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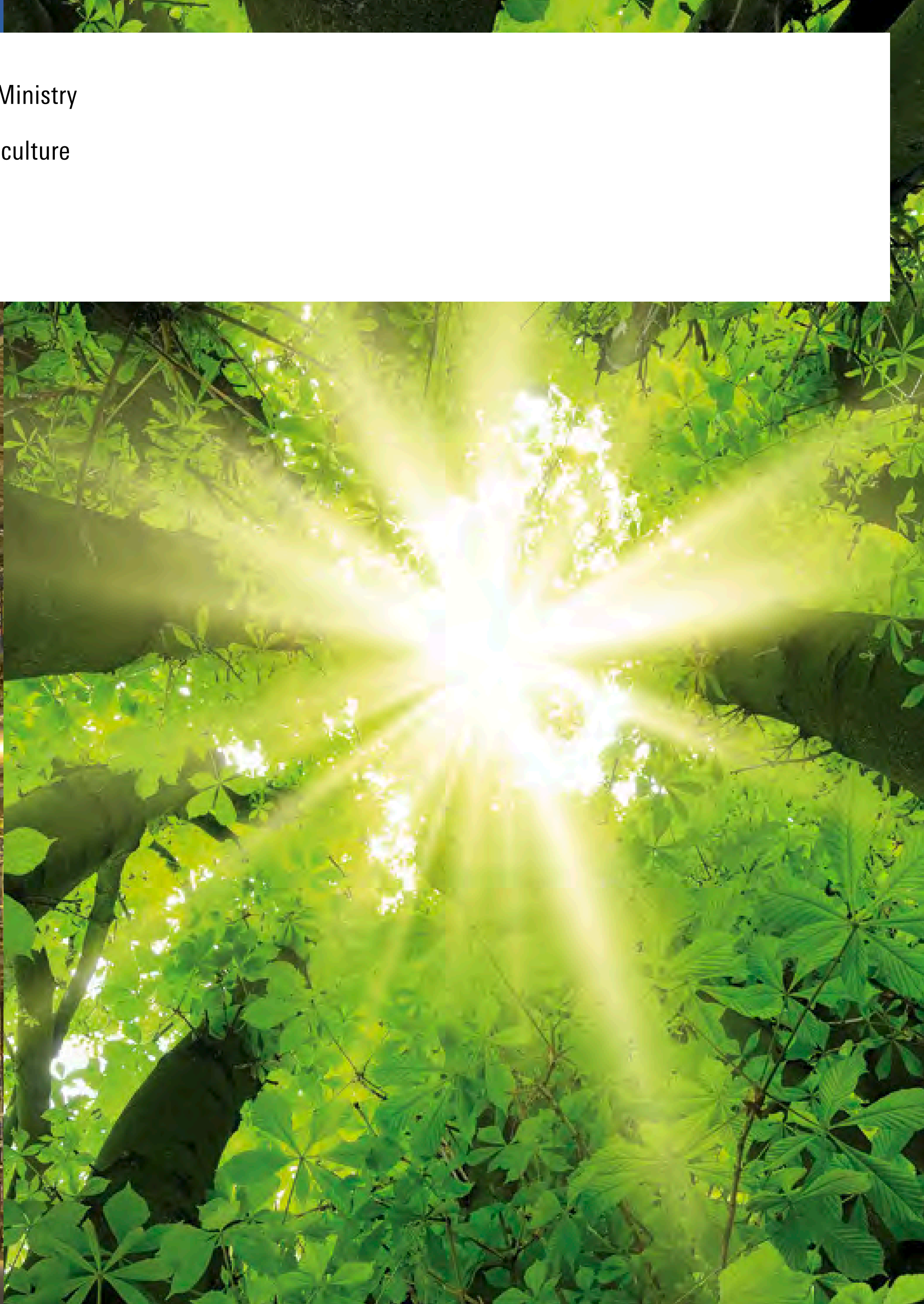

Bioeconomy in Germany

Opportunities for a bio-based and sustainable future

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Contents

Bioeconomy – an introduction

In view of scarce fossil natural resources, climate change and growing word population, it has become all the more urgent to develop sustainable strategies that enable efficient use of our natural resources: to assure over the long term the prosperity of modern societies. Bioeconomy offers the opportunity to achieve economic growth in harmony with protection of nature and our environment. Germany, as a focal point for technology and research, has set itself at the vanguard of this movement.

Otto Wulff GmbH

Consideration only of key statistical data of the leading industrial nations could lead to the conclusion that an optimistic outlook is justified: indeed, never before have so many benefited from advanced, industrial progress; never before did such mobility circle the entire globe; and never before did mankind have access to such sophisticated technologies. At the same time, however, industrial prosperity over the past two centuries has in great part been based on the use of fossil raw materials. Coal, petroleum and natural gas have enabled Germany and the other industrialized countries to experience an upsurge without historical precedent. Without fossil raw materials, this industrial revolution would not have successfully taken place. Still today, these resources represent a key component of our industrial practices. They have provided the basis for continuous technological progress and have contributed to enabling Germany to develop into one of the world's strongest economies. Today, many products of everyday use are based on petroleum, and this resource represents the most important source of raw materials and energy for the chemical industry and its customers.

The world of the twenty-first century is now being faced with a fundamental challenge: How can the world economy sustainably grow? How can we combine economy and ecology?

World economy in transformation

Yet the present form of the world economy is increasingly reaching its limits. Economic dependencies between countries with plentiful reserves of raw materials and countries that do not have such resources have increased in recent years and have repeatedly led to political conflict. Moreover, the use of fossil resources such as petroleum, coal and gas represent an appreciable burden on our climate and our environment. Among experts it is undeniable that present economic forms and our patterns of consumption are responsible for a major share of greenhouse-gas emissions and, in turn, for present global climate problems. The Intergovernmental Panel on Climate Change (IPCC) has recently assessed the current situation: If, within the near future, significant efforts are undertaken and essential changes are implemented, there are still opportunities to cope with global warming. The need for action is clearly perceptible in Central Europe as well: it is, after all, long since the case that not only distant islands or oceans are in danger. Since earliest weather records, in 1881, the average temperature in Germany has risen by 1.2 °C.

But not only climatic conditions have become a challenge: world population has also appreciably increased. During 2013 alone, total world population increased by the amount of the German population. It is expected that more than nine billion women and men will populate the earth by 2050. We have not yet determined a solution to the following problem: how will we nourish nine billion people without further destructive exploitation of natural resources? The growth of prosperity, now evident in many threshold countries, has furthermore led to increasing global demand for products and services: for example, for energy, infrastructure and health services. The world of the twenty-first century is now being faced with a fundamental challenge: How can the world economy sustainably grow? How can we combine economy and ecology?

Bioeconomy can provide an essential contribution to the solution of these problems. Bioeconomy intelligently links economy and ecology and thereby enables bio-based and sustainable economic growth. Bioeconomy is the knowledge-based production and use of regenerative resources – to supply products, processes and services

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in all sectors of the economy, within the context of a future-capable economic system. In order to achieve sustainable economic growth, bioeconomy resorts to two fundamental principles: it is based on sustainably produced, renewable natural resources, and on bio-based innovations. Beginning as early as the Industrial Revolution, innovations in the natural sciences and in engineering have contributed decisively to prosperity and growth. Countries such as Germany without plentiful natural resources are forced to apply existing knowledge and excellence in achievement to assure renewable raw materials, new products and services, and innovation-driven economic growth.

In demand: sustainable economic growth

The great present challenge is also to apply innovation and investment efforts to assure the required transformation of economic systems toward achieving sustainability, and to find solutions for the challenges described above. The enormous productivity gains over the past two centuries, as well as to a great degree our technological developments to date, have been based on the easy accessibility of fossil raw materials. We can expect just as great an influence through knowledge advance in the life sciences. In this field, new insights gained over the past decades have completely revolutionized certain aspects of our understanding of biological processes, and have led to the development of high-tech tools that offer tre-

Milestones in bioeconomy

2007 2008 2009 2010

2005 | EU Research Commissioner Janez Potocnik presents the initial concept of a knowledge-based bioeconomy.

2007 | Under German Council presidency, the Cologne Paper is published in Cologne: “En Route to the Knowledge-Based Bioeconomy”. For the first time, it summarizes the objectives involved in bioeconomy.

2009 | The OECD presents the strategy paper “The Bioeconomy to 2030. Designing a Policy”.

2009 | Founding of the Bioeconomy Council. Experts advise the German government in the organization of a bio-based economy.

2010 | The interdepartmental National Research Strategy Bioeconomy 2030 is published by the federal government.

2010 | The Bioeconomy Science Center (Bio-SC) is founded in North Rhine-Westphalia. It is the first institution in Germany explicitly oriented to bio-economic research issues.

mendous potential for sustainable further development of the economy (see section “High-tech tools for bioeconomy”). A technically feasible and, at the same time, more resource-efficient and bio-based structural transformation within industry is consequently not only imaginable, but also well capable of cost-efficient implementation. It is especially in view of alternatives to fossil raw materials – but also with respect to the utilization of renewable resources in industrial process engineering – that entirely new approaches toward bio-based production are becoming apparent in our time.

Bioeconomy delivers the overall framework in society to ensure not only bio-based but also sustainable growth. Indeed: for the overall structural changes required in industry throughout society, solutions are necessary that combine economic growth with global responsibility for world nutrition and for the protection of our environment and climate as well as for animal welfare – and that allow a holistic perspective. It therefore does not suffice simply to shift the raw materials basis from fossil to renewable resources, and to utilize biomass for industrial applications. It likewise fails to suffice merely to integrate biological know-how by individual innovation into already existing process technology. In order to master the challenges of the world economy in the twenty-first century, successful structural change must take place throughout society that links economic growth and ecological compatibility. The economy must take into account growing requirements placed on the manner in which goods and services are produced, and must likewise sufficiently consider aspects involving protection of our environment, our climate, our natural world and the animal kingdom – just as extensively as it assures maintenance of social standards.

“Bioeconomy is the knowledge-based production and utilization of renewable resources, in order to provide products, processes and services in all economic sectors within the context of a future-capable economic system.”

Such a comprehensive transformation process is possible within the framework of bioeconomy. It must be based not only on renewable raw materials but also on bio-based process solutions that resort to the entire spectrum of renewable resources – including microorganisms, cells as well as individual biological constituents (see section “Raw materials sources for bioeconomy”). The guiding principle of bioeconomy is the development of an economy operating on materials-cycle management that enables optimal utilization as well as multiple use of raw materials and material flows, in the sense of resource efficiency and sustainability – also on a cross-industrial-sector basis (see the section entitled “Bio-based production – an overview”).

2011 **2012** **2013** **2014**

2012 | The second period of work begins for the Council for Bioeconomy, with some new members.

2012 | The EU Commission publishes *Innovating for* Sustainable Growth. A Bioeconomy for Europe.

2012 | The BioEconomy Cluster begins work.

2012 | The science campus Plant-Based Bioeconomy opens in Halle, Germany.

2012 | The Fraunhofer Center for Chemical-Biotechnological Processes (CBP) opens in Leuna, Germany.

2013 | Baden-Württemberg launches its Research Programme for Bioeconomy.

2013 | North Rhine-Westphalia enacts its Bioeconomy Strategy.

2013 | Under direction of the BMEL and BMBF, the federal government publishes its National Policy Strategy on Bioeconomy.

2014 | BMBF holds its Halftime Conference on Bioeconomy in Berlin.

2014 | The BMEL holds its International Conference on Bioeconomy – Sustainable Economy with Renewable Resources (3 and 4 Nov).

First half: National Research Strategy Bioeconomy 2030

In 2010, the National Research Strategy Bioeconomy 2030 was published under the direction of the Federal Ministry of Education and Research (BMBF), together with six additional ministries. Until 2016, 2.4 billion euros is provided for research and development (R&D). The content of the strategy involves five key fields of action:

1) Securing global nutrition
2) Producing healthy and safe foods
3) Ensuring sustainable agricultural production
4) Using renewable resources for industry
5) Developing biomass-based energy carriers

At the same time, this strategy established essential guiding principles. For example: securing supplies of food always has priority over other utilization of biomass. Planning is for the intelligent linking of value-added chains to mitigate competition among the various biomass utilization routes: for example, by the parallel production of products and/or energy from biomass and by multiple sequential use. For bioeconomy as well, production must be judged on the basis of whether it conserves resources, nature and climate; is benign to animals; and is ethically acceptable.

Under the aegis of this research strategy, the participating ministries applied a great variety of funding instruments during the initial three years, and measures were launched. Substantial efforts of the BMBF are directed especially toward generation of new research impetus for greater sustainability in the agricultural sector. For example, the BMBF set focus of a funding initiative on the protection and preservation of our soil, as one of the most important resources for agriculture. In addition, the use of regenerative raw materials in industry represents a key funding area within this research strategy. Further approaches have likewise been followed toward new, climate-compatible and climate-adapted research and development for productivity enhancement in plant cultivation as well as for sustainable strategies in food production. The aspect of global responsibility has furthermore been more intensively addressed and has been promoted in targeted research collaboration with developing and threshold countries. Together with the activities of the Federal Ministry for Economic Cooperation and Development (BMZ), this expertise accordingly contributes over the long term, internationally as well, to development of sustainable agriculture. A further essential module within the national research strategy is funding of research and development efforts in the economy, especially those made by small and medium-sized enterprises (see box on page 10). New collaboration has likewise been initiated between science and business throughout the entire value-added chain, with the objective of placing greater emphasis on regenerative raw materials and on resource-efficient concepts in industrial production processes.

The activities of the BMBF here complement funding programs of the Federal Ministry of Food and Agriculture (BMEL), which likewise funds with a number of supporting initiatives the ongoing development of new approaches for the industrial utilization of biomass. Most of these activities concentrate on the sustainable further development of agriculture and animal husbandry, as well as of forestry and fishery. Furthermore, innovations are being promoted along the entire value-added chain in the areas of nutrition and agriculture – with attention directed to ecological agriculture, preservation of biological resources, enhancement of the efficiency of plant and animal breeding, and development of new models for multi-use of agricultural biomass. The further development of bioenergy strategies represents a further aspect of innovation promotion under the umbrella of bioeconomy. Since the most recent German parliamentary elections, The Federal Ministry for Economic Affairs and Energy (BMWi) has been responsible for promotion of research projects for the energetic use of biomass. These activities have been supplemented by promotion measures by the BMEL, which have as objective the optimization of processes and technologies for the production of power, heat and fuels from biomass.

More information: www.biooekonomie.de

Understood in this sense, bioeconomy as a holistic approach unites economic growth and sustainability. Bioeconomy offers the opportunity to develop innovation-driven, bio-based solution approaches for current and future challenges. As a result of the extensive availability of biological resources, implementation of advanced bioeconomy is additionally not restricted to industrialized nations alone. It fundamentally offers participation to all countries – beyond the limits set by today's prosperity and national systems. Bioeconomy is a concept that encompasses policies entailing research, industry and energy; agriculture, forestry and fishery; as well as climate, environment and development policy.


