of the whole organism and that of its descendants.

Here we can see a major difference to technical solutions, which are maximized to attain a narrow, often time-limited main purpose – such as output – and which tend to ignore all but a handful of dependencies. Partly, this is because technical solutions are often developed on a monodisciplinary basis. Negative consequences tend to irrupt unexpectedly at different times and places because parameters and dependencies were not taken into account. Repair attempts on the fly are also generally based on monocausal thinking, which is not adequate for the requirements of joined-up problem management.

Biological transformation means connectivity

Like nature, biologically transformed systems are also characterized by connected material cycles instead of linearity – and by optimization of the overall system instead of maximizing the yield from individual processes. They reinforce all three pillars of sustainability: They are ecological in how they balance different parameters to achieve an optimized system; economical in how they use the natural principle of resource efficiency and material cycles; and social in how they safeguard basic human needs such as food, health and mobility. As such, the goals of biological transformation map well onto Maslow's hierarchy of needs.

Advances in the life sciences and information technology over the past few years have enabled us to understand and simulate complex processes in nature right down to the molecular level and adapt them for human technology. This has given people brand-new tools to help them understand their own actions, recognize the complexity of their activity in its many different strands, and modify their behavior in ways apt to optimize the overall system.

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ENHANCING THE VALUE OF CROPS FOR THE FARMER – ACTIVE SUBSTANCES FROM THE FIELD

Soil is becoming saltier, nitrogen compounds are accumulating in ground and surface water, and new pests and diseases are lowering yields. In short, agriculture is facing a host of serious problems. If things are to change, new ways of thinking are needed. Instead of relying on a few crops, the goal should be to take into account the regional conditions and grow the greatest possible variety of plants. If farmers switch over to niche crops, that will benefit not only the environment, but their bank accounts, too. After all, various active ingredients can be extracted from such crops. Moreover, if farmers process the plants on their property, they increase their product diversity and are much less vulnerable to market fluctuations. Researchers at the Fraunhofer Institute for Molecular Biology and Applied Ecology IME are investigating which niche plants are suitable for which soils and what active ingredients can be extracted from them.

Most crop fields in Germany are covered with maize, wheat or rapeseed – the "major crops" as they are known. To have a sustainable bioeconomy, however, niche plants are also important. As we move toward sustainability, we should therefore take a closer look at the conditions present on particular farmland and bring more variety back to these fields in ways adapted to the specific conditions. The main focus is on plants that have been rather neglected in recent times.

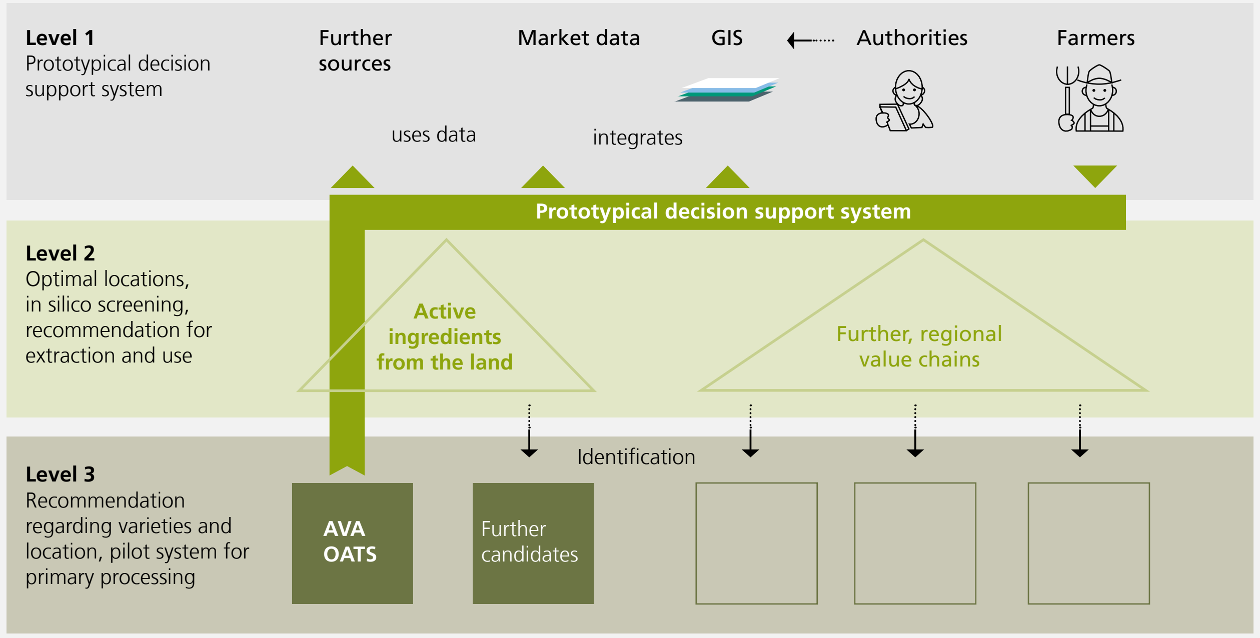
Why niche crops?

But how can we convince farmers to switch over to niche crops? Primarily, as is so often the case, through economic incentives. Technologies are currently being developed that render all parts of the plant useful. For example, grain can be used as food for humans or as animal feed; active ingredients can be obtained from leaves, stalks and husks using modern chemical analysis and in silico screening techniques (i.e. computer analyses) to identify them; the residual materials can be used as energy sources; and the ashes produced can be spread over fields as fertilizer. This is known in the sector as dual or cascading use. New cultivation systems such as contour and strip farming and adapted crop rotation are designed to ensure that different plant species interact well with each other. For farmers this means they can increase the added value generated on their farms by carrying out primary processing tasks such as drying, cleaning and extraction directly on their premises. In this way, they increase their product diversity and are less affected by market fluctuations. Furthermore, the variety of plants reduces the area for pests and diseases to attack and ensures that farmers require less pesticide and less mineral nitrogen as fertilizer.

Back to niche crops with Fraunhofer

Researchers at Fraunhofer IME are working on ways of evaluating landscape ecology site factors in detail. Are certain soils suitable for certain niche crops? What advantages and disadvantages would there be in cultivating them? At the first level, they want to provide land-specific data – regarding, for example, the location or the infrastructure – and current market data. This data will then be analyzed and prepared in a system designed specifically to support small and medium-sized farmers in their decision-making. Depending on the cultivation conditions and crop species, this will facilitate the development of new regional cluster locations, which comprise both dual production and processing and the valorization of food, energy and active ingredient crops.
At the second working level, the scientists will study the "Active ingredients from the field" value chain as an example. Essentially this will involve analyzing specific plant ingredients. What effects do they have in terms of crop protection, cosmetics or health? The researchers identify selected niche crops with interesting ingredients, describe optimum cultivation conditions and regions, and reveal their potential uses. Oats are a good example of such an "Active ingredients from the field" value chain. After all, oats are a traditional food and animal feed crop which you rarely see growing in fields any more. The focus is on so-called avenanthramides (AVA), which can be obtained from oats. How do the cultivation conditions affect the production of avenanthramides (AVA) in various oat varieties? How can the plant-derived active ingredients be used in crop protection and pharmaceutics? These are just some of the questions that Fraunhofer IME is interested in. In this way, the researchers are contributing to the development of new regional production lines – from the breeding objective to the sales market – and promoting oat cultivation with the very positive attendant consequences in terms of crop rotation. For this reason, it is important to bring the providers of different agricultural products in contact with the buyers, such as the various suppliers of processing technologies. If highly specialized processing companies are closely connected in a variety of ways with farming businesses that respond to their needs, this will greatly boost regional value creation. At the same time, a closely interwoven network of different value chains is resilient against crises, because it permits flexible adaptations.

Overall concept with the three working levels



Dr. Kristina Bette, Prof. Christoph Schäfers
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FUNGI AS PRODUCERS – DETERGENTS FROM THE FERMENTER

The Paris Climate Agreement is meant to put a check on global warming. But how is the virtually carbon-neutral economy envisioned by the agreement supposed to work? The details are still quite vague, but one thing is clear: If we can produce chemicals out of renewable raw materials – that is, by biotechnological means – then we will have taken a big step toward carbon neutrality. When we burn oil, we release the CO_2 that had been trapped inside it for millions of years into the atmosphere – something which does not happen with renewable raw materials. There are no limits to product diversity when it comes to renewable raw materials: Mother Nature has an inexhaustible store of potential production organisms. Researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB investigate the biotechnological manufacture of biosurfactants, which are used as detergents, emulsifiers, cosmetic and pharmaceutical active ingredients, and plant protection agents. To this end, they use fungi – more precisely, yeasts, smuts and molds.

If you find a blue-green layer of mold covering your bread, fruit or some other food, you'll quite rightly throw it in the garbage. After all, these fungi are harmful to your health. In the laboratories of Fraunhofer IGB in Stuttgart, however, the researchers covet a wide variety of different fungi – including molds (specifically molds in the genus Aspergillus), smuts (Ustilaginomycotina) and of course yeasts. This is because the fungi can be used to manufacture substances in a carbon-neutral manner – bringing implementation of the Paris Agreement resolutions one step closer. And it is urgent that we do this, because we are still stuck in the starting blocks when it comes to a carbon-neutral economy.

Although fungi are just one of the possible ways of producing chemicals on the basis of renewable raw materials, they are a very promising avenue to pursue. A big advantage they offer is that some fungi – unlike most micro-organisms – are able to break down sugar rings containing five-carbon rings. As such, the fungus is able to utilize xylose, a major component of wood – and therefore a raw material that people do not use as food. Therefore, the food versus fuel dilemma does not arise: we do not have to choose between using land for food or for raw materials to be turned into chemicals or fuel.

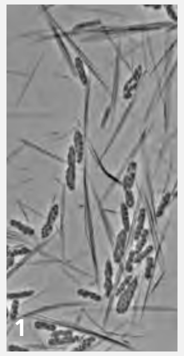
Manufacturing biosurfactants – from renewable raw materials

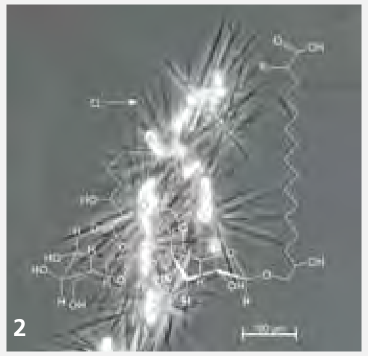
Smuts can be used to manufacture biosurfactants, which can be used in turn to produce detergents, emulsifiers, cosmetic and pharmaceutical active ingredients, and pesticides. Meanwhile, molds can be used to manufacture malic acid, the market for which is growing rapidly. Among other uses, it gives products such as jams and juices their sour taste and improves the shelf life of baked goods. It can also be used as a building block for biobased polyesters. The production process for biosurfactants and malic acid is similar to the brewing of beer. Micro-organisms are used to ferment sugars or vegetable oils, transforming them in the process. When making beer, it is yeasts that transform the malt sugar in the barley. Although fermentation like this works very well on a

laboratory scale, improvements are still needed for industrial production. There is scope for improvement in the yields that can be obtained from fermentation and also in the product composition of the biosurfactants. In addition, yeast fungi produce interesting molecules, which can be used for synthesizing plastics such as polyesters. Chemically, however, these molecules are difficult to manufacture. Fraunhofer IGB has already managed to establish a technique for the manufacture of dicarboxylic acids with the yeast Candida viswanathii, successfully producing octadecanoic dicarboxylic acid out of oleic acid in commercially significant concentrations by means of fermentation. To be able to manufacture biobased chemicals such as the abovementioned surfactants, food components and plastics in sufficient quantities for use in the various sectors, manufacturing techniques have to be transferred to an industrial scale. At present, the worldwide production volume of surfactants is around 18 million metric tons per year. Scaling up the processes from kilograms to tons involves a great deal of engineering and computing. How can you find the perfect balance of mineral salt media? What are the best feeding strategies? These questions can be answered on a small scale at Fraunhofer IGB.

Scaling up:
Fraunhofer pilot plant and biorefinery

Subsequently, these processes are implemented on a large scale at facilities such as the Fraunhofer Center for Chemical-Biotechnological Processes CBP, where the pilot plant permits upscaling up to a volume of ten cubic meters. Such huge volumes of biobased chemicals require an enormous amount of raw materials; after all, the fungi need something to feed on. This is where lignocellulose-based sugar solutions, which also contain the abovementioned xylose, come in. These "wood sugars" are added to the growth medium, and can be obtained directly in the Fraunhofer CBP lignocellulose biorefinery.