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Milestones for bioeconomy in Germany

In bioeconomy, Germany occupies a leading international position. As one of the first countries, Germany in late 2010 published its National Research Strategy Bioeconomy 2030: a strategy designed for six years for implementation across policy areas. For the first time in Germany, it accordingly set a specific course for bio-based transformation of industry and society. The strategy was developed under the direction of the Federal Ministry of Education and Research (BMBF), together with six further ministries. Until 2016, 2.4 billion euros is provided for research and development (see box at the left). The measures implemented during the first three years of the National Research Strategy have succeeded in promoting concepts for resource efficiency and sustainability for industry, and in exploiting opportunities associated with bioeconomy for the intended social and economic transformation.

In its National Policy Strategy on Bioeconomy, enacted by the Federal Cabinet in summer of 2013, the German government set an additional milestone for a bio-based and sustainable economy. This strategy – prepared under the direction of the Federal Ministry of Food and Agriculture for implementation across policy areas – included the objective of enabling coherent development of policy (see box on p. 8). Within the context of the inter-ministerial Task Force for Bioeconomy set up in 2013, the required governmental activities have been coordinated and vigorously advanced. The associated Bioeconomy Council advised the federal government in the specific elaboration and implementation of the National Research Strategy. The Bioeconomy Council, which began work in 2009, is currently in its second period of work. Consisting of experts from various professional disciplines in science and business, it prepares recommendations for the further development of future research focal points, and promotes civic dialog with all social stakeholders (also see the section entitled "Outlook – bioeconomy in social dialogue").

Bioeconomy on the level of the federal states

Not least owing to broad funding from the federal government policy level, bioeconomy in Germany has by now been likewise pursued by the individual federal states as a theme in its research promotion programs.

North Rhine-Westphalia
In July of 2013, the federal state of North Rhine-Westphalia enacted its own bioeconomy strategy. This state has based its work here on the promotion of interdepartmental networking and on intensive integration of work in humanities and social sciences for the development of "Good Standards" for bioeconomy. Its work has consequently included support for the interdisciplinary Bioeconomy Science Centre (BioSC), in which German universities in Aachen, Bonn and Düsseldorf, as well as the research centre Forschungszentrum Jülich, in Germany, participate. Further work by the state government of

The National Policy Strategy on Bioeconomy

In the summer of 2013 the Federal Cabinet enacted its National Policy Strategy on Bioeconomy. In this strategy, the federal government describes goals, strategic approaches, and measures to exploit the potentials of added value and job creation, within the context of sustainable economy, and to fund structural change toward a bio-based economy. The strategy, prepared under the direction of the BMEL, acts on an interministerial basis and has the objective of coherent policy. Proposals for action have been worked up for all areas of policy that are relevant for an internationally competitive bioeconomy. The strategy formulates measures not only for research and innovation policy, but also explicitly for industry, energy and agriculture policy; for climate and environment policy; as well as for development policy. Within the framework of an interministerial Working Group for Bioeconomy, constituted in 2013, appropriate governmental activities were coordinated and advanced. The National Policy Strategy on Bioeconomy is based on the sustainability strategy of the federal government and is closely linked to the National Research Strategy Bioeconomy 2030, enacted in 2010.

North Rhine-Westphalia has been based on further development of biopolymers and functionalized surfaces; biorefineries; and biopharmaceuticals, diagnostic agents and medical technology.

Baden-Württemberg

The Bioeconomy Research Programme for the state of Baden-Württemberg was launched in July of 2013. It is based on recommendations by scientists from the Bioeconomic Council, which was organized in 2012 by the Ministry of Science, Research and Art (MWK) of Baden-Württemberg. The goal of this program is to fund transdisciplinary joint ventures throughout the state to enhance networking of the potential existing in the region: for example, at universities in Hohenheim, Karlsruhe and Stuttgart. Over a period of five years, investment is planned in the main areas of biogas, lignocellulosic biomass and microalgae.

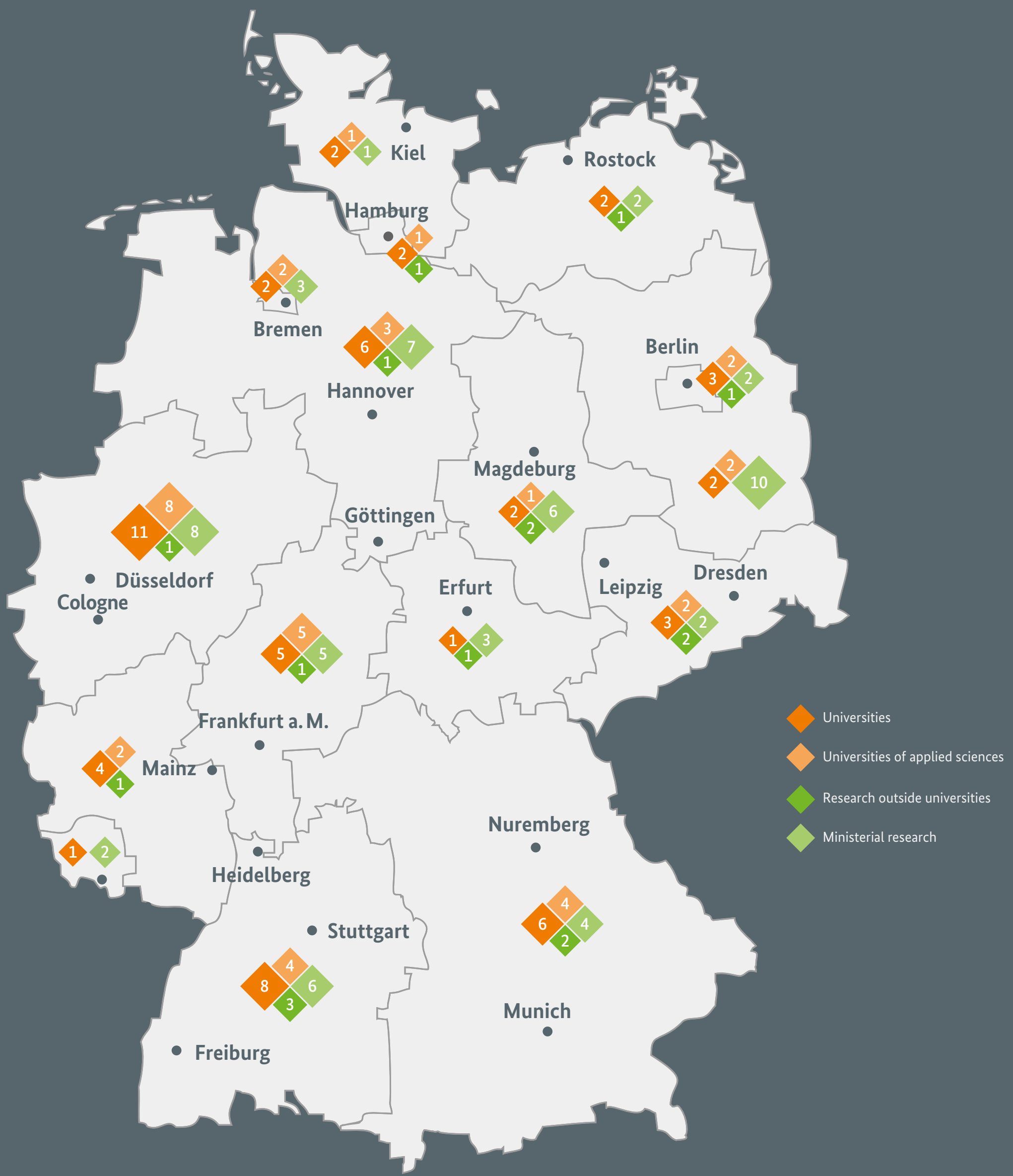
North Germany

In the predominantly agricultural states of Northern Germany, state governments have not set up explicit bioeconomy strategies. Nevertheless, networks in this area have formed on the regional level. In the Weser-Emsland region, the Strategy Council for Bioeconomy and Agrarian Systems Technology was founded, and the German Institute of Food Technologies and the Osnabrück University of Applied Sciences has founded a Centre of Applied Bioeconomy (CAB). The state government of Mecklenburg-Vorpommern has initiated its Analysis of the Potentials of Bioeconomy, and the state government of Schleswig-Holstein plans to focus work on marine biotechnology and on the development of innovative aquacultures.

Central Germany

At the traditional chemistry site in Leuna, in Central Germany, the Fraunhofer Gesellschaft has established a Center for Chemical-Biotechnological Processes (CBP), which was dedicated by German Chancellor Angela Merkel in October of 2012 (see section "Bio-based production"). Biorefineries are designed to produce an extensive spectrum of chemical raw materials, as well as energy, in a manner comparable to today's petroleum refineries. Most biorefinery concepts are still in the stage of research and development. The CBP Centre is focused on up-scaling of research from the lab to the pilot-facility stages: for which CBP has set up a number of pilot facilities on 2,000 m^2, which will be used by partners from science and business. The federal state of Saxony-Anhalt and the three Federal Ministries for Research, Agriculture and Environment have provided approximately 50 million euros to realize the CBP. Since 2012 this region has received additional funding from BMBF through its funding of the BioEconomy Cluster, for the purpose of developing Central Germany as a focal point for bioeconomy activities. In addition, the Halle Scientific Campus for Plant-Based Bioeconomy has provided important academic impetus for this effort in Central Germany – in which the Leibnitz Institutes in Halle, as well as Halle-Wittenberg University, have collaborated on an interdisciplinary basis. By now, bioeconomy has also been introduced into the leading-market strategy of the state of Saxony-Anhalt.

Overview of the bioeconomy research landscape in Germany



The bioeconomy research landscape in Germany is broadly based: there are relevant activities at 60 German universities and 37 universities of applied sciences. Other locations include 61 research facilities outside universities: for example, the Fraunhofer Gesellschaft, the Max-Plank Gesellschaft, the Leibniz Gemeinschaft, the Helmholtz Gemeinschaft, and 17 locations operated by German ministries. The research activities in bioeconomy are not restricted to one professional discipline. They include agricultural sciences, life sciences, mechanical engineering, plant engineering and in part social sciences.

Small and medium-sized enterprises at the focus of funding

In order to enable application of bioeconomy approaches in as many industrial sectors as possible, the federal government targets funding for research and development efforts in the economy. Special focus is on small and medium-sized enterprises, since these include innovative growth drivers. Tailored funding measures on national and European levels enabled the launching of promising bioeconomy projects under the umbrella of the National Research Strategy, and stimulated considerable private investment.

In 2011, moreover, the Innovation Initiative for Industrial Biotechnology was introduced to form strategic alliances between science and business throughout the entire value-added chain. These alliances now operate with public funding to enhance emphasis placed on regenerative raw materials and on resource-efficient concepts within the context of various industrial production processes. Until now, five such strategic alliances have been selected for public funding, of which three are coordinated by one small and medium-sized enterprise.

www.biooekonomie.de/innovationsinitiative

Bavaria
In Bavaria as well, bioeconomy approaches are attracting increasing attention: for example, under the aegis of the Bavarian chemistry cluster. In this context, the Bavarian state government is funding product and process innovations for new, primarily international markets. In these efforts, cluster management is not only combining intra-sector associations, but is likewise coordinating the acquisition of third-party resources, providing progress supervision for the project, and performing project-associated transfer services. The Clariant specialist chemical group plays a central role in Bavarian bioeconomy. This company operates a demonstration plant in Straubing for the conversion of straw to biofuel (also see the section entitled "Energy").

Hesse
The government of the state of Hesse funds such efforts with funds from the Hessian state Offensive for the Development of Scientific and Economic Excellence (LOEWE). One of its beneficiaries is the Centre for Synthetic Microbiology (SYNMIKRO), which is operated jointly by Philipps University and the Max Planck Institute for Terrestrial Microbiology in Marburg. The state government, in addition, provides funding for key efforts in biotechnology and environmental technology.

A highly diverse research landscape

On an intra-state basis, major German research organizations are furthermore active in bioeconomy: for example, the Fraunhofer Gesellschaft, the Helmholtz Gemeinschaft, the Max Planck Gesellschaft, and the Leibniz Gemeinschaft. The significance that they attach to further development of bio-based economy is evident, for example, in their participation in the project Strategy Process for Biotechnology 2020+. Together with BMBF, this project was launched in 2010 to develop visions for bio-based production of the future. By now, research organizations have begun large-scale structural projects, in each of which institutes from life and engineering sciences are participating. These and other networks have shown that, in bioeconomy, it is essential to assemble as much relevant experience as possible under one roof. It is especially crucial to ally the branches of science and engineering – but economics and social sciences also play increasingly important roles. The map on page 9 provides an overview of research activities in Germany.

From Germany into Europe and the world

The advancement of bioeconomy cannot, however, remain on any national agenda alone. With its strategy enacted in 2012 – Innovating for Sustainable Growth: A Bioeconomy for Europe – and with its associated plan of action, the European Union funds a competitive, bio-based economy that efficiently uses its raw materials. In 2013 the EU Commission and numerous representatives of European countries linked their efforts in sponsoring a public-private partnership (PPP) named Bio-Based Industries (BBI). For the coming seven years, these sponsors have committed a total of 3.7 billion euros, including nearly 1 billion euros from the European

Commission, to this venture for research projects and demonstration facilities. Around 140 partners from throughout Europe are participating, including corporate groups, small- and medium-sized companies, as well as clusters and professional associations from Germany. The primary purpose is to create value-added chains beyond traditional avenues. These include new recycling concepts for wood, grain and organic waste – in addition to multiple usage of biomass for bioenergy and fine chemicals.

Bioeconomy in the everyday

The many and various bioeconomy approaches that already exist today – and that can further develop, partly on the basis of traditional processes – evidence that there is need for action from the industrial standpoint. The application of renewable raw materials in industry is, indeed, not principally a new idea. For food, for clothing and for health: many regenerative raw materials have entered products and economic processes. Some of these processes are already hundreds of years old, such as in the production of cheese and beer. Others have developed only in the course of molecular-biological advances in the 1980s – for example, production by the pharmaceutical industry of innovative cancer medication from bacteria or cells. Others have been developed only very recently, as with processes for the production of biosynthetic materials. In all cases, bio-based economy is not restricted to any one industrial sector. The value of biological resources has been recognized in many areas of industry; the biologization of products, production engineering and processes of all kinds increases; and the results are by now apparent in the everyday life of everyone (see section "Bioeconomy in everyday life"). Within this context, bioeconomy is a factor in business and will gain significance in the future.

At the same time, however, many ideas are still at the beginning of their economic realization. A series of pilot and demonstration facilities has, to be sure, demonstrated the feasibility of intelligent parallel production of products and/or energy from biomass, as well as multiple sequential use of biological resources, residue and waste materials. The challenge is now to implement these facilities into extensive industrial applications and to realize the principle of the biorefinery as basis for the industrial production of the future. In 2012, the BMBF and BMEL summarized the detailed challenges entailed here in their Biorefineries Roadmap – an overview of the most important technologies and their avenues toward realization in the material and energetic utilization of renewable raw materials.