1 Cells of the smut fungus Ustilago maydis at a single cell stage.
2 Cellobiose lipids as needle-shaped crystals (with structural formula).

From the original idea to an application-ready technique

Fraunhofer IGB and Fraunhofer CBP are thus committed to obtaining chemicals from the widest variety of fungi and to optimizing and scaling the requisite processes. In achieving this objective, Fraunhofer IGB specializes in selecting and optimizing the micro-organisms, developing suitable conversion processes on a laboratory scale and transferring these techniques to a pilot scale using mathematical-technical methods. Meanwhile, Fraunhofer CBP is responsible for implementing production on a large scale. In other words: Fraunhofer IGB and Fraunhofer CBP have all the capabilities required to take a good idea and create application-ready techniques in the laboratory – which in turn generate enough of the required substance to manufacture products for the market.

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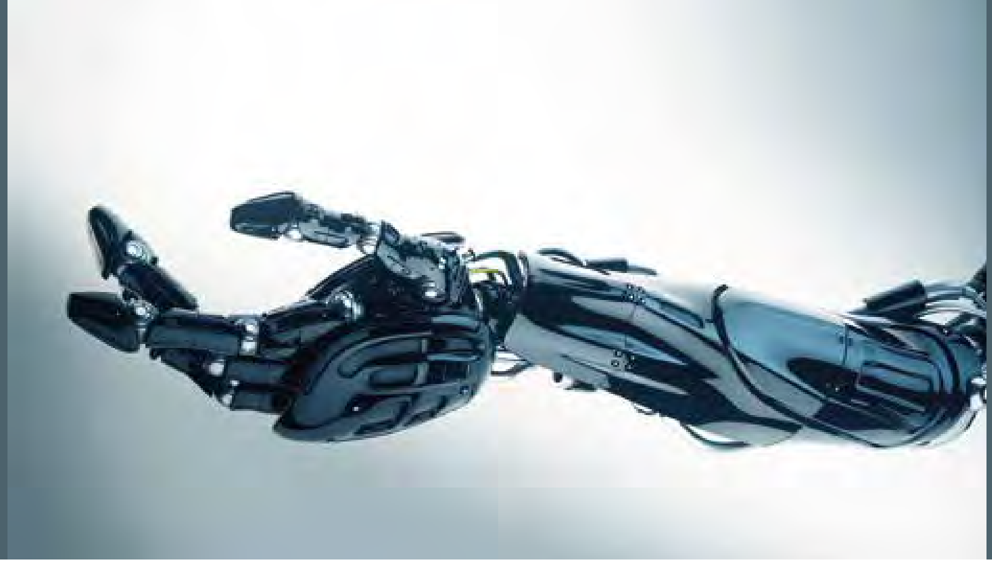
Fraunhofer IGB, **www.igb.fraunhofer.de/en.html**
www.cbp.fraunhofer.de/en.html



COMBINING NATURE AND TECHNOLOGY – BIOLOGICAL-TECHNICAL INTERFACES

If we want to communicate from person to person, we use language. But if we want to communicate with technological devices, we need suitable interfaces. Before now, this has effectively meant that technology has defined the way and humans have adapted accordingly. This is set to change in the future, when machines and devices will learn to respond to the mental states of their users.
What are the preferences and intentions of the user? Are they irritated or even out of their depth? Neuroadaptive interfaces are able to record these states using neurophysiological sensors. Researchers at the Fraunhofer Institute for Industrial Engineering IAO are working on ways of using these interfaces to render technology sensitive to user needs.

When the sun peeps out from behind the clouds and makes it suddenly brighter, modern computer screens adjust their brightness automatically. Park assist systems warn drivers if they get too close to an obstacle while maneuvering into a space. And in manufacturing environments, industrial robots work together side by side. As the examples above attest, technical systems are already able to recognize various environmental conditions, adapt to different situations and – increasingly as technology advances – operate flexibly and autonomously. This is not enough, however, if we want smart technology to interact with people in an optimal manner that yields maximum benefits – it needs to go beyond recording environmental conditions to also register the preferences and intentions of the user. People will only perceive technology as cooperative and "human-friendly" – and accept it as an assistant or even as a partner – when it is sensitive and intuitive and responds promptly to their needs. What this means is that the technology should continuously recognize and take into account mental states, such as the emotions, changes in attentiveness levels, stress and cognitive exertion of the user. Wherever possible it should register this information right at the source – namely, the brain.
Failing that, it should measure the states where they manifest themselves with the greatest intensity, such as heart activity, peripheral muscle tension and eye movement. If the technology recognizes people's mental states in this direct manner, it can adjust more precisely to them – without the need for additional interaction effort on the part of the user.

Solution: Developing neuroadaptive interfaces

Neurotechnological interfaces make this possible. Based on activation patterns in the brain or the dynamics of eye movements or of excitations in the peripheral cardiovascular system, the interfaces make inferences about mental and emotional states. This creates a new field of research: neuroadaptive human-machine interfaces that work in a human-technology control loop, recording neurophysiological data in real time, interpreting the user's states from it, and adapting the system's behavior accordingly. But how do we obtain the requisite data? Brain-computer interfaces (BCIs) are a particularly promising approach, while electroencephalography (EEG) is a useful measurement technique that directly records the electrical activity of synchronized neuron populations in the cortex. Another option is functional near-infrared spectroscopy (fNIRS), an optical technique that measures metabolic processes which are related to these neural patterns (EEG).

Where can neuroadaptive interfaces be used?

To date, neuroadaptive interfaces have been used primarily for medical applications – for example, to communicate with severely paralyzed patients. But they also hold great potential outside the medical sphere. We could have driver assistance systems, for instance, that respond to the attentiveness, the mental exertion and the alertness of the driver. Or we could have personalized assistance systems for smart living that would adapt contents as well as display and interaction mechanisms to individual needs. Another technology that would enter the realms of possibility is collaborative robots, which would respond sensitively to user intentions, emotions and attentiveness.

Fraunhofer at the cutting edge of research

As a research field, neuroadaptive interfaces is still in its infancy. Interdisciplinary cooperation is required if applied research is to advance and if the results are to be transferred to scientific practice. Researchers at Fraunhofer IAO are working on freeing the recorded data from interference and motion artifacts and classifying the states of the user continuously and without time lags. How can the system behavior – that is, the response of the technical system to the detected user states – be shaped and controlled? This is also something that Fraunhofer IAO scientists are researching. Because if neuroadaptive interfaces are used in the non-medical sphere, they must be systematically aligned with the needs and ethical values of their users and of society.

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Biodegradable electronics for active implants

Electronic components that completely dissolve once they have completed their work? That may sound like science fiction, but it has already been accomplished in the laboratory. It goes by the name of biodegradable electronics, and it not only reduces ecological footprints, but also opens the door to innovative applications in a variety of sectors, such as medical implants, biotechnology and the food industry. In Fraunhofer's in-house "bioElektron" project, researchers at the Fraunhofer Institutes FEP, ENAS, IBMT, ISC and the Project Group for Materials Recycling and Resource Strategies at Fraunhofer ISC are developing important components for these electronic implants that will be able to biodegrade in the body in the future. These include conductor paths, electrode contacts for electrical signal derivation or stimulation, thin-film transistors and circuits, barrier coatings to keep out water and gas, and electrical isolation layers – all biodegradable.

ALGAE VERSATILITY IS THE KEY TO SUSTAINABLE CHEMICAL PRODUCTION

Microalgae are unique: Basically, all they need is sun, water and carbon dioxide to grow and generate biomass. The one-cell organisms use sunlight more efficiently than flowers, trees and grasses. These qualities make algae perfect for producing biobased materials. It is no wonder, then, that they are currently conquering new, growing markets – for example in the food and pharma industries.

People and many animals can go without food for days and even weeks, provided that they have enough water. In the long term, however, no living creature can survive without food. It is a similar story in the plant kingdom: trees, flowers and grasses need light and soil with nutrients in order to grow and thrive. But microalgae are different. They build up biomass in freshwater or seawater out of sun, water, carbon dioxide and anorganic nutrients, making them very interesting as a biomass source.

Microalgae as a new raw materials source

The frugal nature of microalgae is far from the only advantage they have to offer. They only need little input to give good biomass yields: microalgae produce up to five times more biomass than land plants per area and time. In addition, they do not need fields and pastures in order to grow – marine microalgae, for example, thrive in seawater, as their name indicates. Moreover, their harvests are not tied to specific seasons, so they can be cultivated all year round. They are homogeneous – in other words, every cell is identical and not differentiated according to leaf, stem and root – and free from lignocellulose. As lignocellulose content entails higher energy input for biomass decomposition and processing, this means that microalgae are easier to extract. A further advantage is that exhaust gases containing carbon dioxide can be used for their cultivation.

Microalgae have got what it takes

We should note, however, that microalgae are by no means all alike. It is estimated that there are more than 100,000 species of algae, which offer great potential as sources of various substances such as carotenoids, phytosterols and beta-glucans. These ingredients appear in concentrations about ten times higher than in land plants. The composition of algae biomass can be controlled by means of targeted cultivation conditions. One thing that all microalgae have in common is that they contain a lot of proteins – more than 60 percent of their dry weight in fact. Depending on culture conditions, however, lipids can also account for up to 60 percent of the cell dry weight. If the conditions are set in such a way that algae growth is only moderate, many of them also produce oil or carbohydrates as reserves. Other valuable substances such as vitamins and long-chain polyunsaturated fatty acids can also be extracted from the algae. Among other applications, the fatty acids are used for health and nutrition or as colorants.

Using algae to produce valuable substances in photobioreactors

None of this is particularly easy, however, as algae need special production conditions. Effectively this means closed photobioreactors. The limiting factor here is light. If the algae cultures are dense, they cast shadows over each other. Consequently, the algae have to be efficiently mixed in a targeted manner, so that all of them get some of the light on the reactor surface. To this end, researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB developed a photobioreactor for algae production in the laboratory and outdoors, which was subsequently commercialized by Subitec GmbH, a spin-off of Fraunhofer IGB. There are some substances that algae only develop when nutrients are scarce. The best-known examples of this are fats and polysaccharides, and also carotenoids such as beta-carotene. Nutrient limitation is carried out by the researchers at Fraunhofer IGB in a second production stage. This two-stage cultivation presents particular challenges, as both stages have to be optimized and adapted to each other. In a third stage, the researchers process the biomass to achieve defined qualities according to the substances that are to be extracted from it.

Process chain for obtaining food ingredients from algae

Strain selection	Production	Cell disruption	Cascade extraction		Products
55 % proteins 5 % omega-3 fatty acid EPA > 3 % carotenoids	Process development in laboratory Scale outdoors	Mechanical cell disruption High-pressure homogenizer Stirred media mill	Pressurized liquid extraction (PLE)	Extraction using supercritical fluids (SCF)	Fucoxanthin EPA Biomass with proteins

Customized algae production on an industrial scale

To be able to commercially exploit the wide spectrum of algal ingredients, we need customized algae production with high process stability on an industrial scale. For this purpose, Fraunhofer IGB has developed processes in the laboratory and transferred them to outdoor production. Success was not long in coming: The concentrations of the omega-3 fatty acid EPA and the carotenoid fucoxanthin were the highest yet published for a long-term production operation. In this way, it is possible to produce naturally occurring carotenoids, omega-3 fatty acids, proteins and other healthy ingredients in a targeted process. These natural extracts will then command substantially higher prices on the market than their synthetically manufactured equivalents.