Bioeconomy around the world

Bioeconomy is on the advance globally. Many countries have by now enacted bioeconomy strategies, including the USA, Canada, Russia, Great Britain, Finland, Sweden, Brazil, Argentina and South Africa. Similar to Germany, bioeconomy is considered a highly promising concept for renewal of the economy, as well as a key basis for innovation policy. In accordance with their technological strengths and their access to biological raw materials, the various countries have established various focal points in the areas of innovation, bioenergy and the like. In order to better network the activities existing in Europe, bioeconomy enjoys priority within the framework of the eighth EU Framework Programme, Horizon 2020.

www.biooekonomie.de/weltweit

Fossil raw materials in everyday life – from petroleum to the bio-based economy

Fossil raw materials were the impetus for industrialization and still today represent important resources. Alternatives, however, are increasingly being sought, not least owing to technological progress. Throughout all economic sectors, strategies have been developed for sustainable and bio-based forms of economic activity. As a result, bioeconomy has gradually entered the daily life of us all.

How can we achieve bio-based and sustainable forms of the economy? What are the challenges, and where do promising approaches already exist? On the basis of currently available corporate figures, this section will briefly describe the most important overall sectors located in Germany, with details on staff levels and sales. Bioeconomy-relevant developments will be explained on the basis of facts and figures available. A variety of examples of bio-based products and processes will provide evidence that bioeconomy has already become part of our daily lives.

- Number of companies
- Number of employees
- Total sales in billions of euros

AUTOMOTIVE SECTOR

17 | 756,000 | €362 billion

Examples of bioeconomy:
Car-body parts reinforced by natural fibres, car-interior lining and seats based on bioplastics, tyres based on dandelion

MECHANICAL ENGINEERING

6,227 | 978,000 | €207 billion

Examples of bioeconomy:
Bioreactors, bioprocess engineering, agricultural technology and equipment, greenhouse technology, biolubricants

BUILDING INDUSTRY

317,300 | 1,900,000 | €172 billion

Examples of bioeconomy:
Wooden structures, composite materials reinforced by natural fibres, insulation materials, bio-based screw anchors, bio-based concrete admixtures

FOOD AND BEVERAGE INDUSTRY

6,000 | 555,000 | €170 billion

Examples of bioeconomy:
Enzymes, fragrances, amino acids, natural food additives, probiotics, food from lupin protein

CHEMICAL INDUSTRY

2,121 | 434,312 | €186 billion

Examples of bioeconomy:
Bioplastics, bio-based platform chemicals

PHARMACEUTICALS INDUSTRY

923 | 135,773 | €41.4 billion

Examples of bioeconomy:
Biopharmaceuticals, medicinal plants and herbs

ENERGY

923 | 220,157 | €466 billion

Examples of bioeconomy:
Pellet stoves, biogas, biodiesel fuel, bioethanol, synthetic fuels, algae, kerosene

CONSUMER GOODS

no data | no data | €203 billion

Examples of bioeconomy:
Bio-based tensides, bio-active constituents in cosmetics, enzyme-based additives for cleaning agents

AGRICULTURE AND FORESTRY

285,000 | 1,000,000 | €32 billion

Examples of bioeconomy:
Precision agriculture, plant and animal breeding, short-rotation forestry, aquaculture

TEXTILES AND CLOTHING

1,300 | 111,313 | €11.33 billion

Examples of bioeconomy:
Natural raw materials for synthetic fibres, high-tech fibres made of spider web, plant tannins

Automotive sector

Facts & Figures

No. of companies	17
Employees	756,000
Sales	€362 billion

Examples of bioeconomy:
Car-body parts reinforced by natural fibres, car-interior lining and seats based on bioplastics

© VDA, 2013 (only manufacturers)

The mobility of today would be hardly imaginable without the automobile. In view of climate change, sustainable mobility concepts are increasingly in demand. The automotive sector is one of the largest users of bioplastics and is otherwise also increasingly sympathetic for bio-based materials.

For the average German, modern life is hardly imaginable without the automobile. Each person in Germany now travels an average distance of 11.7 km per day, and the car is responsible for 55 % of all distances travelled. A total of 78 % of households have at least one car, and 80 % of adult Germans have a driving licence. These figures are also reflected in statistical data for the automotive sector. The German Association of the Automotive Industry (VDA) declares that its sector is one of the key business areas of our present-day economy. With annual sales of 362 billion euros, it represents 3.9 % of the German gross domestic product. Just over one-third of research and development resources in Germany flows directly or indirectly into the car industry. It is the most research-intensive sector of Germany – in 2013, 18 billion euros were invested in this industry. A total of 840,000 men and women are employed by car manufacturers and subcontractors.

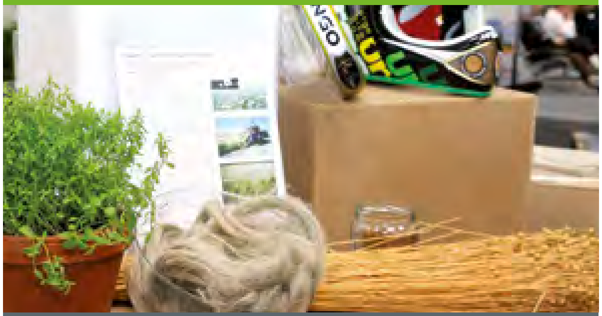
The challenge of sustainability

The shadow side of mobility is likewise measurable in numbers: 20 % of all greenhouse gas is attributable to the automobile. Surfaces sealed by streets and roads cover more than 2 % of German land area. Noise, fine-particle pollution, sub-divided landscapes and billions of euros spent for maintenance and expansion of infrastructure must also be taken into account. More than half of international petroleum consumption, furthermore, is used for transportation. Petroleum is not only used here in the form of petrol, diesel fuel and lubricants – it is also widely employed as raw material for many automobile components, such as car paint, numerous parts of vehicle interiors, electronic components and displays. Since the 1950s, when private vehicles began to dominate the streets and become consumer articles, the share of plastic, synthetic fibres and foam derived from petroleum and used in our cars has continued to grow. Today, approximately 10 % of plastics annually produced in Germany is used by the automotive industry. This is primarily because these materials are light, easily formed and highly effective for heat and noise insulation. Hybrid components, composed of metal and plastics, are also widely used. A number of the plastics are so robust that they can act as a substitute for metals.

Regenerative raw-material sources for materials

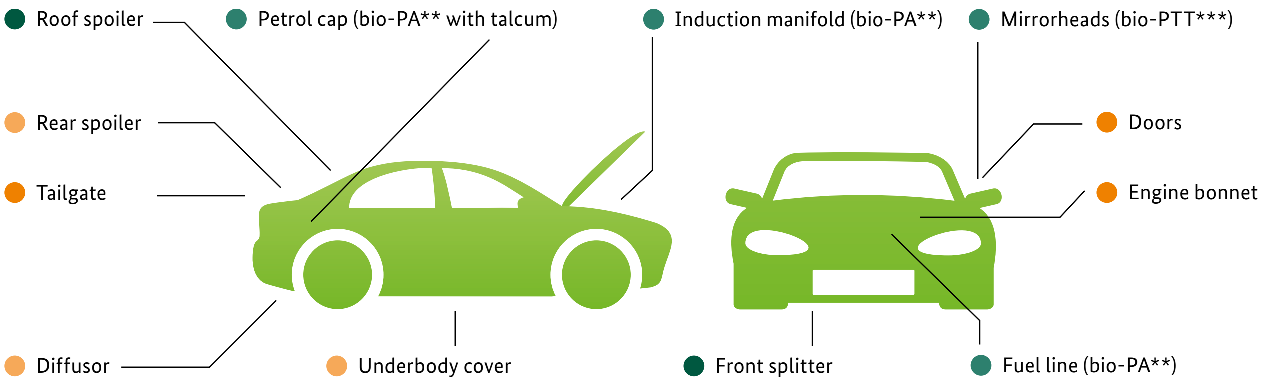
The topic of sustainability is also gaining in significance in the automotive industry. Consumers are asking for petrol economy, and the government stipulates lowered CO_2 emissions. These expectations have above all led to greater focus by manufacturers on innovative materials. The impetus of increasing application of plastics in light automobile design have also enabled bio-based plastics and bio-hybrid materials – such as natural-fibre-reinforced composite materials – to gain increasingly stronger market positions.

Automobile components from natural domestic fibres



Bio-based automobile parts made of natural fibres such as flax are popular among car makers owing to their light weight. The network FENAFA, funded by the BMEL since 2009, has contributed to this development. This acronym stands in German for “Holistic supply, processing and production strategies for natural-fibre raw materials”. The objective of the project is to optimize industrial plants and processes for further development of technical natural fibres native to Germany. The aims here range from enhancement of harvesting technologies all the way to product development, and toward access of new application areas. Participants primarily include small and medium-sized enterprises.

Overview of biomaterial components in the Bio-Concept Car



Today:	Earlier:
Bio-based thermoset material* with linen fibres	Steel sheet
Bio-based thermoset material* with linen fibres	Petroleum-based thermoset material with carbon fibres
Bio-based thermoset material* with linen fibres	Petroleum-based thermoplastics
Bio-based thermoplastics	Petroleum-based thermoplastics

*Epoxy resin, by vacuum-bag process
** PA = polyamide
***PTT = Polytrimethylterephthalat (PTT)

Source: IfBB

Currently, for example, approximately 90,000 tons of wood-plastic composites are being used annually in the European car sector. Small companies, such as Tecnaro GmbH, also profit from rising demand for bio-based materials. Tecnaro, funded by the BMBF, developed a process for using residual material from cellulose production as basis for thermoplastic materials.

In fact, the use of biomaterials is not an entirely new trend. Already in 1915, Henry Ford installed in his legendary model-T a starter box made of the wheat protein gluten, reinforced with asbestos fibres. In the 1920s he designed car prototypes with body parts made of hemp fibres and soya flour. This material was so strong that Henry Ford, for advertising purposes, took an axe to the boot lid, without ruining it. The peak of this development was finally a prototype whose body was made entirely from regenerative materials. Since 2008 bio-based materials have been used for the Ford Mustang, although to a lesser degree. Just 5 % of the weight of a Mustang consists of biomaterial. It is made from polyurethane foam, 40 % of which consists of soya. Other automobile makers such as Toyota and Hyundai likewise count on bio-based plastics. In series production for its A-Class, Daimler Benz has a car bonnet of which 70 % is made from plant-based raw materials. The processing characteristics of bio-based plastics used in car production represent one of the challenges here. A great deal of research and development work involves the problem of how existing injection moulding processes can be adapted to produce bio-based car components. The IfBB Institute for Bioplastics and Biocomposites at the college Hochschule Hannover conducts such work in its collaboration with all major car makers and companies along the value-added chain, to prepare the way for bio-based materials and their industrial processing.

Funded by the Federal Ministry of Food and Agriculture (BMEL), the IfBB is developing its Bioconcept-Car: a racing car from the car-racing team Four Motors GmbH in Reutlingen, Germany, which also includes the singer Smudo from the hip-hop group “Die Fantastischen Vier”. This project involves the development, manufacture and assembly of biocomposites with shares of regenerative raw materials from 30 to 70 %, as well as of similar car body and interior parts. The IfBB tests the bio-based components in its lab before and after application in racing cars. Between races and at the end of the season, the IfBB removes the components and subjects them to extensive and non-destructive testing (see illustration on the left).

Tyres made of dandelion

But not only car bodies and interior are increasingly featuring bio-based material: alternatives are also being developed for rubber car tyre production. Until now, caoutchouc from rubber trees has been imported from subtropical climates. For this use, Russian dandelion *(Taraxacum kok-saghyz)* is also suitable: a plant that can be cultivated in Germany as well. Caoutchouc harvesting from the dandelion root is considerably less dependent on weather conditions and, owing to its ease of cultivation, opens entire new potentials, especially for unused agrarian areas. Within the context of a project funded by BMBF, research has taken place at Münster University on how the characteristics of the herbaceous plant *Taraxacum kok-saghyz* can be adapted to the requirements of mass cultivation. The Fraunhofer Institute for Molecular Biology and Applied Ecology (IME) in Aachen, Germany, together with the tyre producer Continental, are currently building a pilot plant in Münster to produce dandelion caoutchouc on an industrial scale. Within only a few years, researchers want to put car tyres made in this way on the streets. Already now, tests by Fraunhofer researchers have confirmed that the quality of the new rubber is the same as that of conventional material.

Overview of natural fibres for interior components in the automotive industry

Plant fibres

- **Seed fibres**
  - → **Cotton**
  - → **Kapok**
- **Bast fibres**
  - → **Flax**
  - → **Hemp**
  - → **Jute**
  - → **Kenaf**
  - → **Ramie**
  - → **Kava jute**
- **Hard fibres**
  - → **Agave**
    - → Sisal
    - → Yucca
    - → Mauritius hemp
  - → **Pineapple**
  - → **Abaca/Manila hemp**
- **Fruit fibres**
  - → **Coconut**
- **Wood fibres**
  - → **Spruce**
  - → **Pine**

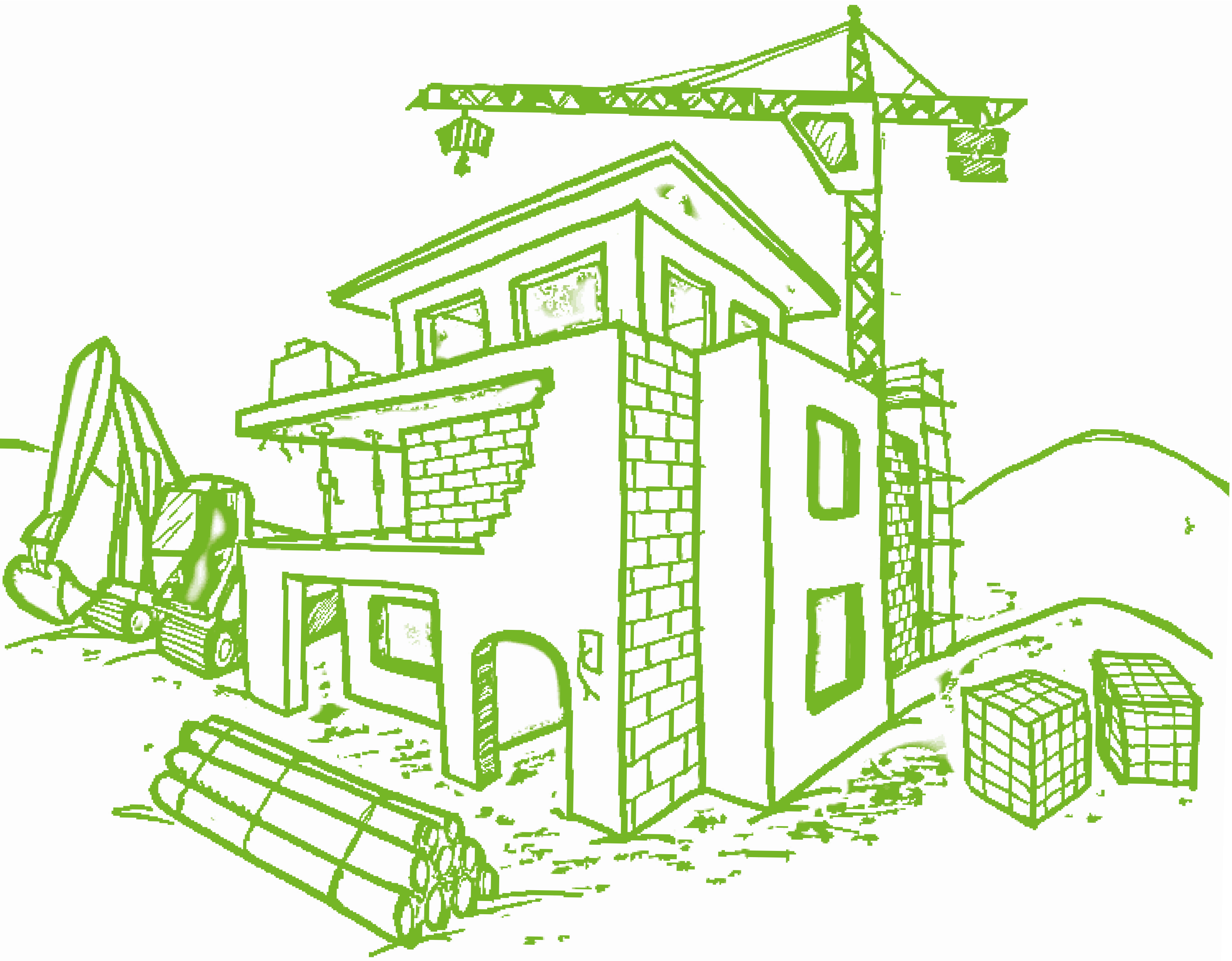
Source: Johnson Controls

Construction

Facts & Figures

No. of companies	317,300
Employees	1,900,000
Sales	€172 billion

Examples of bioeconomy:
Wooden structures, composites reinforced with natural fibres, bio-based screw anchors



As raw materials for building, general construction materials, insulation and materials for interior finishing work: regenerative raw materials are appealing owing to their good material characteristics. They improve environmental balance sheets and are often more compatible with human health. Within this context, natural construction materials are increasingly interesting not only for new building, but also for restoration. In addition, there are now bio-based strategies for greater sustainability with conventional products in the construction sector as well – for example, concrete and asphalt. A constructive contribution to bioeconomy.

Since humans have built dwellings, they have used regenerative raw materials such as wood and straw as building materials. Since sustainability and energy efficiency have become increasingly important in the construction sector, the acceptance of bio-based materials is again on the rise. Wood, for example, is being more widely employed in constructive building. Bio-based binders are still in trials. To enhance added value in domestic agriculture and forestry, efforts increasingly go to enlarge the portfolios of natural sources for construction materials. There are likewise new approaches in structural and ground engineering – for example, in rendering petroleum-based processes in building chemistry more climate-friendly in the manufacture of concrete. The construction sector in Germany, with approximately 300,000 companies and 1,900,000 employees, is therefore of key importance in the further development of bioeconomy.

Wooden construction on the advance

According to data from the Federal Bureau of Statistics, construction materials made of wood had a production value of approximately 14 billion euros in 2011. For lumber, this value was about 4 billion euros for planed and 4 billion euros for sawn wood. Owing to its superior characteristics, coniferous lumber contributes the majority here: in 2011 this was 21.6 million m³. For production of wood building materials, wood chips are glued and pressed in the form of board material. Chip board, the most important product in the wood-materials industry, achieved in 2011 a production value of 1.5 billion euros, with 5.7 million m³.

These figures make wood the most important regenerative construction material. This is the result of its building-physics properties: it is not only flexible, light and easily worked – it is also good in load-bearing capacity, stable under pressure and extremely flexurally strong in processed form. An additional benefit is its sustainability: wood stores carbon, manufacture of wood products for construction takes less energy than do conventional construction products and demolition of wooden structures leaves behind no pollution. Binders and adhesives for wood, to be sure, are still primarily made from petroleum-based chemicals – but there are already bio-based alternatives whose effectiveness is currently being tested: for example, binders based on wheat protein and potato starch, lignin and tannin. The related research and development projects are at the focus of a new research funding program that the BMEL initiated in 2014.

HolzbauPlus: German-wide competition with wood

The federal government intends to increase sustainably the use of wood in housing construction and furnishing. In 2013, model projects in wood construction received awards at “HolzbauPlus – building with regenerative raw materials” in nationwide competition initiated by the BMEL. Competition included a total of 151 projects, and the competition was held again in 2014. Private, commercial and public builders can compete with new-construction and restoration projects. Essential building components should consist of wood.

www.holzbauplus-wettbewerb.info

Deciduous trees such as beeches are also processed to lumber in Germany.

A glance at materials used in new construction shows that the construction sector grants key priority to sustainability and energy efficiency. The use of natural material is increasing: already 15 % of new buildings in Germany is now made of wood. Increasingly, architects are also using wood for load-bearing structural members. The nationwide competition for wood, HolzbauPlus, sponsored by the BMEL, has distinguished especially successful projects with this technology (see box). In Berlin, for example, a number of five- and six-storey residential buildings have been recently constructed entirely of wood.

The possibilities of advanced wood technologies, however, mean that experts see a far greater future for wood: for example, for construction of wind-turbine towers more than 100 m in height. The lumber company Pollmeier Massivbau in Thuringia, Germany, specialists in deciduous wood, plans the use of structural beech for such structures. The product is called BauBuche, an innovative material arising from rotary peeling of a beech trunk and bonding of the wood in layers. The result is a high-tech material suitable for structural wood construction. Pollmeier is a partner in the BioEconomy cluster in Central Germany, which received distinction as part of the Leading-Edge Cluster Competition BMBF 2012. This network concentrates on maximum added value and virtually complete use of beech trees.

Wood instead of steel

Advanced wood material is not only potentially capable of reaching extreme heights: in a project funded by the BMEL, researchers at Chemnitz Technical University have examined the possibility of using wood materials to possibly replace supporting components made of steel or aluminium in what is called vertical conveyor technology. Conveyor systems are a key element in industrial production processes and play an important role in warehousing and materials-flow systems. A variety of transport systems is used, depending on the characteristics of the goods conveyed. Vertical systems are primarily required when complex production systems are involved, in order to move certain goods back and forth throughout various levels.

Manufacturers of fibre-reinforced composite materials are also increasingly turning to wood as a source of raw materials. This market has tremendously developed over recent years, with double-figure growth rates in some cases. The largest application area for natural-fibre-reinforced composites is the automotive industry (see section "Automotive sector"), but approaches are also being tested with respect to structural building components (see box).

So-called wood-anhydrite composite systems, developed at Bauhaus University in Weimar, likewise contribute to greater sustainability in multi-storey buildings. Anhydrite is a naturally occurring substance similar to gypsum (calcium sulphate). Compared to concrete, it can be recovered and processed without great use of energy. In a highly impressive trial, engineers from Weimar have directly applied a screed of anhydrite onto wooden elements. The resulting composite components are solid and offer the benefits not only of great load-bearing capacity, but also create a pleasant and healthy room climate. In the project funded by the BMEL, researchers have worked with local small and medium-sized enterprises and with the company Maxit Baustoffwerke GmbH, which extracts the mineral in Thuringia – and which assures regional added value.

Insulation and lining for interior finishing

In an age of energy-efficient construction and restoration, natural insulation materials also enjoy greater demand – their production requires less energy and they have positive effect on household climate and human health. In summer, natural materials provide good heat insulation. In addition, they can absorb great amounts of moisture and are in many ways allergy-friendly. Already today, the market share of insulation made from regenerative materials is approximately 7 %. Coniferous trees, owing to their fibre characteristics, are primarily used to produce wood-fibre insulation. Research efforts in forestry have focused here on more efficient use of coniferous wood as raw material (see section "Agriculture and forestry"). Cellulose from defibrated old paper also serves as

Bio-based screw anchors made of castor oil

Many areas of construction could not function today without synthetic materials. Estimates state that, in the area of construction materials in 2011, the amount of plastics on the basis of regenerative raw materials was approximately 38,400 tons. A salient example here is the plastic screw anchor (wall plugs), an invention by Artur Fischer that revolutionized the possibilities of wall fastening. The company he founded, in Waldachtal in southwest Germany, also now offers on the DIY market anchors made of bio-based polyamide plastic, more than 50 % of whose chemical building blocks derive from castor oil. The finished plastic material is named Polyamide PA 6.10, which costs slightly more to produce but which – according to the manufacturer – sells well. This bio-based anchor was developed from its predecessor, which Fischer had developed together with the chemical group BASF in a joint project funded by the BMBF as part of the Bioindustry 2021 initiative. In production here, microbes are re-programmed such that they can produce in a bioreactor the chemical building block diaminopentane, which is then processed to the plastic polyamide. In tests, bio-based anchors made of this material have been equally effective as nylon anchors.

© Fischer

raw material for insulation. Also used here are hemp, flax, meadow grass, straw and sheep's wool. Market-introduction programmes of the BMEL, by now concluded, systematically promoted the use of natural-fibre insulation in Germany. Between 2002 and 2008, a total of 17,000 home and flat owners had profited from this funding.

The federal government furthermore promotes awareness of the application of natural paints – the market share of which is currently only 3 %. They offer, however, many benefits: for example, wood surfaces treated with natural oils can continue to "breathe". Also, a wall coated with casein-natural resin paint enhances indoor climate. Natural resin/latex glue emits no toxic vapour. Natural paints are produced from natural mineral and regenerative plant sources, and contain far less solvent. These benefits are not offered by conventional chemical products such as acrylic and alkyd products, or by reaction, nitro or polyurethane lacquers. The most important of more than 100 natural-paint products include wall paints, wood finishing agents, natural-resin paints, oils and waxes.

Bio-based components for load-bearing walls

© Andreas Krombholz

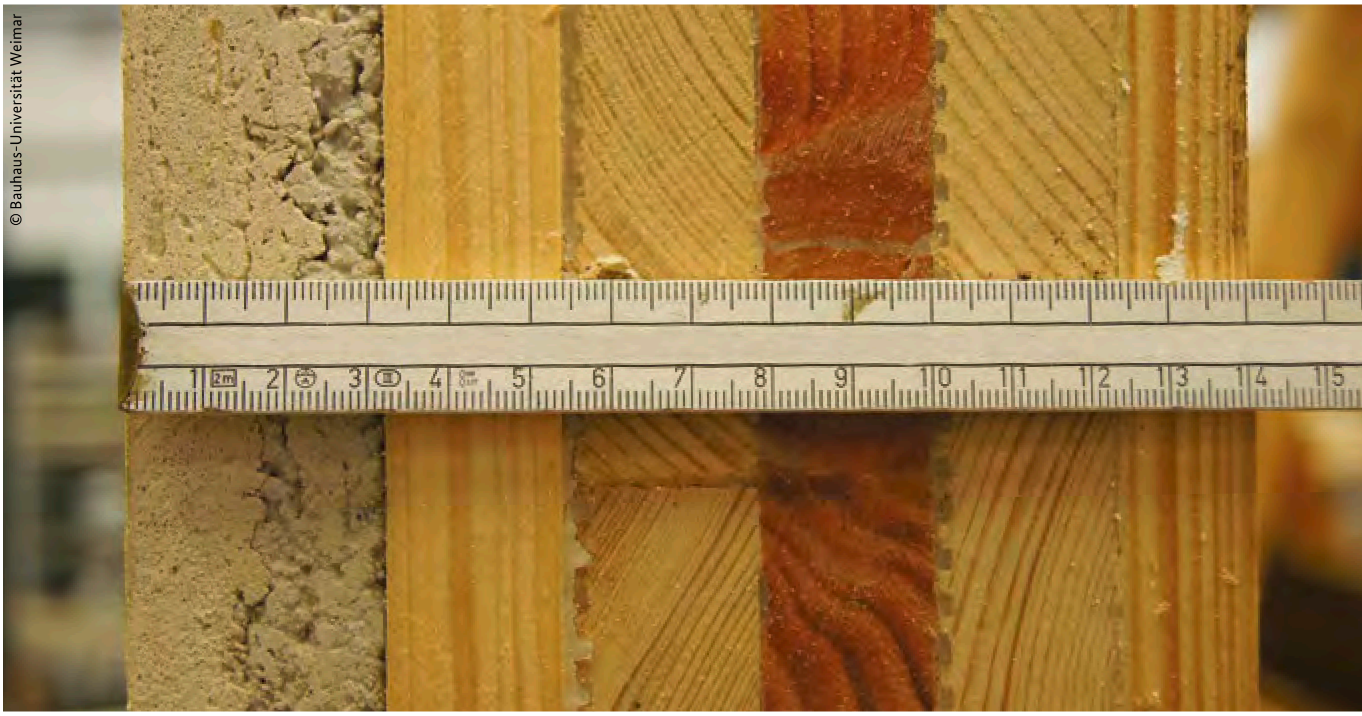
Polymer foam is generally used for heat insulation. When it is combined with sturdy outer layers as a sandwich, however, it can effectively be used for constructive building. In the Ligno-Sandwich Alliance Project, sponsored by the BMBF, seven partners from Saxony and Saxony-Anhalt are developing such building components from parts that are obtained from beech wood. The outer layers of the sandwich assembly are made of phenolic resins (polymers) that consist primarily of the natural substance lignin. The system is reinforced with wood fibres – which produce a sturdy composite made of natural substances. The foam is also bio-based and likewise consists of lignin.

Regenerative raw materials play a greater and more extensive commercial role for flooring. They provide the basis for wood flooring such as parquet, floor boards and laminate – as well as cork and sisal flooring. Linoleum consists primarily of linseed oil, cork and wood dust, pulverized limestone, pigments as well as jute fabric as supporting layer. Current efforts in the sector have addressed the need to increase the use of domestic wood. One good example is the company Timura Holzmanufaktur GmbH from the Wood Cluster Rottleberode in the South Harz district: a key raw materials supplier to the Central German Leading-Edge Custer BioEconomy. Timura has developed, for example, a thermal process for enhancing domestic wood to provide it with the properties of tropical products. Floor boards that are treated with special heating plates are more durable than conventional wood; they are virtually odourless and can be produced in many colour shades.

From bio-waste to concrete liquefiers

Currently, the least sustainable area in the construction sector is chemistry – particularly for the production of concrete, the most important basis for structural and ground construction. Cement, the binding agent for concrete, requires many resources for its production, including water. There are, however, new approaches here as well. With funding by the BMBF, an alliance headed by the biotechnology company Evocatal from Dusseldorf has set the objective of developing a bio-based concrete liquefier that would save even more water than current products.

Already today, other concrete liquefiers reduce water consumption for mixing concrete by around 15 %. These agents also assure that the concrete remains flowable for a long time and that it can support extremely high loads after setting. Until now, however, these high-performance liquefiers were produced from petroleum. For production of a bio-based variant, Evocatal works with



Able to support great loads, and good for indoor climate: in wood-anhydrite composite systems, civil engineers from Bauhaus University in Weimar apply anhydrite, similar to gypsum, directly onto wood.

innovative enzymes. These enzymes can transform waste products from cellulose factories into processable products. Paper manufacture, for example, produces around 50 million tons of the wood substance lignin every year around the world. With the aid of special enzymes, lignin can be transformed to an interesting substitute for concrete. Together with the partners of this alliance, biotechnologists have already disclosed prospective enzymes that could create a rugged and innovative product from the natural substance lignin.