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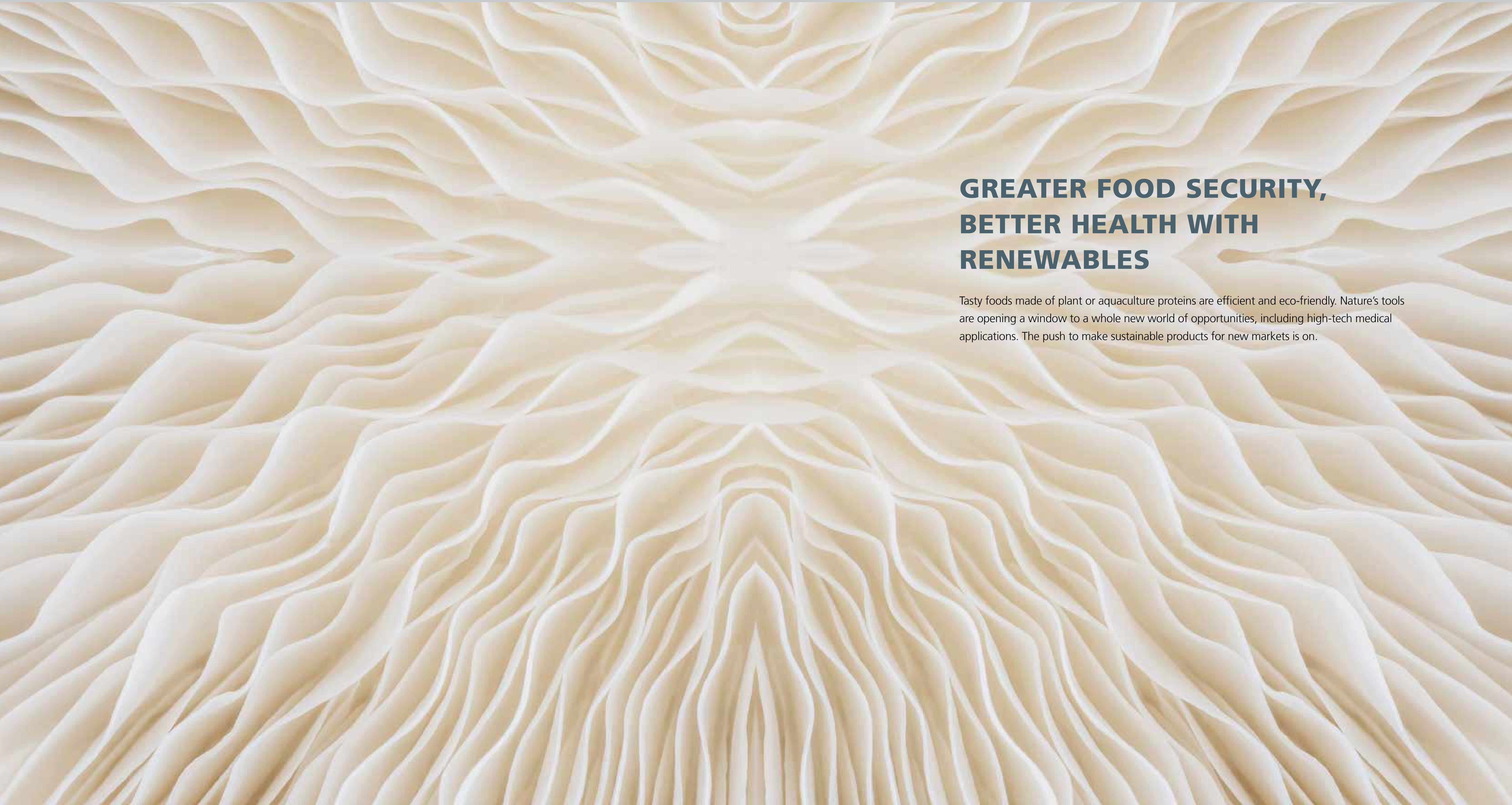
Fraunhofer IGB, **www.igb.fraunhofer.de/en.html**

1 Outdoor facility at Fraunhofer CBP for microalgae production with 180 L-FPA reactors.



GREATER FOOD SECURITY, BETTER HEALTH WITH RENEWABLES

Tasty foods made of plant or aquaculture proteins are efficient and eco-friendly. Nature's tools are opening a window to a whole new world of opportunities, including high-tech medical applications. The push to make sustainable products for new markets is on.

HIGH-TECH SILK – OUT OF THE LAB AND INTO MEDICAL APPLICATIONS

The gossamer strands of a spider's web may look fragile, but appearances deceive. On a scaled comparison, these fibers are stronger than steel cables, yet more elastic than nylon. Silk produced by the lacewing also exhibits superlative properties, particularly its tremendous flexural strength. The industry has taken a shine to these new materials, for example, lightweight polymers for use in transportation and biocompatible silk coatings for medical implants. Having discovered the silk protein of the green lacewing as a source for a new type of biofiber, researchers at the Fraunhofer Institute for Applied Polymer Research IAP are now seeking to mass manufacture this biotech in the lab. A dedicated research unit department set up by Fraunhofer IAP two years ago is also investigating other proteins, some of which could serve as filters to separate chiral materials.

The silk spun by spiders is a fascinating material. Its fibers are more elastic than nylon, yet sturdier than steel cables, relatively speaking. They can absorb three times more energy than synthetic Kevlar fibers before a strand tears. This remarkable tensile strength is attributable to the material's protein structures. Other silks also exhibit outstanding properties. People have been tapping the cocoons of the mulberry silk moth, a yellowish grey nocturnal butterfly, for 5000 years. This silk still figures prominently in high-performance materials such as parachute canopies. The enormous tensile and flexural strength of the lacewing's silk is no less impressive. It has to be strong by nature, as green lacewings deposit their eggs on the underside of leaves, perching their offspring on the tip of silk filaments to keep them safe from ground-borne predators. These eggs stalks are only 15 micrometers thick, yet they easily hold the offspring's weight.

Silk for high-performance fibers and films

It is no great surprise, then, that these fine protein fibers also harbor great promise for industrial applications. Spider silk could be made to serve many medical purposes, for example, for bandages, surgical sutures, and cartilage and tendon implants. Other potential applications include cosmetics, paper products and adhesives. The rigid fibers of green lacewing silk would seem an excellent prospect for lightweight designs, where they could replace the glass fibers in composite materials. This would certainly simplify recycling. While conventional glass fiber composites leave glass fiber residue when incinerated, products made with rigid lacewing silk proteins can be composted or incinerated in a CO_2-neutral way that leaves no residue.

Man-made lacewing silk

Attempts to manufacture the silk proteins of the green lacewing in sufficient quantity and purity are yet to succeed. The researchers at Fraunhofer IAP aim to change that. In a joint research project with AMSilk GmbH, they have conscripted bacteria in an attempt to produce large quantities of green lacewing silk proteins in a biotechnological process. The University of Bayreuth's Department of Biomaterials did the molecular groundwork, constructing a gene sequence that empowers bacteria to produce the silk protein. Fraunhofer IAP is fine-tuning the manufacturing process with an eye to producing this silk protein at low cost in industrial quantities. With the benefit of biotech and polymer research capabilities housed under the same roof, Fraunhofer IAP has the assets needed to produce lacewing silk fibers. This includes a pilot wet and melt spinning plant that can process both solutions and molten material to deliver technical fibers on a near-industrial scale.

Membranes to separate mirror-image molecules

The researchers at Fraunhofer IAP are not only interested in spider silk; they are also investigating other proteins. Amino acids, the building blocks of proteins, and other small molecules often present as chiral combinations.
This means that the variants consist of the same atoms, arranged differently in a mirror image that does not exhibit the same chemical properties as its chiral twin. For example, the two variants may not have the same fragrance. Separating these mirror-image twins is a technically demanding task, and quite expensive, depending on the substance. Fraunhofer IAP and RWTH Aachen University teamed up to develop a new breed of membrane that can readily separate these combinations by filtration. To this end, the researchers slotted natural protein channels that are just three to four nanometers wide into the ultra-thin polymer membranes. These channels are equipped with functional groups so that just one of the two mirror images can pass through the channel. The application potential for these membranes is vast. With more than half of today's active pharmaceutical ingredients made up of these mirror-image twins, there is a lot of purification to be done

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ALL FLAVOR, NO REMORSE – SUSTAINABLE YET SCRUMPTIOUS VEGETABLE PROTEIN

Our planet's population is on the rise. There are 7.5 billion of us today and the forecast calls for the headcount to reach 9.7 billion by 2050. One of the great challenges of our age is to provide safe, high-quality food to all these people when resources such as arable land, water and fertilizers are finite. Meat, eggs, milk and fish still figure prominently in today's diet, but sustainable plant-based alternatives will soon be very much in demand. Meat production is hardly efficient, given the vast quantities of nutrients consumed along the way. In the interests of global food security, we will have to find protein-rich, nutritious foods that are tasty alternatives to meat. That is exactly what researchers at the Fraunhofer Institute for Process Engineering and Packaging IVV are striving to do.

These days, when people fire up the barbecue on a hot summer's day, many also treat vegetarian or vegan family members and friends to a selection of vegetables. Even so, a lawn party without barbecued beef or Christmas dinner without roast turkey is unthinkable for many of us. That will have to change eventually. Livestock has to eat three to ten kilograms of vegetable feed such as cereals or soya to produce one kilogram of animal protein. Consuming meat is anything but eco-friendly. Animal husbandry requires a great deal of water, energy and arable land, and livestock's digestive systems produce a lot of greenhouse gases that end up in the atmosphere. More than 60 percent of the vegetables, cereals and the like cultivated in fields end up in feed troughs for the livestock reared to satisfy humankind's big appetite for meat. A growing population and rising prosperity is driving the consumption of meat, eggs, milk and fish; the Food and Agriculture Organization FAO of the United Nations (FAO) expects it to increase 70 percent by 2050. It does not take a degree in higher math to figure that this rate of consumption is unsustainable.

Even so, meat-lovers' fears of a vegan food police are unfounded; no one will be inspecting barbecues for illicit non-veggie sausages any time soon. However, meat consumption would have to be halved from the current 88 kilograms per capita per year to at least hold Germany's total annual meat production to the current level. That is not going to happen without a tasty plant-based alternative. Consumers snubbed meat alternatives such as tofu mainly because of the products' texture. To change that, scientists must come up with quality plant-based alternatives with the fibrous consistency of meat.

1

Cutlets and roasts made of plant fibers

Researchers are striving to develop succulent vegetarian alternatives that are tasty, juicy and chewy in a way that mimics the texture of meat. Fraunhofer IVV is devising and characterizing protein-rich recipes and investigating their behavior in the production process. This is done with a special extrusion process that allows ingredients to be mixed, kneaded and rapidly heated under pressure all at once, and then cooled in a special nozzle. When the source material is fairly dry, this produces granules that serve as the base material for foods much like minced meat. When source materials containing a lot of water are boiled and then slowly cooled, this produces fibrous protein structures with a meat-like grain and consistency. This protein may then be processed into products with the familiar texture of cutlets, roasts and steaks.

Lupin proteins and fibers for vegan cold cuts

Fraunhofer IVV joined forces with ten companies and three other research institutes in the PlantsProFood alliance to produce food ingredients from the seeds of native blue lupin beans. Their benefits are many: Lupin fibers and proteins' flavor is neutral, they exhibit very good functional properties, and they are nutritious. And that makes them an excellent base material for vegan cold cuts and spreads. With this in mind, the researchers set out to develop a suitable extraction process and recipes. Their efforts met with success: The manufactured products look and feel like the real thing, and they spread and cut well. Even their color is very much like that of conventional products.

What's in it for the industry?

The food industry is the most important sector of Europe's manufacturing business; around 40 percent of revenues in Germany are generated by businesses that make, process and sell animal products. Potential bottlenecks in the commodities supply line and rising prices for animal foodstuffs pose major risks for this industry. New business prospects will emerge for the industry as companies begin to embrace innovative products made of plant proteins. Recent studies show that vegan products are going mainstream. Multinationals dominate this market. If the research efforts outlined above enable small and medium-sized enterprises in Germany to offer tasty vegan products, these companies could grow their market shares at home and abroad and increase their competitive edge.

Dr. Peter Eisner
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1 *An extruder at Fraunhofer IVV.*

A MEDICAL (R)EVOLUTION – BIOLOGICAL THERAPIES AND IMPLANTS

Change is afoot in the world of commerce; principles of nature are making inroads into humankind's factories. A term has been coined to describe this ingress driven by advances in life sciences, and especially in biotech – biologization. This word covers quite a lot of ground. Biological processes that take place in cells and tissues of natural organisms help scientists develop unprecedented medical therapies. And artificial neural networks could help improve manufacturing processes.

Like humans who have evolved and adapted over time, biological systems have also been subjected to nature's efforts towards perfection for millions of years. Although we believe we understand some of the basic principles at work here, the very complex processes that optimize biological systems such as the human brain or highly selective immune systems are difficult to fathom. If we were to harness the power of such evolutionary processes, we could put it to good use for medical applications, as the following Fraunhofer research case studies go to show.