Plant starch is another biopolymer suitable as concrete substitute. This carbohydrate, for example, can be added to shotcrete as used in tunnel construction. Starch ether obtained from maize is added to a mixture of sand and cement. This enables shotcrete to adhere better to walls, and it reduces the material and energy required for lining tunnel walls. In a BMEL-funded project, researchers of the Südzucker corporate group have experimented here with starch molecules that are additionally provided with chemical appendages. At test facilities at Ruhr University in Bochum, this maize-starch additive especially enabled fast early strength of shotcrete – a characteristic much appreciated among tunnel builders.

Asphalt made of discarded frying oil

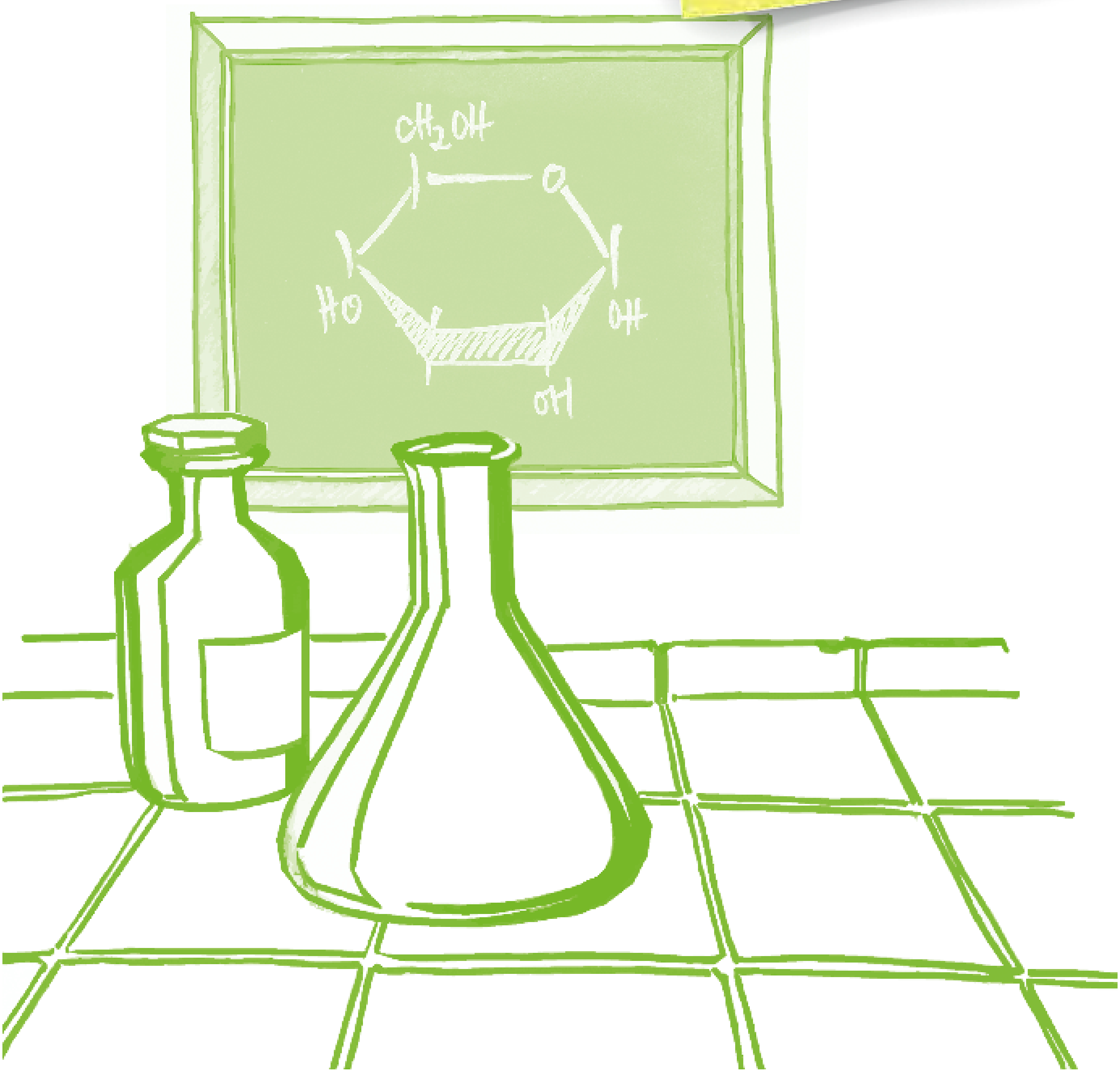
For street construction, researchers have also experimented with bio-based asphalt. Sticky bitumen can be produced from bio-waste: for example, from vegetable oil discarded from frying in the catering trade. Mixed with flue ash from coal-fired power plants, this waste oil goes to produce asphalt that in initial testing has already revealed interesting properties. Further testing will be necessary to determine whether such bioasphalt is effective in uses for rugged and long-lived street and road surfacing

Chemistry

Facts & Figures

No. of companies	2,121
Employees	434,312
Sales	€186 billion

Examples of bioeconomy:
Bioplastics, bio-based platform chemicals, bio-based lubricants



The chemical industry today is still primarily based on petroleum, a fossil raw material. Existing fully integrated modes of production have until now countered comprehensive structural transformation. The topic of sustainability, however, has become increasingly important, as a number of initiatives toward green chemistry have shown. Companies apply bio-based approaches above all when they save costs or improve product quality.

The German chemical industry, with approximately 2,100 companies, is one of the most important basic pillars of the German economy. More than 400,000 are employed in this sector, and major, internationally active chemical groups such as BASF and Evonik have their headquarters in Germany. These companies also represent the majority of annual sector sales, at 186 billion euros in 2012. The product portfolio of the chemical industry is enormous and includes more than 30,000 products. The automobile industry is its largest customer, with around 40 %.

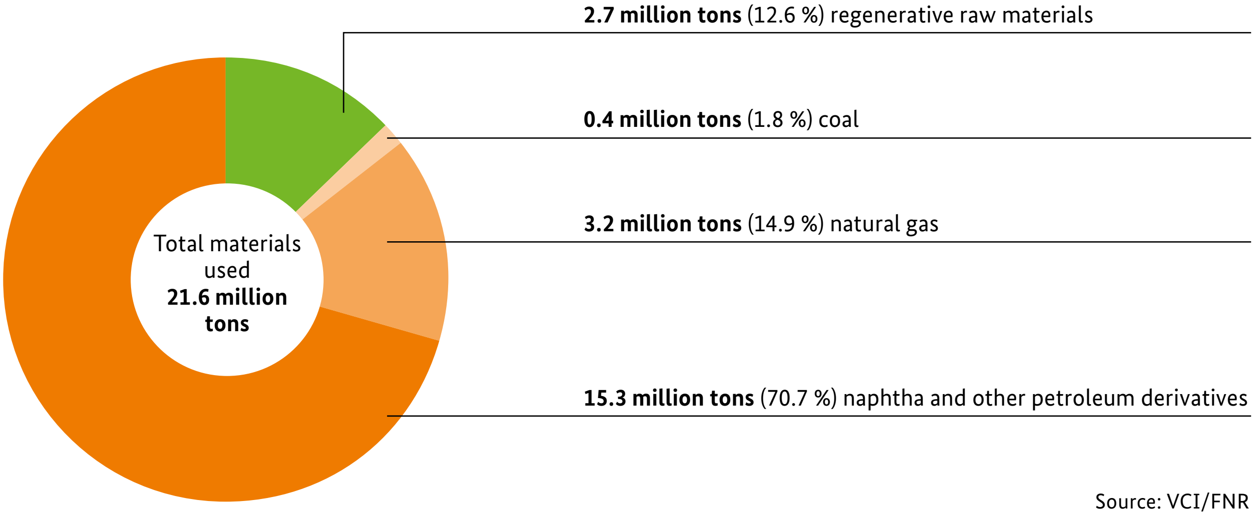
Petroleum and natural gas are presently by far the most important raw materials in the chemical industry. In 2011 it consumed 18.5 million tons of fossil resources (see box). Processed in large refineries and cracking plants, the various constituents of oil and gas serve as source material for production of plastics, adhesives, paint and much more. The top priority of companies in the chemical sector is efficiency. At so-called networked sites, waste products from one reaction often serve as raw materials for a subsequent process. Although the sector invests relatively great sums in research and development, experts see the great extent of integration in production as one reason why extensive transformation of the raw material basis can take place only slowly in the chemical industry. Bio-based processes therefore have the best opportunity if they can be integrated as a drop-in solution in existing facilities: raw materials from regenerative sources whose properties are identical to conventional, petroleum-based platform chemicals. Bio-based platform chemicals with new properties, however, also arouse interest: they open up new possibilities of utilization, because they can be applied in entirely different production stages and application areas. With respect to the environmental balance sheet, the development of new tools has likewise opened new ways in process technology (see section "High-tech tools for bioeconomy"). Benefits of bio-based approaches: like enzymes, microorganisms and bio-catalysers perform many reaction steps with great yield, and at room temperatures under normal pressure – instead of the many conventional chemical processes that typically take place under high pressure and at high temperatures. Around 60 predominantly small and medium-sized enterprises have specialized in this field of activity and are working on the development of technical enzymes and biotechnical production processes on the basis of microorganisms. These companies in industrial biotechnology have demonstrated growing sales in recent years, and the chemical sector – in addition to the food and pharmaceutical industries – is among their key custom-

Raw-materials basis and product portfolio


© Evonik Industries

In 2011 the German chemical industry employed 18.7 million tons of fossil raw materials. Petroleum and natural gas, now as before, are among the most important resources in this sector. Annually, 2.7 million tons come from regenerative raw materials sources. With a share of 27 % in sales, fine and special chemicals are included among the most important products: followed by polymers (20 %), washing agents and body care products (8 %) and basic inorganic chemicals (8 %).

Raw materials basis of the German chemical industry in production of plastics (in 2011)



Source: VCI/FNR

ers. The high-tech tools of biotech companies often serve to optimize existing production steps or to establish new processes.

The majority of regenerative raw materials already used in the chemical industry are animal fats and plant oils from the fruit of palm, rape and soya plants. These oils and fats are further processed to bio-based tensides used in the cleaning and washing-agent industries, and in cosmetic products (see section "Consumer goods").

Bioplastics in the focus of manufacturers

An even greater market for bio-based products results from the manufacture of plastics. These substances represent the second-largest product segment of the chemical industry and are for the most part now based on petroleum (see diagram above). They are used for a great number and variety of applications, primarily in the automotive industry (see box on page 25). The share of bio-based processes, nevertheless, has increased steadily. Bioplastics, to be sure, are not new inventions. On the contrary: the very first industrially produced synthetic material was manufactured in 1869 and was a biomolecule: celluloid. It was only at the beginning of the 20th century, however, that the first plastics based on petroleum were invented. Beginning in 1956, large-scale production processes were initiated for the plastics polyethylene and polypropylene, which now dominate the market. Since then, the palettes of plastics for the many and various areas of application have continuously grown (see illustration). Since the early 1980s, industry has once again focused attention on bioplastics. There are two basic, different types of bioplastics: first, biologically degradable plastics – which must not necessarily be produced from regenerative raw materials (there are also petroleum-based, biologically degradable plastics). On the other hand, there are bioplastics made of regenerative raw materials that are not necessarily biologically degradable (see diagram on page 28).

Today, starch and cellulose are especially important starting materials for the production of bioplastics. Initially, starch-containing fruits such as maize and potatoes were used as raw materials, but research now concentrates on utilizing regenerative resources that do not compete with food production. This development has placed greater emphasis on substances such as chitin, chitosan and lignin – which occur as waste products in other areas of the economy, and which until now have hardly been used. These substances also include waste products from the food industry such as casein from milk that can no longer be sold, animal fat from abattoir waste and proteins from rapeseed processing.

Evonik, the specialized chemical group, also makes intensive use of regenerative raw materials for production of plastics. In 2013 this company opened a new production plant in Slovakia, where it produces bio-based gamma aminolaurin acid (ALS), an alternative to petroleum-based laurolactam. These two chemicals serve as starting materials for production of a particular polyamide type called PA12. Owing to their outstanding strength and toughness, polyamides are often used as construction materials. This synthetic is also used in the automotive industry, for household appliances and for sports articles. The pilot plant in Slovenska Lupca, Slovakia, is intended to promote process development for large-scale industrial application. At present, Evonik still uses palm kernel oil, but in later development stages it plans to use biological waste materials.

A research network funded by the BMEL pursues the objective of especially using rapeseed, a domestic oil plant, for production of plastics. The company Phytowelt GreenTechnologies GmbH in Nettetal, Germany, is coordinating this alliance – called System Biotechnology with use of Regenerative Raw Materials – which consists of 17 project partners. Participating companies come from throughout the value-added chain. A number of project partners have concentrated here on enhancing cultivation conditions for the source material needed for production. Other companies have focused on the mechanical harvesting of plant oils, and still others are responsible for promoting the conversion of raw materials into valuable chemicals. Members of this alliance include research facilities, small and medium-sized enterprises and large corporate groups.

Bio-based platform chemicals

Moreover, microorganisms as producers of bioplastics have become interesting, since they – as biological mini-factories – can use various natural raw materials as sources. This applies, for example, to the production of

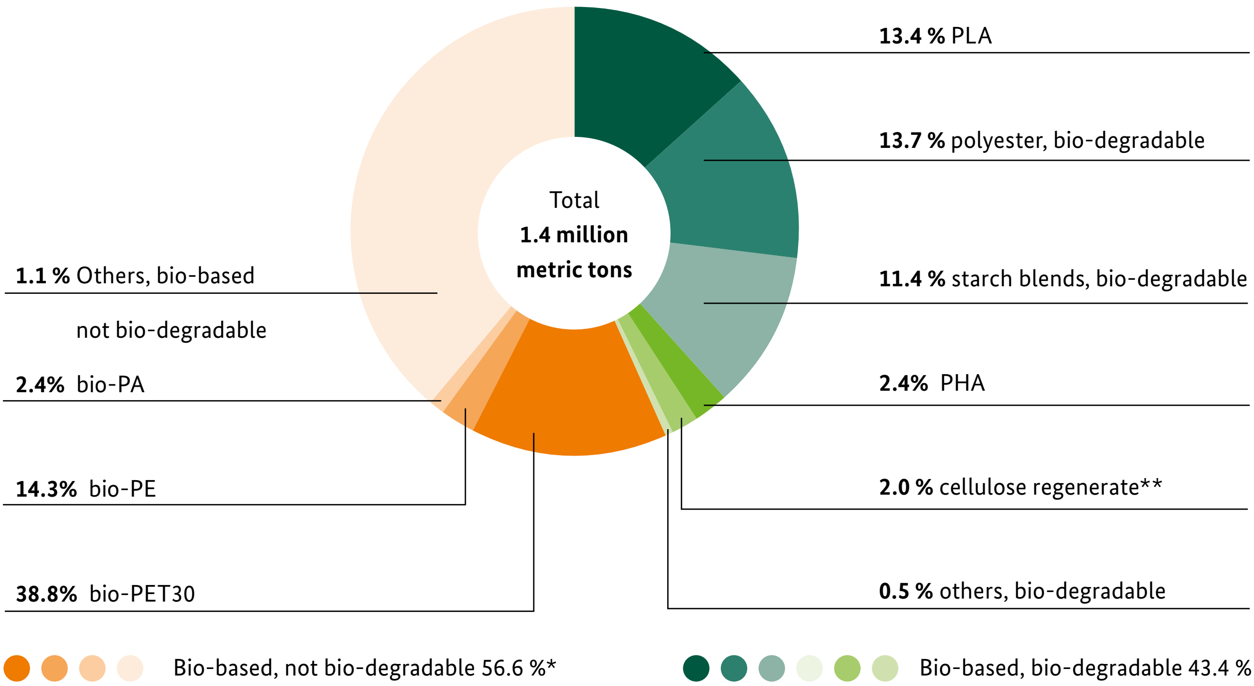
At the Fraunhofer Center for Chemical-Biotechnological Processes (CBP) in Leuna, wood is broken down into its individual chemical constituents.

succinic acid. This chemical is an essential precursor product in the manufacture of plastics such as polybutylene succinate (PBS) and polyurethanes. It can also be used for the manufacture of nonwoven fabrics – which in turn are widely used for sport clothing, furniture and construction applications. In this context, BASF and the Dutch company Corbion Purac have carried out research in the field of bio-based succinic acid since 2009. A joint venture with headquarters in Dusseldorf was founded under the name Succinity GmbH, which plans to promote production and marketing of bio-based succinic acid. Joint efforts here succeeded in producing a dedicated microorganism: *Basfia succiniciproducens,* a microbe that enables flexible application of various raw materials sources. Thanks to a closed, cycle-based production system, moreover, it is possible to prevent major waste flow. Since 2014 a plant in Spain annually produces 100,000 tons of bio-based succinic acid, and an additional factory is already in planning.