Regenerative medicine: From wound healing to herbal medicine

Researchers are pursuing remarkably diverse avenues to develop new therapies. Some are technical, such as unprecedented radiation therapies. Others are mechanical, like ultra advanced prostheses for joints and extremities. Still others are biological; these new procedures are based on biological functions executed in the cells and tissues of natural organisms. Recent methodological breakthroughs in gene and cell therapy and tissue engineering have given rise to these advanced therapies. The term regenerative medicine has been coined to describe the intended goal, which is to restore healthy functions with biological means. One variant is to deploy enzymes to strip an organ of its cells while preserving its structure so it can be colonized with the patient's body cells. Experienced biologists at the Fraunhofer Institute for Chemical Technology ICT are taking this approach to keep vessels alive and allow organs to be grown outside the body. The human immune system not only protects us from infections; it also inhibits the proliferation of cancer cells. Multinational pharmaceuticals and biotech companies have tasked the Fraunhofer Institute for Cell Therapy and Immunology IZI in Leipzig to develop clinical trial preparations for new cell therapies. These treatments reinforce and control the healthy immune system's natural activation strategies in very specific ways. Genetically engineered receptors are inserted into the patient's immune cells to this end. These antigen receptors detect the surface characteristics of cancer cells. When the altered immune cells are injected back into the patient's body, they destroy the mutated cancer cells very effectively. Researchers at the Fraunhofer Institute for Marine Biotechnology and Cell Technology EMB are devoting their efforts to yet another field, wound healing.
They have developed an outpatient procedure to retrieve stem cells from the sweat glands of patients. When these stem cells are applied to the wound, they form skin cells that manage the healing process. The patient's body does not reject its own cells when they are reintroduced. How do plant-derived agents affect human health and the clinical expression of diseases? Healers have been seeking answers to this question for centuries. There is a treasure-trove of knowledge out there, but the nuggets of wisdom are scattered far and wide. Much has yet to be investigated by scientists. A research group at Fraunhofer IZI teamed up with scientists from the Makerere University in Uganda to investigate extracts from East African plants used by traditional healers, for example, to treat the emaciation brought on by cancer. These active substances could also significantly reduce the use of antibiotics in factory farming.

Artificial neural networks inspired by the nervous system's connectivity

Biological models can also teach us a lot about networks. After all, the neurons in our nervous system do not fire at random; they are connected to serve a specific purpose. It is due to that connectivity that scientists call this a neural network. Researchers engaged in computer science, information technology and robotics replicate these structures in artificial neural networks, sometimes in modified forms. These neural networks can serve many applications. One example from the Fraunhofer Institute for Production Technology IPT is milling. Milling machines often direct all their energy to a short stretch of the blade, where it then wears very fast. Researchers engaged in the OptiWear project developed an artificial neural network to analyze the sections of the blade expected to endure particularly high levels of wear. The network learns to precisely predict tool wear during milling; it then adjusts the blade's path to distribute the wear over a large area of the cutting edge. In the field of computational neurosciences, neural networks like this are used to gain deeper insight into the human brain and develop better medical treatment options. The Federal Ministry of Education and Research (BMBF) set up the Bernstein Network as part of the government's high-tech strategy; it now encompasses over 200 working groups at more than 25 locations throughout Germany. The former Fraunhofer Institute for Computer Architecture and Software Technology FIRST was one of the working groups looking into intelligent data analysis; the Neurolab at the Fraunhofer Institute for Industrial Engineering IAO was also involved. Scientists at the Neurolab deal are seeking answers to questions such as: Are users comfortable with or stressed out by technology? How high is the cognitive load at the workplace? What can we do to design tech that creates a positive user experience?

Designing ecological processes to make biological products

Ever since the Industrial Revolution mechanized manufacturing, people have been extracting more and more products from ecosystems every year. Human interference has thrown off the biological balance. If we want to redress these imbalances, we must first understand biological systems and then simulate their material cycles and causal chains in modern manufacturing.
This is exactly what the land-based Integrated Multi-Trophic Aquaculture (IMTA) system developed by researchers at the Fraunhofer EMB is here to do. An IMTA replicates various levels of the ecosystem to simultaneously cultivate fish, mussels, algae and the like. This has multiple benefits. The water is reused several times; biological waste is repurposed as a food source. And the aqua-farmer can bring several products to market at once to further boost these recirculation systems' efficiency.

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1 *Charting neurophysiological data.*

LOCAL, SMART, URBAN – THE FUTURE OF FOOD PRODUCTION

Apples from New Zealand, tomatoes from Spain – we have the global division of labor to thank for our fresh-food supply chain. However, the amount of arable land that can be managed sustainably is finite on this planet, and it is in particularly short supply amid the urban sprawl near megacities. This is why urban agriculture is lifting off into the third dimension with vertical farming in multi-story buildings. On the rise in urban settings around the world, vertical farms are an attempt to use energy and resources more efficiently, for example, by making the most of material cycles. Active pharmaceutical ingredients sourced from plants may also become a vertical success story. Fraunhofer researchers are certainly working on solutions to make that happen.

Downtown vegetable farming? Many people are warming to the idea of growing vegetables and herbs sold in the supermarket on the roofs or facades of neighboring office buildings rather than trucking or shipping them in from afar. Ideally, these foods will be harvested in the morning to be offered fresh off the shelves with the flavors and vitamins intact and the transportation costs negligible.

Vegetable farming in the city, for the city

With time, the importance of locally sourced food will rise. On one hand, the world's population is growing; experts fear that a food shortage could occur as early as 2050. On the other, customers are increasingly demanding local products. But there is not enough arable land in and around metropolitan regions and megacities to meet today's demand for local fruit, vegetables and cereals. If we want tomorrow's food supply chain to be sustainable we will have to adopt more innovative farming systems. Urban farming, where vegetables are cultivated in rooftop greenhouses, is one approach; vertical farming, where vertical plants and vegetables grow on facades or over several floors, is another. Both are hot topics in many countries. Everything plants need to grow – light, water, heat and nutrients – is available in urban areas. The savings potential is considerable, especially with smart systems that link (residual) material and energy flows with the building's infrastructure.

There is plenty of room for urban farms. The space available on the flat roofs of Germany's non-residential buildings alone comes to more than a trillion square meters. About a third of it can be used to cultivate plants in rooftop greenhouses. This could bind around 3.5 million metric tons or carbon a year, which is roughly ten percent of the CO_2 emitted annually by industrial enterprises in Germany. It all sounds very simple on paper, but urban agriculture's production speed, costs and scalability will have to be optimized for maximum economic efficiency. One intriguing way of doing this is to grow plants and make high-quality products with their pharmaceutically active ingredients, as this creates a lot more value per square meter of cultivated area.

Urban farming:
Fraunhofer UMSICHT's inFarming® concept

Researchers at the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT are busy developing the inFarming® concept, a set of building-integrated agricultural methods, and are optimizing the technologies and farming methods needed to do this. This concept calls for a vegetable greenhouse to be built on the flat roof of a five-story office building. Moss will cover the entire facade to bind particulate matter. This system uses and treats water in closed cycles. It taps waste as a source of nutrients or for energy to light and heat the greenhouse. UMSICHT researchers are jointly developing an inFarming® prototype with their US partner BrightFarm Systems at the Fraunhofer inHaus Center in Duisburg.
The first application center for building-integrated inFarming® horticulture is going up now in Oberhausen with around 1200 square meters space.

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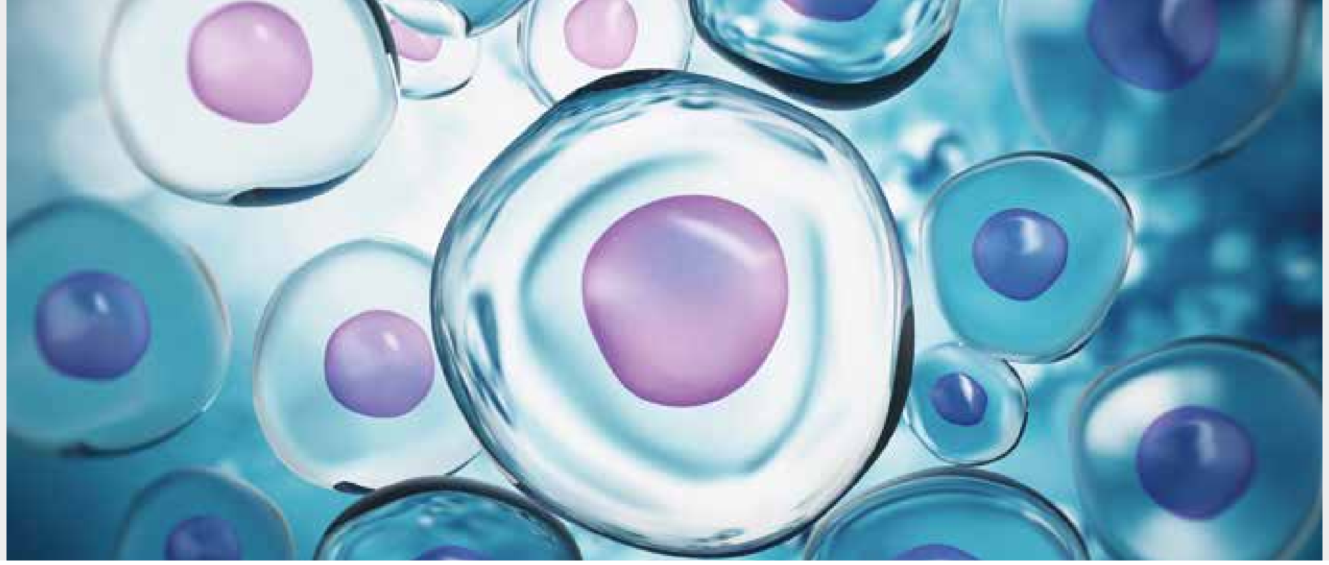
Next-generation vertical farming at Fraunhofer IME

What will it take to make vertical farming work? Experts from the Fraunhofer Institute for Molecular Biology and Applied Ecology IME teamed up with their counterparts at the Fraunhofer Institute for Production Technology IPT to answer this question. An automated plant production system with a central vertical farming unit is serving as their high-tech test field.
This vertical farming unit consists of eight levels with an effective cultivation area of some 550 square meters. It yields up to 100 kilos of plant biomass or up to 10,000 plants per week depending on the species and production mode. An automated logistics system is in place to sow, cultivate and harvest plants continuously or in batches. Active ingredients may be extracted from the plant material and fed into two 100-liter homogenizers for purification. Integrated scanners from the Fraunhofer Institute for Integrated Circuits IIS monitor various parameters throughout the plant's lifecycle to track how they grow and flourish, providing the information needed for assuring quality and assessing horticultural methods. This new vertical farming system at Fraunhofer IME will enable researchers to evaluate and develop innovative, sustainable concepts under real-world conditions to make a valuable contribution to tomorrow's organic-based production economy.

1 *Cultivation of tobacco plants.*
2 *Winter wheat in the vertical farming prototype under LED lighting in a plant growth chamber.*



CELLS AND STEEL – AUTOMATED CELL PRODUCTION

In the pharmaceutical industry, in biotech startups, in hospitals - wherever medical researchers are striving to develop and obtain approval for new drugs, they need model systems to provide meaningful data. Information sourced from animal trials are of limited value and therefore less suitable for elaborate development projects. Society wants fewer animal experiments; policymakers have pledged to curb these trials. It would appear that patient-specific cells – or more accurately, precision-induced pluripotent stem cells – will play a large role in the future of medical research. As it stands now, though, scientists lack the tech needed to automate cell propagation. The Fraunhofer Institute for Biomedical Engineering IBMT is looking to change that.

A new drug has to pass a battery of approval tests before it earns a rightful place on pharmacy shelves. Does it produce the intended effect? And most importantly, is it safe for patients? Researchers tasked to answer questions like these and bring medicines to market need model systems on which to test drugs. The long-term objective here is to tailor therapies as precisely as possible to the patient and to be able to track the course of this personalized therapy.

The ethics of animal experiments are controversial; the value of the information they provide is limited. They are also expensive. The push to bring down the number of animal trials is on for all these reasons. Cell systems like those used in labs are ineffectual in personalized therapies. These cells are altered in the lab to extend their longevity so they can grow in cultures for prolonged periods – experts call this immortalization. The problem is that once cells are immortalized they no longer behave like the bodily cells.