BASF has not yet progressed so far with bio-based acrylic acid. This product serves as starting material for production of highly absorbent plastics such as used in sanitary articles and baby nappies. In 2013 BASF introduced a process that succeeded in producing on a pilot scale a key intermediate product for manufacture of bio-based acrylic acid: 3-hydroxypropionic acid (3-HP). Bio-based succinic acid is also on the agenda of the steel producer Thyssen-Krupp. The company, through ThyssenKrupp Uhde GmbH, its business area for plant engineering and construction, built a production plant for bioplastics in Leuna, a site with a long refinery tradition. Thyssen-Krupp invested five years and more than 20 million euros for conversion work to produce the first European multi-purpose fermentation plant for continuous production of bio-based chemicals.

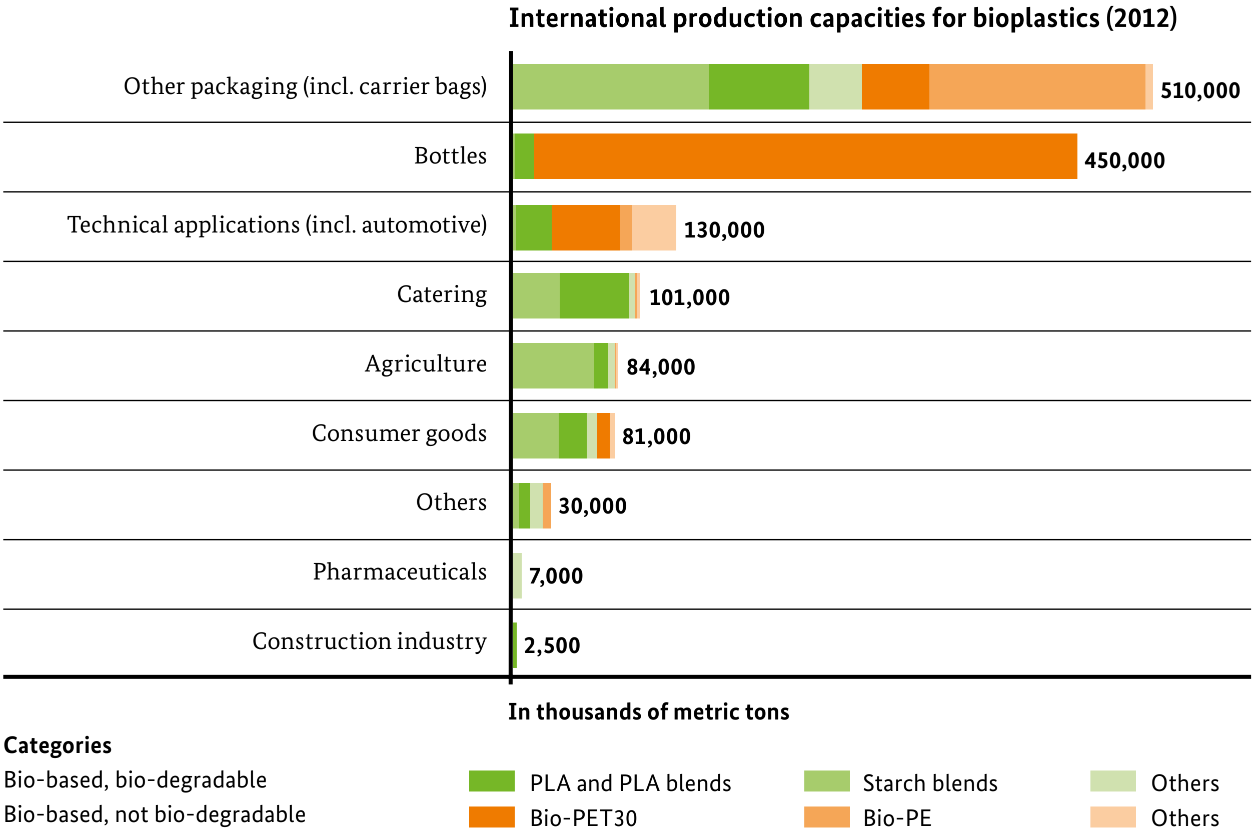
The ThyssenKrupp product portfolio includes not only succinic acid, but also lactic acid – a substance that forms the basis for the synthetic polylactic acid. The capacity in

Production capacities for bioplastics in % (2012)



* Includes drop-in solutions and technical polymers
** Only hydrated cellulose film

Source: European Bioplastics, IfBB



Source: European Bioplastics, IfBB

Leuna allows for annual production of more than 1,000 tons of succinic acid and lactic acid, as well as for testing on an industrial scale of fermentation and pre-processing techniques developed in the lab. The results, in turn, are applied for customers around the world. In the USA, ThyssenKrupp Uhde – together with the US company Myriant – operates a facility that currently produces 13,400 tons of bio-based succinic acid per year. As a result, a biorefinery research centre has by now become established in Central Germany that enjoys international recognition. Leuna forms the core of the BioEconomy Cluster launched by the BMBF in early 2012. More than 60 partners from science and business from Saxony and Saxony-Anhalt have concentrated their competence there in order to push the biorefinery concept (also see section entitled "Bio-based production"). By now the French company Global Bioenergies also has a location at this site and carries out research on innovative methods of producing so-called light olefins. This entails platform chemicals: the starting points for production of numerous further products. Olefines include, for example, isobutene, propylene and butadiene. These substances could not until now be produced by bio-technological means, since the required metabolic paths do not exist in bacteria. By applying the methods of synthetic biology, the company Global Bioenergies has now developed new, artificial metabolic paths and has inserted genetic information for the required synthetic enzymes into *E. coli* strains. This new gas-generating fermentation process requires no distillation and therefore offers an enhanced environmental balance sheet. The BMBF has funded establishment of the required pilot facility in Leuna with approximately 5.7 million euros. This plant will include two 5,000-litre fermenters as well as a complete purification system – and will accordingly model all aspects of an industrial plant. The production capacity in Leuna of up to 100 tons of isobutene per year will enable offering this basic material to interested industrial companies for

Nylon from wood waste

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Nylon is the oldest fully synthetically produced synthetic fibre in the world. It results from linking two basic materials obtained from petroleum: adipic acid and hexamethylenediamine. In the future, however, it could at least partially be possible to produce this polyamide fibre by bio-technological processes. Researchers at the University of the Saarland are working on production of adipic acid with the aid of bacteria. *Pseudomonas putida* microbes will be employed in future to crack the compounds required for the biosynthesis of adipic acid from wood waste. The biotechnological production of adipic acid offers a genuine alternative to the previously necessary, energy-intensive petrochemical synthesis of the basic material required – one hitherto producing climate-relevant gas. In initial tests, it was possible to lower the energy consumption of the production process by approximately 25 to 50 % of that with petrochemical technology. Interest among the 20 to 25 major nylon producers in the world is therefore great. It will be necessary, however, to render industry-compatible this new process developed on laboratory scale. The BMBF is funding with around 1.4 million euros the required efforts as part of the program Validation of the Innovation Potential of Scientific Research (VIP).

their own test purposes. Isobutene can, for example, be used for the production of plastics, elastomers and fuel. Sugar is still being used as bacteria nutrient, but plans are for the facility also to operate with agricultural residue. Over the coming three years, a comprehensive funding research program is planned to aid in the optimization of these processes.

Biological lubricants

By supplying oil and grease, the chemical industry provides the basis for the extensive product spectrum of lubricants. For recent years in Germany, annual domestic sales of lubricants have remained constant at just over 1 million tons. Commercially, bio-based approaches have until now played only a subordinate role. Their market share is around 3 % – primarily owing to their higher prices, but also because of ignorance of their use. Presently, the greatest uses of biolubricants are as oils for hydraulic systems, chain saws and for concrete formwork (see section "Mechanical engineering"). It is not, however, only from aspects of sustainability that biolubricants offer a series of benefits. In fact: they are often biologically degradable, they are non-toxic in many cases and – at least compared to petroleum-based products – they provide greater lubrication effectiveness. Current research work also includes efforts to expand the raw material basis of biolubricants. The company Danico, for example, has developed a process that uses sunflower oil as basis for biological high-performance lubricants.

Other companies are aiming at expanding the potential application areas of biolubricants. With funding from the BMEL, eight partner firms – under direction of the company Fuchs Europe Schmierstoffe GmbH in Mannheim – have begun to adapt bio-based lubricants for use in offshore wind parks. This Mannheim group also participates in the alliance Technofunctional Proteins, under leadership of Animox GmbH. The fourteen partners have invested 9 million euros in this alliance, with half of this amount coming from the BMBF. Objectives here involve not only new sources for biolubricants, but also for binding agents, paints and pigments. Every year in Germany, oil mills produce about 1.5 million tons of pressed residues from rapeseed plants that cannot be used for animal fodder. This residue provides the raw materials for the alliance. Researchers from Animox and the Fraunhofer Institute for Process Engineering and Packaging (IVV) in Freising, Germany, have attempted to extract proteins from this residue. Proteins, to be sure, exhibit many properties that would make them widely applicable – but the chemical industry lost sight of them long

Use of regenerative raw materials in the chemical industry (in tons)

	2008	2011
Plant oil and fat	1,100,000	1,000,000
Animal fat	350,000	210,000
Chemical starch*	272,000	187,000
Starch-equivalent chemical ethanol*		87,000
Chemical sugar*	136,000	60,000
Sugar-equivalent chemical ethanol*		44,000
Chemical cellulose	300,000	401,000
Proteins	24,000	139,000
Others	525,000	591,000
Total for regenerative raw materials	2,707,000	2,719,000

*Diverging database in 2008

Source: FRN (2014)

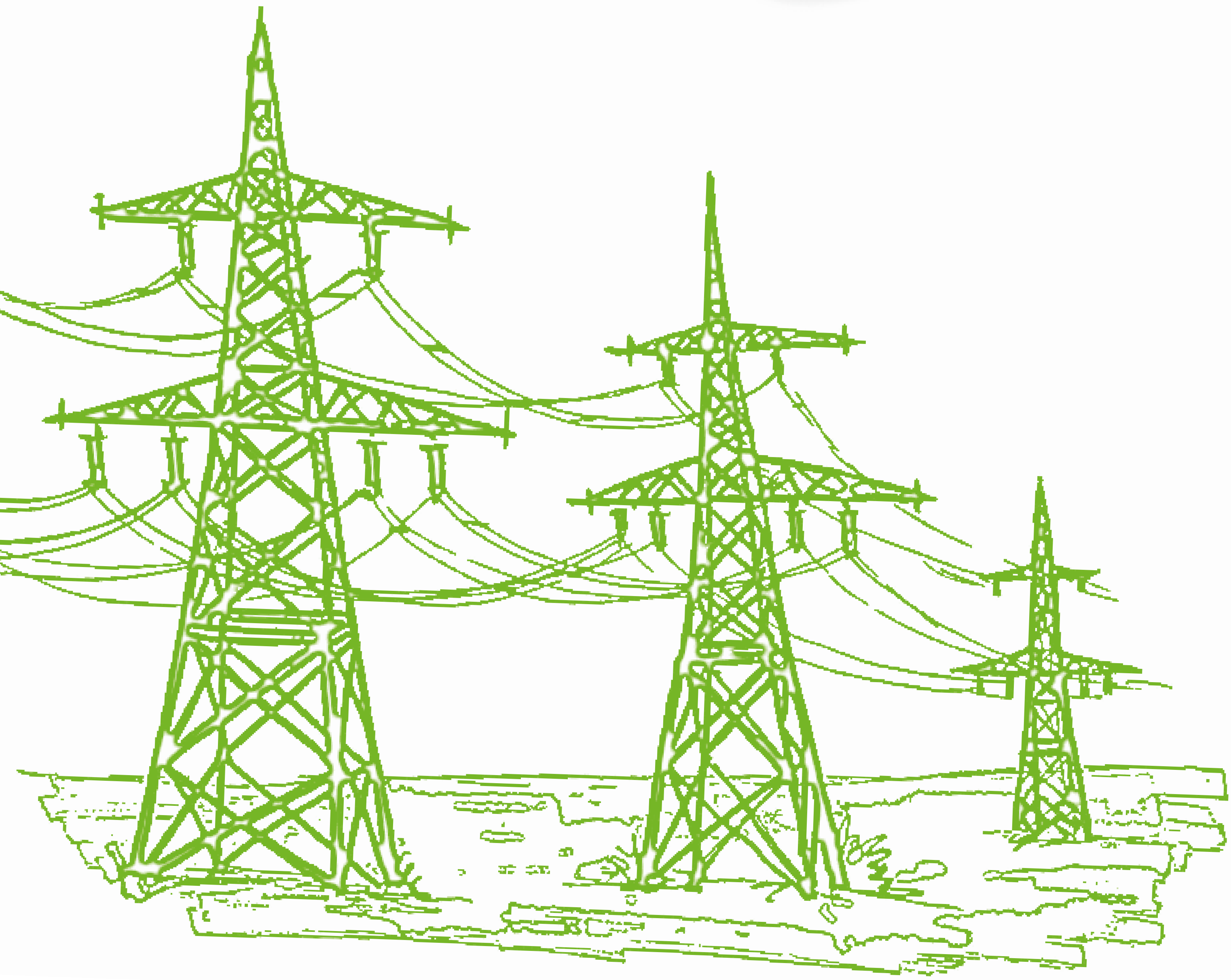
ago. The alliance has set as goal the establishment of proteins – in addition to previously used carbohydrates, greases and oils – as additional regenerative raw material in the chemical industry. Enzymes and hydrothermal processes can modify protein molecules such that they can serve as basic materials or additives for producers of biolubricants, adhesives, paints and pigments. The company Landshuter Lackfabrik – a paint producer – and the cleaning-agent specialist Vermop are also members of the alliance.