Patient-specific cells – that is, human induced pluripotent stem cells – would appear to be a far more promising alternative. Stem cells can become any type of cell in an organism. Pluripotent stem cells are produced by removing highly specialized adult cells with very specific functions from the patient's skin, for example. Introducing specific genetic factors into these cells conjures something akin to a miracle: These specialized cells acquire abilities that nature has reserved for cells from an embryo – they can divide indefinitely and develop into any type of cell found in the human body. They may even be endowed with the properties that cells would exhibit in various clinical expressions. The pharmaceutical industry has found this type of cell type to be an excellent vehicle for testing active ingredients in their R&D activities.

A bio-economic bottleneck

The European Commission and the European Federation of Pharmaceutical Industries (EFPIA) has launched two major programs – StemBANCC and European Bank for induced pluripotent Stem Cells (EBiSC) to make this cell source available for biomedical research. These programs provide the infrastructure for producing and distributing stem cells. However, labs have to produce many lines of stem cells in sufficient quantities to meet industrial needs, and convert them into the required target cells such as cardiac muscle cells. And these cells must reliably perform their natural function in a technical environment. This work is done by hand, which requires many people and costs a lot of money. Attempts to adopt automation technologies and processes from consumer product manufacturing failed because humans are more sophisticated than machines by nature. These manufacturing plants are far less efficient than lab staff. It will take a different breed of autonomous system to do this job; a learning system that is able to acquire and tap an experienced scientist or technician's implicit knowledge to make context-based predictive decisions.

Strides towards automation

Researchers at Fraunhofer IBMT have developed the technologies required for these autonomous systems. Their predecessors were as big as entire rooms and could only execute tasks sequentially. Fraunhofer researchers shrunk the footprint and added smarts with a system that is small, parallel and redundant. Scientists recruited stem cells that adhere well to certain bioactive materials to create conditions like those in the human body. This also marks the first time microscopes can automatically identify simple processes such as dividing cells and beating cardiac muscle cells.
In their next step, the researchers aim to integrate artificial intelligence (AI) enabled by artificial neural networks. These technologies are readily available, but not the lessons and examples AI needs to learn before it can serve to help produce human cells. An autonomous cell production system needs this information like a self-driving car needs archived maps and driving situations – without data to guide them, these machines are going nowhere. It will take a joint effort to generate this data. And Fraunhofer IBMT has started doing its part.

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AQUACULTURE – ANOTHER PIECE IN THE SUSTAINABLE FOOD PRODUCTION PUZZLE

Fish farming is going swimmingly. Forecasts suggest that the volume of fish produced worldwide will multiply nearly 20-fold from 4.6 million metric tons in 1980 to 73.8 million in 2020. And the fact is that the farmed fish harvest already exceeds the global wild catch, as studies have confirmed. The potential for sustainable growth, however, is limited: fish farms need high-quality water, fish seeds, feed and healthy stock. Other interests compete for the best spots. Investments in infrastructure are lagging. And there are other challenges that diminish the potential. But if scientists manage to develop new aquaculture technologies, tomorrow's markets could benefit. The Fraunhofer Institute for Marine Biotechnology and Cell Technology EMB in Lübeck is working towards this end.

Today most aquacultures are out in open waters, for example, in open-net cages in the sea. This limits the choice of location to large bodies of water where there is nothing to stop wastewater and chemical pollutants such as excrement, feed and medication from escaping. Fish-borne parasites thrive in this sort of environment. One alternative is to breed organisms in land-based plants using closed water circuits where just five to ten percent of the process water per day has to be replaced by fresh water. Enabling farmers to rear fish without exposing them to harmful substances, they may be located anywhere water is available, even near megacities. These plants are easier to protect than open installations or net cages in the sea. Looking to nature for inspiration, scientists are now developing eco-friendly alternatives for farming fish and other aquatic organisms that make the most of cycles and byproduct flows to boost efficiency. One approach is to cultivate fish, algae and mussels collectively. Many challenges have to be surmounted to keep such radically streamlined ecosystems viable and many questions remain to be explored. Fraunhofer EMB has the largest research facility for land-based multifunctional aquacultures in Germany at its disposal. The people who work here find answers to questions about material flows, combinations of different organisms to make the most of available resources, new measurement and control techniques, probes and other technologies. Another important field of research in aquaculture is the wellbeing of farmed animals. Scientists have a long way to go before they understand aquatic organisms' comfort zones – merely measuring animals' stress levels with suitable indicators is no mean feat. The research case studies outlined above are just pieces of a bigger puzzle. However, these efforts are contributing to the optimized, ecologically and economically sustainable development of aquaculture as an important part of future global food security. Entire branches of aquaculture industry are sure to emerge – some to farm and look after the health of fish, others to design and build plants, and others still to develop feedstuff.

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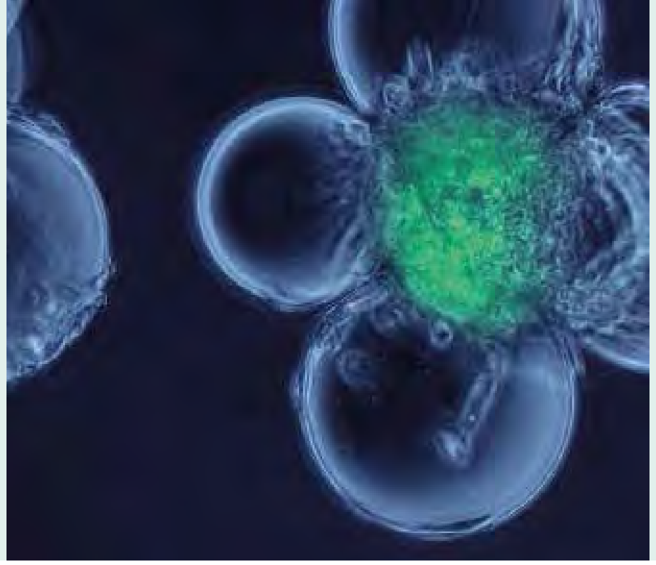

Cells as a biological commodity

Cells figure most prominently in biological transformation. They are the key building blocks of many biotechnological processes, molecular-biological diagnostic procedures, and cell therapies. And they are a renewable resource. Researchers at Fraunhofer EMB have developed a universal platform technology for propagating adherently growing cells. More than 90 percent of all cell types are adherent, which means that they need a surface to multiply and perform their function.

In this Fraunhofer process, cells are first encapsulated in a hydrogel. When they multiply often enough to fill the capsule, it is dissolved and a suspension with the cells grown in this capsule is transferred to other capsules where they can proliferate. Fraunhofer EMB patented this process. When cells can be produced inexpensively and in large quantities at high densities, this will give rise to new lines of business and markets not only for the food industry, but also in cosmetics and medicine. Cell-based model systems could be used to characterize new substances and assure their product safety.

And these complex cell systems can serve many other purposes, for example, to create personalized immunotherapies or tissue therapies. These model systems will also help reduce the number of animal experiments.

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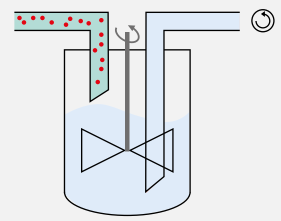
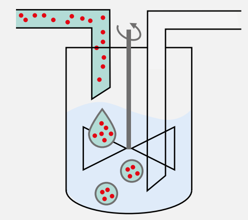
Cyclic process control

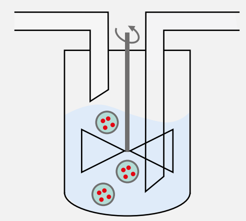
Step 1: Preparation
Prepare cells (top) and the medium + cross-linking agent (stirred tank bioreactor)



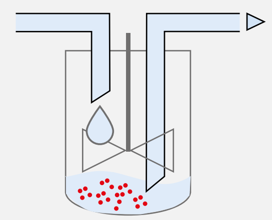
Step 2: Encapsulation
Transfer cell suspension with a dropper to form capsule carriers



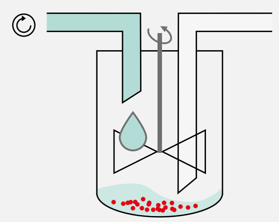
Step 3: Expansion
Grow cells in capsule carriers with a multiplication factor of around 10, depending on the cell



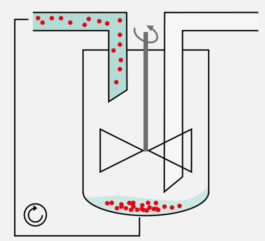
Step 4: Capsule dissolution
Dissolve the capsule carriers; expose and wash the cells

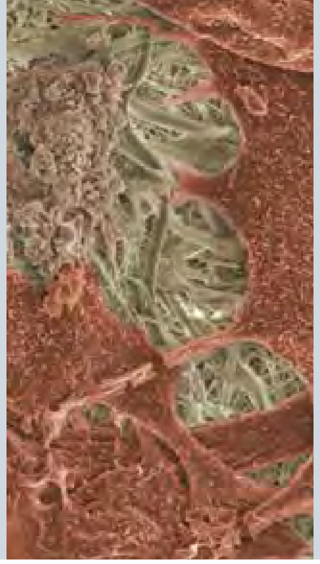


Step 5: Re-suspension
Re-suspend the cells in the gelling agent



Phase 6: Cell harvesting
Transfer cells for reuse in step 1





HEALING NATURE'S WAY WITH BIO-INSPIRED WOUND DRESSINGS

Better ways of treating wounds would be most welcome in a world with an aging population and rising cost pressure in healthcare. Medical science has yet to find a remedy for poorly healing skin injuries such as chronic and extensive wounds. And doctors need dressings that instantly close wounds to counter infections, stem fluid and electrolyte loss, relieve pain, and prevent amputations for more than six million severe burns that occur around the world every year. Biological wound dressings can meet this pressing medical need.

Skin tissue of human and animal origin to redress wounds is in very short supply. And there is always the risk of infection with donor tissue. Today's scaffolding structures that serve to cover wounds are made of synthetic polymers. These materials have their drawbacks: they can only remain on the wound for a short time. Lacking the intact skin's elasticity, they cause causes contractions and put the skin under tension. This distresses the patient and often impairs the healing process. The Fraunhofer Institute for Microstructure of Materials and Systems IMWS is developing new biomaterials for dermal applications. These materials are biocompatible and immunocompatible. They have the biological and mechanical stability required for the given application. And they are inspired by nature, particularly by the biological fiber proteins elastin and collagen. The fact that the skin, lungs, blood vessels and cartilage are elastic, robust and hard-wearing enough to withstand a lifetime of rigors is mainly down to the interaction of these two proteins. Collagen fibers' tremendous tensile strength lends tissue its mechanical stability.
Elastin exhibits complementary properties. As the main component of elastic fibers, it enables fabrics to stretch and then snap back into shape. These wound dressings are fully biodegradable – the body can break them down – yet they hold up very well under physical stress.

Their mechanical properties are not the only upside; bio-inspired wound dressings can also be endowed with functions modeled on nature. These lab-made skin fibers can bind excess enzymes that have the undesirable effect of breaking down newly formed tissue. The fibers also support new tissue formation by enabling skin cells to colonize the wound bed.

Produced using biotech in the lab or purified from animal tissue, these proteins are then processed into fibers. Scientists are working on a method that uses electrical force to spin proteins into nanofibers. It could serve to produce composites in form of nonwoven meshes. The great advantage of this method is that it yields vast quantities of fibers.

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A GREENER WAY OF KEEPING SURFACES SLEEK

Seawater-borne microorganisms require stable living conditions to thrive. They grow in a certain pH range determined by the salinity of the sea and form what is called biofilm on the hulls of ships. Known as biofouling, this accumulation of organic life is a problem for vessels. As the surface gets rougher, it creates frictional drag that impedes a ship's forward motion.
Engines have to work harder. They burn a lot more fuel and emit more greenhouse gases, all of which makes lasting protection against biofouling an economic and ecological imperative. Fraunhofer IMWS has developed a sustainable method of affording hulls permanent protection that involves no toxic paints or varnishes. Its researchers put their knowledge about the realities of marine life to work: Microbiologists know that saltwater microorganisms do not flourish in fresh water; they stop growing and eventually die. However, other microorganisms will quickly encrust the same surface in fresh water, and vice versa.
This is attributable to the change in pH value, which correlates with the water's salinity. Scientists capitalized on this insight into biofilm formation to develop an electrochemical antifouling system that cyclically changes the pH value and makes local life a lot harder for microorganisms.
The pH value has to change only on the hull's surface to significantly reduce biofilm formation. An electronic control unit can serve to set the frequency of pH value changes around the ship. The hull paint is also manufactured with the eco-friendliness of its components in mind. It contains ecological products made of lignin, a paper industry waste product, rather than fossil materials.