Energy

Facts & Figures

No. of companies	923
Employees	220,157
Sales	€466 billion

Examples of bioeconomy:
Wood-pellet heating systems, biogas, biodiesel, bioethanol, synthetic biofuels



In the form of firewood, fuel or biogas: a great diversity of energy media can be obtained from biomass. Bioenergy, as a regenerative energy form, is a key pillar in the energy mix of the future. Attention is now shifting to the efficient use of plant residue, in order to avoid competition with food production. Exploiting the potential of sustainably cultivated energy crops, and promoting innovative process technologies – these are important steps in the bioenergy sector.

Biomass – plants as well as plant and animal residue and waste – is valued among renewable energy carriers for its versatility: it can be used to produce heat, electric power and fuel. Wood fuels are typical for solid bioenergy carriers: for example, wood chips and shavings and wood pellets. Liquid bioenergy carriers include biofuels such as plant oil, biodiesel fuel and bioethanol. Biogas and biomethane constitute the gaseous energy carriers. In addition to the great diversity and flexibility of biomass, there is an additional benefit: biomass can be stored, and bioenergy systems can be flexibly controlled. As a result, they offer the potential of compensating for the fluctuating availability of other regenerative energy sources such as wind power and solar energy.

According to data from the Working Group on Renewable Energy Statistics (AGEE-Stat), Germany in 2013 covered 12.3 % of its final energy consumption with renewable energy. Bioenergy, with a share of 62 % of renewable sources, represented the greatest renewable contribution. As a share of final energy consumption, bioenergy covered 7.7 %. Currently, bioenergy is especially widely used for heat production: of bioenergy used in Germany, 36.7 % is used in the form of heat. For provision of heat, biomass is by far the most important regenerative energy source: it supplies approximately 80 %. In the electric-power area, biomass is the second most-important source of renewable energy: it provides 8 % and ranks second only to wind energy.

With its energy transformation (Energiewende), the federal government intends to increase appreciably the share contributed by renewable energy. Its objectives are for 55 to 60 % of electric power to come from renewable energy sources by 2035 and for 80 %, by 2050. In addition to wind, water and sun, bioenergy represents an important building block toward this objective in this energy mix. Energy from regenerative raw materials supports climate protection: when biomass burns, it releases exactly as much carbon dioxide as an equivalent sustainably produced plant has absorbed during its growth. Regenerative biomass in turn absorbs the released amount of CO_2, which closes the circle. Economically, bioenergy contributes to regional value added and creates jobs in rural areas. This has become evident, for example, in the growing number of bioenergy villages and regions that have grown up throughout Germany.

Upswing for bioenergy

The Renewable Energy Law (EEG), which regulates government subsidies for power production from renewable sources, has enabled vigorous growth in the German bioenergy sector over the past 14 years. This boom, however, has been accompanied by definitely problematic aspects. These include, for example, the fundamental danger that the use of biomass for energy will compete with the production of food and fodder, and with land areas that would otherwise be interesting from the standpoint of nature conservation. The enormous increase in cultivation of only a few energy-plant species – one-sided in some areas – can, in case of continued increases, have deleterious effects on ecosystems. An important objec-

© KIT/Markus Breig

At the Karlsruhe Institute of Technology, plant residue is transformed to synthetic fuel in a pilot plant.

tive is to attenuate the competition among fodder, food and fuel: for example, with a new generation of biofuels obtained from organic residues and waste materials, and not from plant fruit. In Europe and Germany, the pathways of using bioenergy are presently being re-evaluated and their basic conditions adapted as required. In 2014, the Renewable Energy Law was revised for the fourth time. The objective formulated by the federal government for the future will be to concentrate primarily on waste and residual materials in the use of biomass for energy. Concepts and technologies that enable innovative use of sustainable bioenergy will continue to be key points of interest.

Wood: important source of heat

Wood as raw material is of great importance as fuel. Around 60 million tons of wood are burned every year in Germany – chiefly as split logs in the ovens and boilers of private households. With financial support from the government Market Incentive Programme (MAP), the number of automatically fed and low-emission wood-pellet and wood-chip heating systems has risen. To meet this demand, approximately 2.3 million tons of pellets and 6 million tons of wood chips, as regionally available biofuels, are sustainably produced annually in Germany. Around 90 % of renewable heat is produced from biomass, of which over 70 % originates from wood. In view of rising prices of fossil energy carriers, forest wood and wood waste offer previously untapped potentials for production of heat. Traditionally, wood has primarily served as supplier of heat. Single- and multi-family dwellings can today be heated cleanly and efficiently with wood-pellet systems. The advanced and fully automatic technology of pellet heating enables significant reduction in air-pollutant emissions such as fine dust and carbon monoxide. Large-scale wood power plants – often fired chiefly with scrap wood, over-matured wood, and wood residue from forests – simultaneously produce electric power and heat for communities and urban districts by means of cogeneration technology. Now, after technology for wood-gasification in combined heat and power plants (CHP) has in recent rears achieved market and series-production maturity, pellets and wood chips can also produce heat and power in smaller cogeneration systems.

In addition to used-wood markets and forests as energy-wood suppliers, attention also shifts to so-called short-rotation forestry, in which fast-growing trees such as poplars are planted. Once they are planted, their wood can be harvested every four years, and the trees produce new shoots. Such husbandry of wood crops, similar to permanent crop cultivation in vineyards, offers benefits over other energy crops with respect to climate protection and ecological compatibility. The Federal Ministry of Food and Agriculture (BMEL) promotes this field with many and various research and development projects.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In biogas plants, microbes ferment energy crops and liquid manure to biogas.

Fuel from straw: a biorefinery in Straubing produces cellulose ethanol

© Clariant

In Straubing, in Bavaria, the chemical company Clariant has built the largest German demonstration plant for biotechnological production of second-generation biofuels . The plant complex, an investment for 28 million euros partly funded by the BMBF and the Bavarian state government, since 2012 produces ethanol fuel from wheat straw and other agricultural residues. The Sunliquid process uses microbes to crack the long-chain lignocellulose contained in plant fibres. In a second step, yeast then ferments the resulting substances to biofuel. The process, which is virtually climate-neutral, annually converts around 4,500 tons of straw into 1,000 tons of cellulose ethanol.

In a joint venture with car maker Mercedes-Benz and the mineral-oil company Haltermann, initial fleet tests have already taken place. These tests are designed to determine whether a mixture of 20 % bioethanol from regenerative raw materials and 80 % premium grade gasoline is suitable for daily use in series-production vehicles.

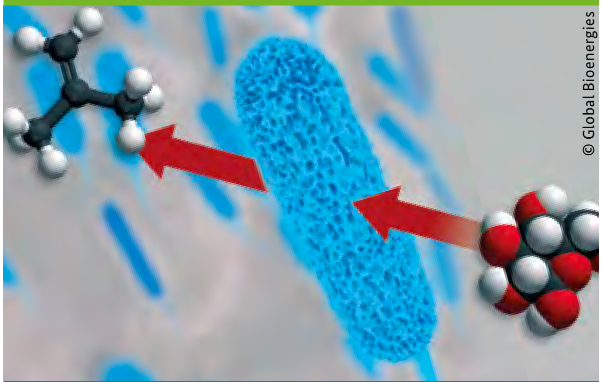
Biogas: energy from domestic fermentation

Biogas plants transform energy crops, animal excrement such as liquid manure, and other residual materials into biogas. In airtight containers known as fermenters, microorganisms ferment biomass to a gas mixture, which consists primarily of methane and carbon dioxide. The resulting biogas is then burned as fuel in combined cogeneration plants (CHP), which produce heat and power. After fermentation, organic material remains and can be used in fields as fertilizer – which closes regional materials cycles. Some plants can also process biogas to biomethane. This process enhances the methane content and the quality of the biogas such that it can be fed into the natural gas network.

During the past ten years, the biogas sector has grown tremendously, driven by financial incentives within the context of the EEG. More and more farmers are additionally becoming "energy farmers". According to the German Biogas Association, there were about 7,700 such biogas facilities in Germany in 2013, which produced 24 billion kWh of power. By far the majority of these plants are located in Bavaria and Lower Saxony. The relevant sector association has counted 40,000 workers who are employed in construction, operation and maintenance of such plants – as well as in cultivation of energy crops. Sales volume was approximately 6.6 billion euros in 2013.

Germany is considered the world leader in biogas technology. This sector, which extensively consists of small and medium-sized enterprises, generated around 40% of its sales in foreign business during 2012. In production and process engineering there is still great potential for improvement, especially in interlinking of the individual steps. The main constituents, for example, in the fermenter – the bacteria and microbsial community at work there – have until now been insufficiently characterized. The BMBF funds a number of collaborative projects in the funding initiative known as Bioenergy – Process-Oriented Research and Innovation (BioProFi), which has addressed this issue. The development of sensors for measuring the fermentation process, and of catalysts for purification of biogas, involves additional aspects with which biogas researchers are experimenting. For years now, the BMEL has also dedicated one focus of its attention to increasing the efficiency of the biogas process. The biogas boom has indeed noticeably changed the face of agriculture in a number of regions: for example, by massively expanding the cultivation of maize as the most productive of energy crops. This, however, has not only restricted diversity, but has in some areas impaired the soil and environment owing to one-sided agriculture.

Leuna: isobutenes from the cell factory



© Global Bioenergies

The French company Global Bioenergies has developed a biotechnological process in which bacteria produce the gaseous carbohydrate isobutene. Here, bacteria that serve as production organisms are provided with innovative metabolic pathways and are converted to serve as cellular gas factories. These bacteria are nourished with sugar molecules from regenerative raw materials. Global Bioenergies is currently opening facilities in the Leuna Industrial Park, in Germany, in order to render this process industrially applicable. The Federal Research Ministry is granting 5.7 million euros of funding for the construction of a new pilot plant within the context of backing the BioEconomy Cluster. This pilot plant is designed for production of up to 100 tons of isobutene annually. As part of an alliance, the car manufacturer Audi will test a bio-based drop-in fuel in automobiles to verify everyday suitability.

Sustainable cultivation concepts for energy crops are therefore a key objective for research funding. The BMEL funds numerous projects to expand species diversity on fields dedicated to energy crops, and to optimize cultivation techniques. Methods considered include crop rotation with annual alternation, as well as companion planting. For several regions of Germany, energy crops adapted to certain locations have been investigated and confirmed as suitable: for example, sorghum millet, the sunflower, the cup plant *(Silphium perfoliatum)* and other wild plants that can be used as energy crops.

Biofuels – obtained from straw

Biofuels support mobility, since they can be used to power internal combustion engines in automobiles, transport vehicles, ships and aircraft. Biofuels are presently the most important renewable alternative for energy-efficient transport structures of the future. In 2012 biofuels covered 5.7 % of German fuel consumption. With annual consumption of 2.2 million tons, biodiesel fuel in 2013 represented the lion's share of the German biofuel market, whereby 1.2 million tons of bioethanol were marketed. It is possible to use biomethane without restriction as fuel in natural-gas vehicles.

Biodiesel fuel is manufactured, primarily from rapeseed oil, at over 30 production locations in Germany. By mixing bioethanol with super-grade petrol, it is possible to produce bio-based fuel for spark-ignition engines. In 2013, the Bioethanol Trade Association reported production growth of over 9 % at the nine production sites in Germany: that year, 672,000 tons of ethanol was manufactured, primarily from sugar beets and cereal grain.

Toward the goal of a new generation of biofuels, manufacturers will concentrate more on complete use of biomass. Ideally, the biomass employed will not compete with food production. Straw and wood chips will be used, and virtually no fruit. So-called biorefineries can transform regenerative raw materials, usually with the aid of biotechnical processes, into valuable products. In high-tech multi-function facilities, the material and energetic exploitation of biomass are interlinked as closely as possible. In order to set the course for biorefinery research and development, the BMEL, together with the BMBF, has commissioned experts to assess the potential of various concepts. Their Biorefineries Roadmap was presented in 2012. A biorefinery demonstration plant for biofuel manufacture has already been launched in Straubing, Germany (see box). Moreover, a company at the Leuna industrial location is likewise aiming at biotechnological production of isobutene, a gaseous biofuel (see box).

Thermochemical path to fuels

A thermochemical utilization concept is being pursued for so-called biomass-to-liquid fuels (BtL). This process transforms, at high temperature, the complex molecules of biomass to synthetic gas: a mixture of carbon monoxide and hydrogen. This synoptic gas is then transformed to liquid hydrocarbons, the desired fuel. The elements also contained in the biomass – such as nitrogen and sulphur – are removed. The resulting synthetic fuel is free of foreign matter and therefore demonstrates combustion characteristics superior to conventional diesel fuel.

A further benefit of synthetic fuel is the potential of using entire plants. Commercial exploitation of the technology has not, however, proved feasible to date – and intensive research on biomass-to-liquid fuels is in progress. The Karlsruhe Institute of Technology (KIT) is developing a process for production of synthetic fuel under the name "bioliq". Together with an industrial partner, KIT is using residual biomass such as straw to create biofuel in a four-stage process. The first stage is particularly characteristic here: the dry residual biomass is transformed locally by fast pyrolysis into a substance with great energy density, one similar to crude oil. This substance can be cost-effectively transported over long distances for central further processing. Work at the pilot plant at the KIT entails testing the entire process chain in its interactions, and optimizing it for large-scale industrial application. Until now, 27 million euros from the BMEL has been invested.

Algae: fuel from green oil sources

Attention is increasingly being directed to microalgae and cyanobacteria for biofuel production. These microorganisms offer the benefit that, with photosynthesis, they can use solar energy to produce energy-rich sugar molecules from carbon dioxide. Depending on their type and cultivation, these organisms store various concentrations of lipids, carbohydrates and proteins. Key technical problems must be solved, however, until the organisms can be used on industrial scale in the sense of the biorefinery concept: for example, the manner in which purification of the bio-based products can be improved.

Upwind: fuels from algae oil for aviation

Global society and a properly functioning international economy are not imaginable without mobility. It is precisely for aviation that biofuels can deliver a climate-friendly alternative to petroleum-based kerosene. One green source for aviation fuel: single-cell algae. They use sunlight directly as energy source, reproduce rapidly and allow cultivation outside agricultural areas. A number of species contain large shares of fatty oils – which are especially interesting for production of bio-based aviation fuel. Test flights with algae-based kerosene are nothing new, but appreciable improvement is now required for algae cultivation and the associated biofuel production. Scientists at the Forschungszentrum Jülich, in collaboration with 12 partners in the AUFWIND ("Upwind") cooperative project, are investigating the extent to which biomass from microalgae is suitable as basis for the production of kerosene. Key issues here are the cost-effective and ecological feasibility of the process. The BMEL funds this project with 5.75 million euros. A dedicated Algae Science Centre has been set up in Jülich for these purposes. Airbus, the largest European aircraft manufacturer, is also a participant in the project.