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THE CIRCULAR ECONOMY – SUSTAINABLE CONSUMPTION AND CLIMATE PROTECTION

Trash, garbage, refuse… It's a problem entirely specific to Homo sapiens. No other species produces waste that does not get recycled in some way or other. Our only hope of reducing our ecological footprint is by learning to modify our products and processes in such a way that any waste material gets used more effectively. For a start, we can take some inspiration from nature, which offers many good examples of recycling: organic waste such as waste wood and milk residues – and, of course, carbon dioxide.

ORGANIC WASTE – VERSATILE COATINGS FROM FRUIT FIBER

Product packaging made of plastic has never been particularly green. Yet in terms of hygiene, durability and availability, we have still to come up with anything better. Researchers from the Fraunhofer Institute for Silicate Research ISC and its project group for Materials Recycling and Resource Strategies (IWKS) are now working on some alternatives. Their work focuses on the development of biologically degradable packaging materials, some of which are produced using biogenic waste. By analyzing how these materials will be recycled, their aim is to create a circular economy.

Unpack your groceries after a visit to the supermarket, and the trash can is soon overflowing. There have long been moves to replace hydrocarbon-based plastic packaging with biodegradable materials. These, however, are permeable to oxygen, moisture and aromas. As packaging for food – particularly for moist products such as fish, meat, cheese and cold cuts – they are unable to guarantee a comparable shelf life.

Barrier properties with bioORMOCER® coatings

Researchers at Fraunhofer ISC have developed biodegradable coatings that endow bioplastics with the properties required for packaging foods. These bioORMOCER® coatings are inorganic–organic hybrid polymers – a class of materials that provides a good barrier against gases and vapors. They therefore offer an ideal material basis for developing biodegradable packaging. Suitable for combination with either bioplastics or paper, bioORMOCER® coatings will also mean that coated paper packaging for takeout products will fulfill its true environmental potential. These coatings are therefore the key to making bioplastics an attractive option to industry as a packaging material. This will pave the way to a successful market launch, the ultimate goal being to make plastic and paper-based packaging become more environmentally friendly in the future.

Food waste for biodegradable packaging

New ideas are needed to keep materials in the recycling chain. For example, researchers from the IWKS project group are now using renewable materials to produce bioORMOCER® coatings for biodegradable packaging. These materials can be extracted from waste matter in the food industry, including fiber-rich byproducts from processing food – especially fruit. These byproducts contain long, branched sugars from the highly diverse group of substances known as hemicelluloses, which are not broken down by the human digestive tract and therefore not metabolized so as to yield energy. Hemicelluloses have good barrier properties against air and aromas. The project group is currently identifying suitable source materials and processes for extracting hemicelluloses. The aim is to obtain molecules that can compete with the petroleum-based raw materials currently used to produce coatings. A pilot plant has now been set up in order to help advance the development of this technology. This ensures sufficient quantities of the branched sugar molecules for the production of coatings and can also be incorporated as a module in small agricultural biorefineries and biogas plants.

bioORMOCER®: a coating with wide applications

Biodegradable coatings also offer numerous benefits in other areas. For example, they can endow organic, cellulose-based, "vegan" fibers – i.e., cotton or viscose – with new and attractive properties, making them water repellent, for example, or good bonding agents in biocomposites and able to block UV radiation. And there are many other associated fields of research that could lead to the development of innovative materials and products for a sustainable management of resources.

For example, Fraunhofer ISC researchers have already developed a fabric coating by the name of InnoSolTEX®. This delivers a variety of properties in one single formula, making textiles antimicrobial, antistatic, flame-retardant, hydrophobic or hydrophilic, and washable. Research will now concentrate on the use of such coatings with natural fibers from renewable resources. This will provide fabrics that remain biologically degradable, despite boasting a range of sophisticated properties.

Smart processes for closed-loop recycling systems

Alongside the development of new materials, researchers from Fraunhofer ISC and the IWKS project group are also working on smart recycling processes. Enhanced design of easily recyclable materials and products together with an innovative pilot plant for sorting waste and a highly selective separation process are now paving the way for the future development of simple and profitable recycling systems that will help conserve resources.

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MORE FOR LESS – BETTER MANAGEMENT OF SOIL NUTRIENTS

Everyone knows that plants need nutrients to grow. Yet mineral fertilizers, when applied too liberally or indiscriminately, are a burden on the environment. The same is true of liquid manure. In either case, organic or inorganic, the real problems begin with overfertilization. What then happens is that the surplus nutrients end up in ground and surface water, where they accumulate and damage the local ecosystems. If we are to continue improving the standards of nutrition for the world's growing population, without harming the environment in the process, we must therefore restore nature's own cycles. This means that nutrients removed from the fields along with the crop at harvest time must be returned to the ground in a controlled manner and form that is available to plants. It is this problem that researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are currently investigating.

What could be more idyllic than the sight of a field of barley gently waving in the breeze? To grow and flourish, cereal and vegetable crops need to absorb nutrients from the soil, such as nitrogen, phosphorus, potassium, calcium and sulfur. After harvesting, the crop may be used as animal feed, as food, as a raw material for industry or even as a feedstock for bioenergy. But whatever the use, the nutrients stored in the crop are removed from the ground. Yet only some of these nutrients find their way back into the soil in the form of organic fertilizers – farmyard manure, liquid manure or compost. Besides, given the environmental problems associated with overfertilization, this process is also strictly regulated. A further complication is that arable farms and livestock holdings are often in different areas, which means that the ready availability of organic fertilizer can vary strongly from region to region. In areas of intensive cultivation, farmers must therefore resort to industrially produced mineral fertilizers in order to replenish their soil with the necessary nutrients.

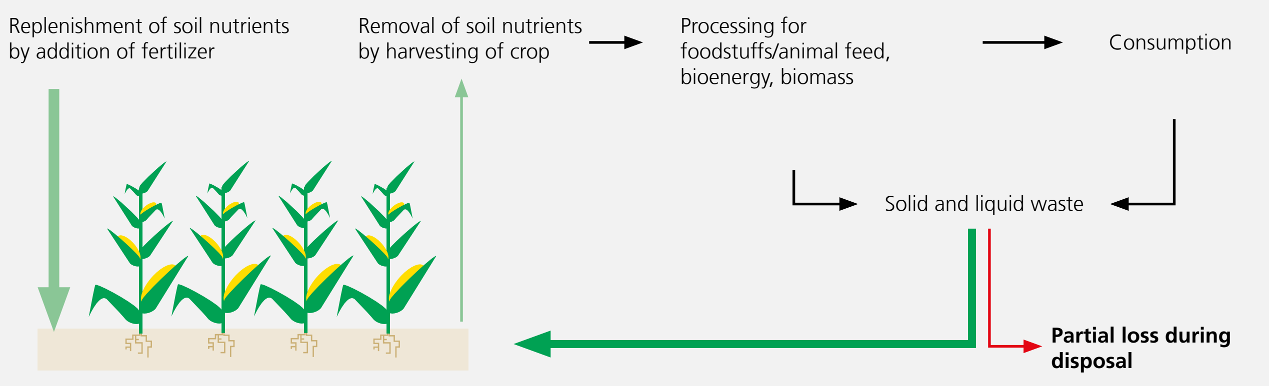
Conventional production of inorganic fertilizers

There are currently no industrially produced mineral fertilizers that are made of renewable materials. Phosphate fertilizers, for example, are mainly produced from rock phosphates, which are mined from deposits around the world. More and more of these deposits are contaminated with heavy metals such as uranium or cadmium. By contrast, atmospheric nitrogen is available in virtually unlimited quantities. This can be converted into ammonia as a source material for the synthesis of nitrogen-based fertilizers. But here, too, there is a problem: an enormous amount of energy is required for the production of synthetic ammonia – the equivalent of around two percent of the world's primary energy production. In fact, the production of nitrogen fertilizers accounts for around five percent of the world's annual consumption of natural gas.

Nutrients are lost from the soil

The nutrients that are removed from the soil together with crops end up, by and large, in wastewater-treatment plants or waste-disposal sites. Municipal sewage plants, for example, tend to use biological nitrification and denitrification processes to remove nitrogen compounds such as ammonia or nitrates from wastewater and then convert them – in a highly energy-intensive process – into gaseous nitrogen, which is then released into the atmosphere. Phosphate, as a rule, is precipitated from wastewater using aluminum or iron salts. The resulting phosphate salts end up as landfill, since they are not in a form available to plants and can release iron and aluminum in concentrations that are toxic to plant life. Estimates indicate that each year around 4.3 million metric tons of phosphorous are lost as a result.

Flow chart for sustainable management of soil nutrients



The problems of overfertilization

In areas with intensive livestock rearing, there is often a surplus of nutrients in the soil as a result of the excessive application, often over many years, of liquid manure. By the same token, when mineral fertilizers are applied in the wrong way or in excessive quantities, they are simply washed out of the soil and end up in ground or surface water, where they accumulate and impact local ecosystems. Similarly, the use of fermentation residues from biogas plants as a fertilizer can also be problematic, since the precise composition of nitrogen, phosphorous and potassium in this waste never corresponds to the needs of the crop. In practice, fermented waste only meets the needs for one specific soil nutrient, usually nitrogen. This means that the other nutrients are applied in excess, which in areas with intensive livestock rearing can lead to a glut of nutrients in the ground, with negative consequences for the environment.

Sustainable management of soil nutrients

If we are to continue improving standards of nutrition for the world's growing population, while respecting the integrity of nature, we must restore nature's own cycles and return to the soil the nutrients that are removed at the time of harvest. To this end, Fraunhofer IGB is working hard to develop and implement sustainable, cost-efficient technologies and strategies designed to provide an integrated management of resources. This work focuses on new and innovative technology and processes to enable the extraction of soil nutrients from wastewater and organic waste such as liquid manure and fermentation residues.

Today, some of these processes are already in commercial operation, with our industrial partners now extracting and marketing soil nutrients in such a form that they can be directly used in agriculture. These products are produced and marketed in both solid and liquid form. They can be tailored to specific applications and mixed according to soil properties and crop type.

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MORE THAN MILK – CHEMICALS FROM WHEY

Whey is a major byproduct of cheese production. Yet only around 40 percent of this substance gets reused in any way. The other 60 percent, along with all the valuable peptides and proteins it contains, is wasted. This is largely the fault of today's fractionation technology, which is costly and inefficient. In hard commercial terms, it is simply not worth processing the remaining whey. Researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are now working on a compact and efficient technology capable of selectively separating complex mixtures of this type. Their aim is to harness the benefits of filtration with those of electrophoresis. They have already achieved promising results with electromembrane filtration, which provides an economic means of extracting previously unrecuperated substances that can then be used in high-grade products for the medical, pharmaceutical, food and bioprocessing industries.

Promising applications for proteins and peptides from whey

Indeed, whey has a lot to offer. In addition to lactose and minerals, it also contains high-grade proteins and peptides, which could be used in the bioprocessing and food industries. Furthermore, a number of these peptides, including the casein macropeptide (CMP), are also of interest for medical applications, since they inhibit bacteria and viruses as well as alleviate the symptoms that these cause. CMP, for example, inhibits the formation of plaque and caries. Other substances from whey are suitable for preparing products for infant, sports and clinical nutrition. Whey proteins can also be used as natural, environmentally friendly substitutes for synthetic foaming agents, emulsifiers, gelling agents and water-retention agents. The processes currently used for fractionating and concentrating proteins involve several steps and are therefore costly and time-consuming. A further problem is that many of the individual stages require high temperatures and, in certain cases, the addition of acids, solvents or buffer solutions. In other words, such processes involve the use of a lot of chemicals and energy, which in turn can damage or even destroy the protein structure.

Electromembrane filtration: the key to efficient fractionation

Electromembrane filtration (EMF) is an efficient way of extracting useful substances from whey. This process separates the peptides and proteins by means of a mechanical membrane and an electrical field. In other words, substances are separated according to not only their molecular size but also their electrical charge. The degree of selectivity is therefore very high – which in turn makes the process very effective in economic terms. It is moreover very attractive from an ecological point of view, since no chemicals are required.

Researchers at Fraunhofer IGB have already demonstrated the potential of electromembrane filtration. Using a demonstration unit not yet optimized for commercial operation, they extracted casein macropeptide (CMP) from whey left over from mozzarella production. In the substance produced, CMP accounted for 81 percent of the total protein content. This is comparable with commercially available formulations, in which the proportion of CMP is between 75 and 85 percent. In other words, the process is suitable for producing a commercially viable product. Moreover, it can also separate out uncharged molecules such as lactose and could therefore be used to produce lactose-free foods for allergy sufferers.

Electromembrane filtration makes use of two different forms of separation: a mechanical membrane and an electrical field. Each of these can be individually controlled, which means that the process as a whole can be tailored to a customer's specific requirements. This technology has huge potential: once neglected substances can now be retrieved and turned into raw materials, which in turn can be used to make high-grade products for the food, animal feed, medical, pharmaceutical and bioprocessing industries.

Having completed basic investigations at the laboratory scale, researchers at Fraunhofer IGB are now developing an EMF system based on an EMF cell. The system is currently operating in semibatch ("feed and bleed") mode, with feed rates of up to 1000 liters per hour, depending on which transmembrane pressure is selected. At present, researchers are working to scale up the process, get it operating continuously and validate it for other source substances.

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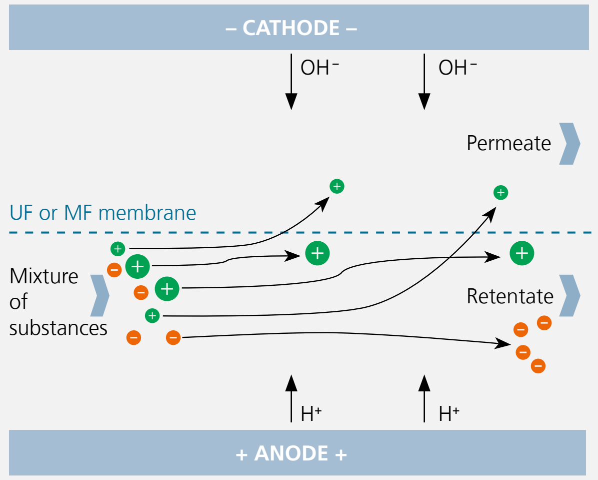
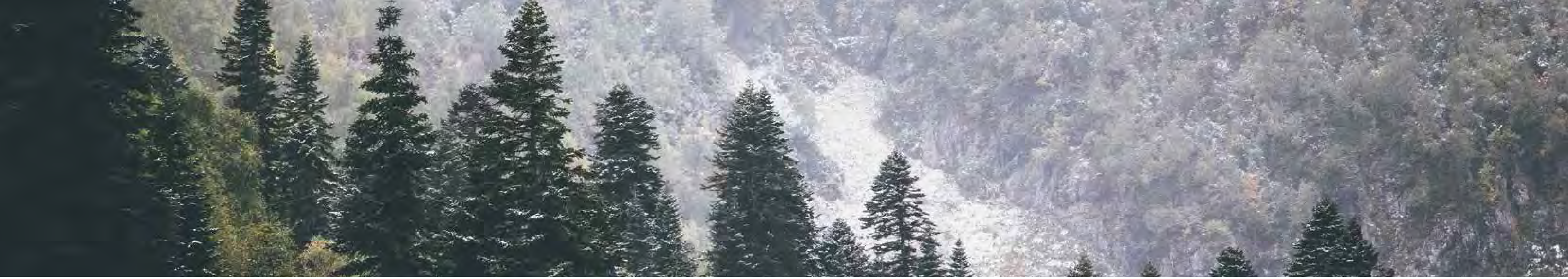
Functional principle of EMF



In the diagram, where the cathode is on the permeate side, the electrical field prevents negatively charged substances passing through the filter, even when their molecular size is smaller than the pore size of the filtration membrane. This enables a higher degree of selectivity than with conventional ultrafiltration.



TOO VALUABLE TO BURN – WASTE WOOD AS A RAW MATERIAL

At present, wood and lignified biomass such as straw are used in a variety of ways: for generating heat, in the construction industry, for making furniture and in agriculture. Yet they could also provide a valuable source of raw material for the chemical industry. Unlike corn or rape, for example, they are not potential sources of food, as they cannot be digested by humans. Yet lignified biomass, when freshly harvested, is difficult to transport efficiently. There are similar problems with low-quality scrap wood: rather than being used as a potentially valuable source of raw materials, it tends to get burned for energy. There have long been methods for isolating cellulose and lignin (in the form of sulfonated lignin) from wood so that they can be used as raw materials. Yet wood has other components such as hemicellulose and lignin (not in its sulfonated form), which are also valuable raw materials with manifold applications. Fraunhofer researchers are therefore working on ways of exploiting these substances.

Regions close to equator, such as northern Brazil, are blessed with abundant sunshine. Here, it is perfectly possible to produce chemicals from biomass cheaply and sustainably all the year round. The challenge facing the chemical industry back in Germany and the rest of Europe is therefore to lever its know-how and develop efficient and sustainable production processes that will enable it to compete. In turn, this will enable it to reduce its dependency on fossil fuels and shift to sustainable alternatives. Increasingly, too, this is the wish of consumers, who today have a growing influence on the chemical industry. They want products made of ingredients that do not negatively impact the environment – products, in other words, made of sustainable raw materials. A viable alternative to crude oil is wood. Treated in a biorefinery, this can be broken down into its principal constituents: cellulose, hemicellulose and lignin. These fractions can then be further refined and used for a variety of applications. This would not only help meet the growing demand for chemicals and other materials but also contribute toward mitigating the effects of climate change.

Preconditioning biomass by drying or torrefaction

Current research tends to focus on the question of how residual and lignified biomass – for example, straw – can best be used either as a source of energy or as raw material. The first problem, however, is how to transport this material in an economic and sustainable way. The regions that are capable of producing a requisite supply of lignified biomass – Scandinavia, for example, or countries in eastern Europe – are a considerable distance away from the major industrial locations where this biomass can be processed and used. At present, there is no viable method for preconditioning damp and easily perishable biomass at the place of production so that it may then be efficiently transported for processing.

Researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are now looking to solve this problem. Their idea is to use mobile units to treat lignocellulosic biomass – for example, residual material from agriculture and forestry – in the region where it is produced, thereby making it fit for transport, storage and further processing. Using a flexible torrefaction process, the biomass is heated for a specific time in an inert atmosphere of pure, superheated steam at ambient pressure. The temperature of this process is below the value at which carbonization (pyrolysis) takes place. The torrefaction process developed at Fraunhofer IGB is based on the established method of drying with superheated steam at atmospheric pressure.

Fraunhofer IGB has already been able to demonstrate the process in a variety of pilot plant projects. Unlike conventional torrefaction processes, the biomass is not contaminated by exhaust gases or degraded as a result of oxidation by atmospheric oxygen. This ensures that the biomass and any substances extracted from it are extremely pure and therefore suitable for high-quality applications. The process can run continuously and is flexible enough to be used for different types of biomass, according to season. The technology can be scaled either up or down, which makes it suitable both for small units for specific applications and for plants capable of handling a large throughput of material. The torrefaction process converts the biomass into a hydrophobic material with a very high calorific value in terms of mass. It can therefore be transported economically. Furthermore, the material can be ground into a powder, which makes it easy to create a large reaction surface for the purposes of further processing. In addition, any volatilized substances are specifically condensed. As a rule, these are valuable organic acids, which can be directly used as platform chemicals.

The key aim of researchers here is to establish a commercially exploitable technology platform. For the SteamBio project, they constructed a semi-mobile demonstrator capable of processing around 150 kilograms of lignified biomass per hour. This unit is now in operation at various locations in Germany and Spain, where it is being used to torrefy at least six different types of agricultural or forestry waste, including conifer, oak and grapevine cuttings. The economic and material characteristics of the various feedstock materials and the products they yield are being defined with a view to developing new business models.

High-grade chemicals from low-grade wood

Long before wood was used to make paper or furniture, people burned it to provide heat. Yet from a bioeconomic perspective, wood is much too valuable to throw on the fire. A better solution is a process known as cascading. Here, the wood is first used in a high-grade product or process. Only the material that is unsuitable for this purpose is burned to produce energy. In the chain to exploit the full potential of the wood, however, other valuable substances can be obtained upstream by means of, for example, the organosolv process, whereby wood is fractionated into its basic constituents using heated organic solvents in a lignocellulosic biorefinery. These can then be used to produce important feedstock materials for the chemical industry, including lactic acid, furfural, aromatic compounds and fibrous matter for new materials.

The Fraunhofer Institute for Chemical Technology ICT, the Fraunhofer Center for Chemical-Biotechnological Processes CBP and the Fraunhofer Institute for Wood Research, Wilhelm-Klauditz-Institut, WKI are all working on such production processes right up to the pilot scale. Using data acquired from such projects, researchers can then draw up a comprehensive analysis of the economic efficiency and sustainability of these processes. At the same time, they are also investigating the potential of scrap wood to provide another secondary feedstock for biorefinery processes. Fraunhofer WKI is conducting an ecological evaluation of the material flows in which scrap wood is used either as a source of material or for generating energy. Fraunhofer ICT is involved in the development of pulping, separation and extraction processes on the pilot scale. And Fraunhofer CBP is collating laboratory findings on pulping and fractionation for different grades of wood and advancing them on a pilot scale. The pilot plant also produces samples on the multi-kilogram scale,

which can then be used to test applications in the areas of fermentation and the utilization of lignin.

Isolation of lignin and hemicellulose

The only substance the pulp industry currently extracts from wood is cellulose. To date, there are no suitable processes for obtaining lignin or hemicellulose. As a result, both of these valuable components are simply burned to generate energy. Researchers at Fraunhofer CBP have now adapted the organosolv process for the separate extraction of both lignin and hemicellulose in a form suitable for further use. The processes required for this purpose are already established on the pilot scale at Fraunhofer CBP. Researchers are now busy optimizing individual process stages. In particular, they are looking at ways of reducing the amount of process medium required and at further integration of the individual process stages. Further processing of these fractions yields biobased platform chemicals. Lignins, for example, have huge potential as intermediates for the production of polymer components – an area in which Fraunhofer Institutes are also carrying out research. Examples here include polyurethane adhesives and EPI adhesives, both of which are now being developed into functional products in joint projects with industry. A further project focuses on the development of lignin-based inks for offset web printing.

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A lignocellulosic biorefinery.


FROM CLIMATE KILLER TO RAW MATERIAL – CO_2 IN CHEMICAL PRODUCTION

If the targets agreed upon at the United Nations Paris Climate Conference are to be achieved, it will take more than just a switchover to renewable energy and electric vehicles. In addition, industry must make its production processes more sustainable – in particular, those processes that emit large amounts of CO_2 into the atmosphere. A promising approach is to use this CO_2 as a feedstock for the chemical industry, thereby imitating the carbon cycle in nature. This has two advantages: a major greenhouse gas is prevented from entering the atmosphere, and CO_2 replaces petroleum as a raw material.

Humans and animals exhale CO_2 into the atmosphere with every breath they take. In the long run, this would spell disaster, were it not for the existence of plant life. Plants remove CO_2 from the atmosphere by breaking it down into carbon and oxygen. They use the carbon to grow and, for example, to produce lignin, while the oxygen is expelled back into the air, where we can breathe it.

In other words, there is a functioning carbon cycle in nature. Is it therefore possible to apply the same principle to industrial emissions and thereby counteract climate change? Specifically, is it possible to use the CO_2 emitted by industry as a feedstock for other uses? The answer is yes. To do so, however, will require the use of energy as well as new developments in gas treatment and process and system engineering. The chemical industry already has experience in a similar field. In the 19th century and the first third of the 20th century, coal was an important feedstock for the chemical industry. Synthesis gas, produced by the gasification of coal, was turned into a whole range of chemical products by means of processes that the industry developed to varying degrees of technological maturity.

From waste product to raw material

Consider the steel industry. Here, plants are operating close to the technically feasible optimum. In other words, there is little scope for any further reduction in CO_2 emissions from this sector. Simple thermodynamics dictate that a substantial amount of coal must be used in order to produce steel with the requisite properties. However, even with this traditional method of steel production, there is still a way to reduce CO_2 emissions: by catalytically converting carbon gases from steel production into chemical products. In turn, this would reduce the carbon emissions of the chemical industry, for which around 90 percent of the feedstock is still derived from fossil fuels. Indeed, CO_2 could serve as a feedstock for a host of chemical products, in the process partially replacing fossil fuels such as crude oil. For example, the gases produced during steel production and electricity generation – blast furnace gas, coke gas and converter gas – contain CO_2. Instead of releasing this greenhouse gas into the atmosphere, it would be possible to convert it almost entirely into chemical products.
Before we can create a closed carbon cycle in industry, however, we must first develop new forms of gas treatment, new catalytic processes and new process technologies.

In other words, much research, development and demonstration work will be required over the next 20 years. This is the focus of the collaborative project Carbon2Chem®, in which involves the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT is a partner. Rather than attempting to optimize individual parts of a process or types of plant – specific chemical processes or blast furnaces, for example – the project is taking a holistic view of the entire constellation. One option here is a return to coal-based chemistry.

Cooperation between different sectors of industry

If this venture is to succeed, it will require close cooperation between the steel industry, chemical industry, process industry and the plant and equipment industry. For example, in order to convert CO_2 into chemical products, large quantities of hydrogen are required. This can be produced by the electrolysis of water, using environmentally friendly electricity generated from renewable sources. Preliminary research carried out by thyssenkrupp AG has already shown ways in which the company's steel works in Duisburg might cooperate with chemical plants. In other words, this form of collaboration is viable.

In order to promote cooperation of this kind, companies from the relevant industries are also participating in the Carbon2Chem® project. The aim is to establish joint locations that combine steel and chemical production and use renewable sources of energy. In order to facilitate Germany's smooth transition to a new energy economy and thereby reduce CO_2 emissions, project partners will be looking to advance the technologies required to develop sustainable modes of production and implement these on an industrial scale. This way, we should be able to get a little closer to the carbon and other cycles in nature and thereby come to regard CO_2 as a raw material rather than a waste product.

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PROTEIN FROM INSECTS – POTENTIALLY A MAJOR NEW SOURCE OF ANIMAL FEED

We have now reached the point where cattle and hogs eat more than we can grow in fodder. The result is that more and more rain forest is being cleared to cultivate soybeans for animal feed. Yet there is an alternative: insects. This would solve several problems. Insects can process organic waste such as pomace or marc, which must otherwise be disposed of at substantial cost. And when turned into protein, insects can provide a sustainable – and healthy – source of feed for livestock.

Steak, ham or pork loin? Whatever the cut of meat that lands on your plate, its production has caused a host of problems. One reason is that cattle and hogs require much more food, measured in nutritional value, than they actually produce in the form of meat. In order to satisfy the growing hunger for meat, large tracts of rain forest around the world are being cleared to grow animal feed. In Brazil alone, some 156,000 square kilometers were lost to soybean production between 2002 and 2012. Moreover, there is an increasing shortfall between the projected production of protein and the amount of protein required for animal feed – a shortfall sometimes referred to as the "protein gap." Experts estimate that by 2025 there will be a shortfall of 100 million metric tons between the amount of protein actually available and the amount required to feed the human population and livestock reared for meat. What's more, this shortfall is forecast to grow by 300 million metric tons by 2050.

Similarly, the need for oils and fats exceeds the amount that can be sustainably produced. The most important source of vegetable fats is now palm oil. Yet the large-scale cultivation of oil palms has devastated swathes of rain forest in Indonesia and Malaysia. This not only poses a huge threat to biodiversity but also aggravates climate change.

Filling feed troughs with insect protein

Insects could offer a solution to all these problems. Biotechnology is now busy developing ways of turning insects – or, more precisely, their organs, cells, molecules or any associated microorganisms – into products. Literally tons of insects such as the black soldier fly (Hermetia illucens) are being bred. Fed on organic waste, these insects will yield proteins, lipids and other valuable substances that can be used to feed livestock or fish reared in aquaculture. This insect farming business is already thriving worldwide and holds huge economic potential for the future.

Insect protein offers big benefits – for the environment, agriculture and livestock rearing

Insect farming is cost-effective, energy-efficient and therefore highly sustainable. Insects offer big advantages compared to the agricultural cultivation of animal feed. A big factor is the amount of land required: it takes one hectare to produce around one metric ton of soybean – or as many as 150 metric tons of insect protein. The insects can furthermore be fed with organic waste, of which there is an abundant supply – not least in the tropics, where, for example, the palm oil industry produces huge amounts. In addition, the excrement of the insects is an excellent organic fertilizer. Moreover, insects do not transmit any diseases harmful to humans or livestock. Nor do they pose any danger to biodiversity. Both small farms and industrial-scale operations can benefit from insect farming. This is because it can be scaled up or down to whatever the size of operation required.

There are also advantages to feeding cattle and hogs with insect protein: not only does it have a high nutritional value, but it also has a positive impact on the animals' health. In other words, industrial-scale solutions to commercially exploit insect protein could help resolve global problems as well as create new value chains.

Pioneering role in insect technology

The Bioresources project group at the Fraunhofer Institute for Molecular Biology and Applied Ecology IME is playing a pioneering role in the development of new technologies involving insects. Together with industrial partners such as Alternative Protein Corp., the group is now pursuing research in the area of insect farming. For example, the AIM Biotech project, which is jointly sponsored by the Fraunhofer-Gesellschaft and the Max Planck Society, is investigating possible industrial uses for the microbes that are associated with insects. Similarly, the Bioresources project group is investigating whether crop yields can be increased by the use of organic fertilizer based on the excrement of black soldier flies.

It is, however, early days to be talking about new technology and the commercial exploitation of insects on an industrial scale. First of all, research must continue to focus on enhancing the reactors used for the industrial breeding of insects and on the development of industrial, automated processes for handling the raw materials that insects provide.

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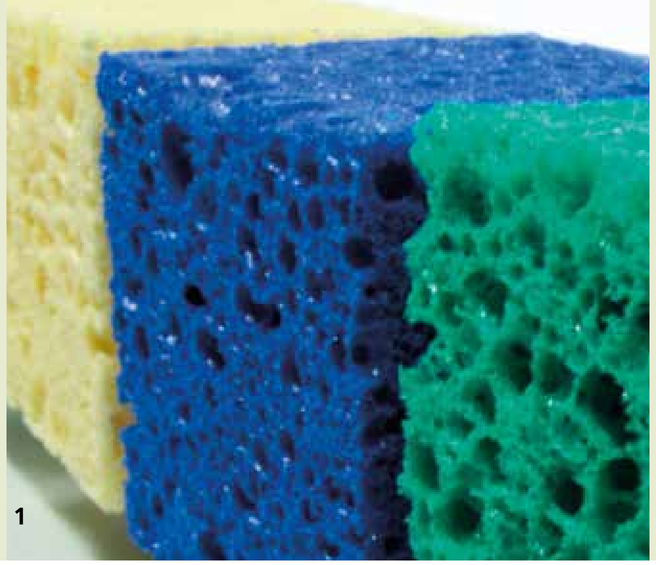
COATINGS AND PAINTS FROM VEGETABLE OIL – PUTTING A SHINE ON SUSTAINABLE CONSUMPTION



Consumer preferences are changing, with more and more people now opting for green, sustainable products. In the case of some consumables, it is relatively easy to change over to wood, cork or some other ecological material. Yet it is a different story when it comes to paints and glues, for example, or insulation. Here, it is not so easy to meet the demand for sustainability. Attempts have already been made to produce epoxy resins – the basic material for such products – from vegetable oil. Yet the composition of these natural oils can vary greatly. Researchers at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS are therefore taking a closer look at the exact properties of environmentally friendly resins and devising sustainable strategies for the use of such materials.

Our climate is changing. The environment is polluted. Each year we produce more garbage than ever. For many people, the time has come to try and reverse this trend. Their answer is to buy goods that are more sustainable. Manufacturers, too, are responding to this new mindset. It is not enough, however, merely to replace plastic with materials such as wood or cork. For products to be genuinely sustainable, manufacturers must also use adhesives, paints and foamed plastics that are made of biobased feedstocks.

Epoxy resins:
the classic material for adhesives and foamed plastics

The standard raw material for paints, adhesives and foamed plastics is thermosetting epoxy resin – synthetic resins that are irreversibly hardened after heating. The feedstock for epoxy resins are monomers. Once a hardener is added, these individual molecules bind together to form a permanently solid plastic, which can no longer be melted. Through the addition of further substances, the properties of the epoxy resin can be tailored to specific applications. For example, it can be colored, protected against heat and sunlight, made flameproof or given properties that make it easier to manipulate. In addition, fillers can be added in order to cut the material costs.

The sustainable alternative:
vegetable oil-based epoxides with natural additives

Yet it is also possible to produce epoxy resins from environmentally friendly materials. Adhesive manufacturers, for example, are already investing much time and effort in the research and development of alternatives that are not only sustainable but also of a better quality and better value than the products they replace. In their quest to come up with a new generation of solvent-free dispersion adhesives, they have already discovered a promising area of research.

Epoxides based on vegetable oils offer the prospect of an ecological alternative to traditional epoxy resins. Here, vegetable oils with a high proportion of unsaturated fats are epoxidized – which sees the unsaturated fats turned into three-atom rings comprising two carbon atoms and one oxygen atom. These vegetable oil epoxides are combined with harmless natural additives to produce highly durable plastics. By varying their composition, these resins can be adapted for a great many applications. In theory, at least, this makes sustainable adhesives, paints and foamed plastics a realistic alternative. Yet there is still one problem: the chemical composition of natural materials can vary considerably. In this case, for example, the raw material is extracted from the seeds of oil plants. The challenges facing producers are therefore considerable.

Ecological adhesives with ideal properties

Researchers at Fraunhofer IMWS are now busy investigating the precise characteristics of these newly developed biogenic resins – on the micro as well as the macro level. Once they have determined what effect feedstock variations have on the resins, they can then set about enhancing and adapting them to specific types of processing. Partners from industry will then transfer these processes from the laboratory to the industrial scale. At the same time, Fraunhofer researchers are busy developing new formulas for adhesives based on these vegetable oil epoxides. Which hardeners are best for which applications? And which fillers and additives can be used to deliver specific properties? A particularly useful property would be high electrical conductivity. Through the application of an electrical current, it would then be possible to heat the adhesive layer from within, thereby ensuring that it hardens in a fast and precise way. Another advantage of these new adhesives is that they are entirely solvent-free.

The Fraunhofer IMWS is also working on alternatives to conventional foamed plastics used, for example, as insulation for buildings. Just like adhesives, they can also be made from plastics based on vegetable oil. Here, it is important to find out which resins are best for a specific production process. Together with partners from industry, Fraunhofer IMWS is working to develop finely tuned formulas for epoxidized fine oils and hardeners, ensuring short hardening times and low viscosity. Here, the challenge is to increase the biogenic share while also improving the material's workability and its properties. The foamed plastics produced by the Fraunhofer researchers currently have a biogenic share by weight of 80 percent. Here, the chief additive is lignin, a waste product from the pulp industry. An estimated volume of around 20 billion metric tons of this substance is produced each year.

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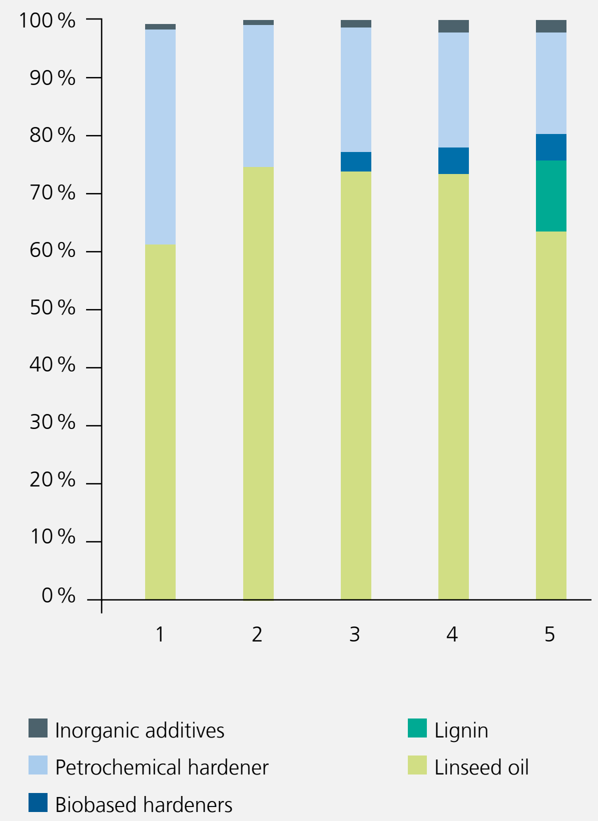
Increase of biogenic share in five different reactive resin systems



1 *Foamed linseed oil epoxide, pigmented.*

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