Agriculture and forestry

Facts & Figures

No. of companies	285,000
Employees	1,000,000
Sales	€32 billion

Examples of bioeconomy:
Bio-based raw materials, aquaculture, farmed wood, plant and animal breeding

Agriculture and forestry are two key pillars of bio-economy. Plant-based biomass, produced in meadows, fields and forests provides the foundation for a bio-based economy. Livestock, in turn, represent an essential resource for the supply of food. Recent research approaches and technologies will further advance sustainable developments in agriculture and forestry.

Animals and plants form the foundation for a bio-based economy. Agriculture and forestry additionally represent an essential economic factor: more than 300,000 companies are active in this field in Germany. The significance of agriculture and forestry for added value in rural areas is great. Those at work on farms and in forests husband more than three-fourths of the area of Germany. After the Second World War, one farmer could feed ten people: today, the number is 147. During recent years, many farmers have expanded their area of activity. They produce, for example, bio-based raw materials for industry as well as biomass for renewable energy. This includes industry and energy crops such as rapeseed and maize, in addition to by-products such as liquid manure and straw. From agricultural biomass, fermenters produce source materials for bio-based plastics and other sustainable chemicals (see section "Chemistry"). Biogas plants and CHP stations likewise supply heat, power and fuels (see section "Energy"). Around half the German farmers also own forests. Wood as raw material goes into many and various products: lumber, plywood, engineered wood, wood-synthetic composites, paper, cardboard, bio-energy pellets and briquettes.

Precision agriculture on the advance

This ongoing development of agriculture in the sense of sustainable and resource-efficient husbandry is based in good part on the tremendous technological advances made over recent decades. In arable farming, for example, precision agriculture is becoming increasingly important. Intelligent tractors and harvesters have already become reality: equipped with sensor systems, on-board computers and satellite navigation, tractors and other farm machines can record plant status as they travel over the fields. They compare this status with programmed fertilizer requirements, combine results with geodata and fertilize the fields exactly in accordance with soil characteristics and nutrient demand. Precision agriculture thereby contributes to demand-driven, environmentally friendly and energy-saving arable farming – and to the reduction of fuel use, agrochemicals and fertilizers. Technical agrarian innovations have also decisively enhanced animal husbandry and animal health. The modern stall is often equipped with high-tech sensors for demand-driven control of supply of water and feed to animals – and to enable automatic milking. Such technological developments will in future contribute to reducing resource consumption in agriculture and to further advancing farm management in the sense of sustainable agriculture. In the context of bio-economy, it will be essential to interlink the diverse

Alliance of agrarian researchers

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DFA, the German Agrarian Research Alliance, is a joint project in German agrarian research. This strategic network, which brings together selected agrarian scientists from public research institutions, pursues the objective of enhancing the performance, the transparency and the international visibility of German agrarian research. The focus of work at DAFA is identification of research challenges. DAFA works with its own specialist forums on the topics of livestock, legumes, grassland, aquaculture and the future of systems of organic farming. The Federal Ministry of Agriculture has funded initial development of the DAFA since 2010 with start-up financing.

More information: www.dafa.de

knowledge in individual areas of agriculture even more extensively than until now, and likewise to further integrate upstream and downstream areas of work.

Increasing farm yields and using resources sustainably

These goals apply especially in view of global demand development: which confronts domestic agriculture with many and various challenges. As a result of the growing world population, demand for biomass is rising steadily. It is not possible to meet this demand simply by growing more plants, since the global availability of farm area per capita is decreasing. The reasons here are sprawling settlements, erosion, effects of climate change and non-sustainable land use. Experts accordingly believe that the increasing demand for biomass can be met especially by improvement of cultivated crops and by innovative and environmentally benign methods of cultivation. Agrarian research and plant breeding can provide impulses here. In international comparison, Germany occupies a favourable position in plant research. In addition to around 30 universities, 25 institutes in Germany conduct agrarian plant-related research at various locations. These institutes include major research organizations and federal government departmental research institutes such as the Julius Kühn Institute and the Johann Heinrich von Thünen Institute. The work of these two institutes is financed by the Federal Ministry of Food and Agriculture (BMEL) and the Federal Ministry of Education and Research (BMBF). In the agrarian area, research is also conducted at many small and

Making crops fit for agriculture of the future

For high-yield grain, robust sugar beets and faster-growing poplars: The development of crops that meet the requirements of the future demand innovative research approaches. Research activities for applied plant research that are funded by the BMBF are concentrated under the aegis of PLANT 2030. Currently included here are the funding initiative called Plant Biotechnology for the Future, as well as funding projects that are part of the transnational programme PLANT-KBBE. Public research institutions and companies involved in plant breeding and related areas of bioeconomy collaborate here. Private participants themselves finance part of the costs for their sub-projects. The privately owned companies are organized in the business association Wirtschaftsverbund PflanzenInnovation (Plant Innovation, or WPI). The projects for applied plant research are especially supported here by knowledge assembled in genome research over recent years. The insights collected are interesting for all of agriculture. German plant researchers have made internationally recognized contributions around the world: for example, in mapping the sugar-beet genome. In preparation of the most detailed gene catalogue to date for barley, German researchers participated in an international consortium in a leading capacity – and have set the course for the complete sequencing of the complex genome. These findings can now be incorporated into further development of new barley varieties, and in optimization of cultivation methods.

More info: www.pflanzenforschung.de

medium-sized agricultural enterprises, as well as at facilities of the German States, including the institutes of the Leibniz Association (WGL).

A number of objectives have driven research for the husbandry of plants in the sense of bio-based economy. One prime goal is increasing the yield of crops by use of plants that are more robust and better adapted to respective environmental conditions. Advanced plant breeding, however, should also contribute to enlargement of plant diversity and to enhancing the spectrum of substances produced by plants. Demand is especially great for new varieties that are resistant to stress factors such as drought, lack of nutrient and excess of salt. Additional guidelines include an optimum of efficiency and sustainability in using available environmental resources such as soil, water and nutrients – while keeping sight of biodiversity.

Cooperative projects in the BMBF funding initiative Innovative Plant Breeding within the Cultivation System (IPAS), for example, investigate the benefits and disadvantages of new techniques in plant breeding. The overall objective here is to consider plants in an overall system and to examine current developments in agriculture with regard to their social, ecologic and economic consequences.

Focus on the genomes of barley and sugar beet

Plant genome research, which represents an essential building block in plant breeding, addresses the following questions: How have plants adapted over the years to their environmental conditions? Which plant characteristics are genetically embedded in traditional plant varieties, and which have possibly become lost in the course of modern breeding? Between 1999 and 2014, the BMBF funded researchers in science and business with approximately 160 million euros, within the context of the funding measure Genome Analysis of the Plant Biological System, (GABI), in order to address such questions as these. These activities will be continued in the initiative PLANT 2030 (see box).

In conjunction with studies conducted on model plants, researchers together with companies are investigating important crops on the molecular level. One example:

Innovation promotion by the BMEL

Plant breeding: In research funding granted by the BMEL, plant breeding naturally enjoys high priority. In the BMEL Programme for Innovation Support, for example, the Ministry funds projects that contribute to assuring the adaptability of cultivated plants and their quality under varying local and climatic conditions. This is an important contribution to safeguarding food supply for the world. A current supportive measure is part of the project Breeding of High-Yield Wheat Varieties. With cultivated area of over 215 million hectares, wheat is one of the world's most important crops. The application and use of advanced techniques of plant breeding is intended to contribute to assuring supply of wheat as human food and animal fodder, and as raw material – under the climate changes that have become apparent.

Plant protection: The efficient and environmentally benign protection of plants is one of the decisive elements toward assurance of a sufficient quantity of plant products as well as associated high plant quality. The innovation programme of the BMEL promotes the optimization of integrated plant-protection techniques: from diagnosis of plant disease to computer- and geoinformation-supported decision funding for the use of plant-protection agents.

Agricultural technology: An additional important element for assuring the supply with raw materials from cultivated plants is efficient agricultural technology. Here as well, the innovation programme of the BMEL funds ongoing optimization, whereby current emphasis is directed to aspects of information and communications technology for open- and closed-loop control, monitoring and automation of the machines employed.

Barley ranks after wheat ass the second most important grain in Germany. Despite its size and complexity, the genotype of barley has by now been almost entirely decoded. An international consortium under the direction of scientists from Gatersleben, Germany, has per-

In advanced greenhouses, researchers at the Helmholtz Centre for Environmental Research in Bad Lauchstädt, Germany, are investigating how various climate conditions affect the growth and yield of plants.

formed a thorough inventory of the barley genome and has prepared a comprehensive gene catalogue. This molecular-genetic map is an extraordinarily valuable resource for plant researchers and plant breeders around the world, because it enables complete sequencing of the barley genome. Consequently, new varieties of barley are developed as a next step. Similar sequencing projects are also underway for other crops – for example, for the sugar beet. German researchers are likewise playing important roles here in decoding and in genome analysis.

Plant scientists can use a great variety of tools here (see section "High-tech tools for bioeconomy"). They aid in detecting interesting characteristics and, under use of biotechnological methods, in accelerating the overall breeding process. Also involved are research approaches that – with the aid of the latest techniques – can simulate various climate scenarios in the greenhouse and, on this basis, can calculate consequences for growth and yield. Such projects are being carried out, for example, at the Helmholtz Centre for Environmental Research in Bad Lauchstädt, Germany. Whereas the long-term and global effects of climate change are being intensively studied, there have so far been hardly any robust conclusions concerning extreme weather conditions that regionally fluctuate greatly as a result of climate change.

To obtain sound information on this issue, the BMEL has additionally initiated the research project entitled Agricultural Extreme Weather and Risk Management Possibilities. The ministerial research institutes of the BMEL, the Thünen Institute and the Julius Kühn Institute in collaboration with Deutscher Wetterdienst (DWD, Germany's National Meteorological Service), as well as various external research units, are executing this effort as a cooperative project. Initial findings indicate that hailstorms, late frost, drought and water build-up represent the greatest challenges for farm operations with vegetables, fruit, vineyards and hops. In contrast, storm damage, extreme drought and heat are most significant for forestry. In spring of 2015 the experts involved submitted a final report. Furthermore, observations of transforming external characteristics of plants are becoming increasingly important. To examine and understand the effects of certain genetic alterations on a plant, it is essential to study its interaction with the environment. This takes place by means of phenotyping: searching for plants according to complex external characteristics or properties, and recording these characteristics without harming or destroying the plants. To develop such capacities in Germany, the BMBF has since early 2013 funded the German Plant Phenotyping Network (DPPN) in Jülich, where a high-throughput facility to measure plants is being set up. Insights that are being gained here – in collaboration with researchers at the Helmholtz Centre in Munich and at the IPK in Gatersleben – can in turn be incorporated into plant breeding.

Ecological agriculture: more effective green manure

For organic farmers, sustainable bio-based operations have been the core of their work for many years. To farm with methods that conserve resources, protect the environment and minimize intrusions into nature, organic farmers value closed-cycle operations to the maximum possible extent. They also cultivate the fodder for their animals primarily on their own farms. They shun the use of easily soluble mineral fertilizers and chemical substances for plant protection. To keep the soil fertile, organic farmers fertilize primarily with solid or liquid animal manure – or they regularly cultivate crops such as field beans, peas and clover, which enhance the fertility of the soil. In 2012, approximately 23,000 farms (7.7 % of all) operated on the principles of ecological agriculture. In total, they farmed around 6 % of all agriculturally used land in Germany: just over one million hectares. As with their conventionally farming colleagues, the topic of yield is also an important issue in organic agriculture – also not least with a view to the increasingly great demand for organic products in society.

Interest is consequently great in new research findings on land use and soil fertility, and in other strategies to sustainably raise crop yields. The potential for legumes is considered by no means to be exhausted here. The rhizobia on the roots of these plants fix nitrogen taken from

Nitrogen collectors on the fields: fertile soil from legumes

Organic agriculture attempts to achieve farming in harmony with nature, especially by avoiding chemical plant protection and mineral fertilizers, In fact, plant-protection agents are permitted in organic agriculture only to a highly restricted degree. Instead, these farmers use stall manure, liquid manure and fermentation residue from biogas systems as nutrients. They also use legumes.

In arable farming, legumes serve as nitrogen collectors and protein sources in animal husbandry. The cultivation of peas, field beans and lupins is essential; it, however, is considered demanding and is inferior to other cultivated plants from a business standpoint. Experience has also shown that fields show symptoms of soil fatigue after several years of such cultivation. In an interdisciplinary alliance project on soil fertility – as part of the Federal Organic Farming Scheme (BÖLN) funded by the BMEL – strategies were tested between 2008 and 2012 in 32 farms that were aimed at optimizing cultivation of legumes. Project results showed a great variety of new ways for farm practice: for example, measures for supplementary soil fertilization with wood chips, composted green waste and restriction of unwanted plant growth. In the context of the Protein Plant Strategy published by the BMEL in 2012, a series of additional research and network projects has been launched throughout Germany that is aimed at improving the cultivation and the use of legumes along the entire value-added process chain.

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the air. They accordingly represent an important fertilizer source for soils. They are likewise rich in proteins and are therefore a valuable source of proteins. In the context of bioeconomy, the federal government funds projects in conjunction with the Protein Plant Strategy that are designed to lead to renewed increase in Germany in the breeding of protein-rich lupins, soya, peas and field beans (see box on page 43).

Promoting wood production by systematic cultivation

Forests are one of our most important natural resources, since wood is a valuable raw material for a great diversity of industrial sectors. Within this context, the federal government in 2012 published its Forest Strategy 2020. The purpose of this strategy is to find a harmonious and viable balance between the increasing and partly competing expectations of society for forests, and their sustainable output capability. This strategy also stipulates strategic objectives for sustainable wood production from German forests. Cultivation plays a key role here, since tree breeding is particularly expensive and tedious. Nevertheless, to assure long-term continuity, the institutions of the federal government and the states that are responsible for breeding forest plants have produced a Breeding Strategy under the direction of the Thünen Institute for Forest Genetics. This strategy is planned for the coming 15 years and applies to six tree species. This strategy is the basis for an initial alliance project, FitForClim, which is funded through the Forest Climate Fund of the Federal Ministries of Agriculture and of the Environment. To assure that the forest of the future is suited for its respective climate and location conditions, the Thünen Institute for Forest Genetics collaborates here with the forestry experimentation laboratories of the German states in supply of viable and high-value forest reproductive material for the following species of trees: Douglas fir, spruce, pine, sycamore maple, larch and oak. Work here includes identifying zones of use, selection of trees for planting and development of breeding populations. Plant technologies and insights gained into forest genetics can accordingly help to develop new reproductive material faster. This also applies to the economically important market with Christmas trees: Germans spend almost 700 million euros for approximately 29 million of them every year. As part of the BMBF funding initiative KMU Innovativ (SME Innovative), research is conducted at the tree nursery Baumschulen Oberdorla to breed robust Douglas and other firs and to breed them

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Poplar harvest in short-rotation forestry: after three years of undisturbed growth, the tree trunks are cut down and shredded.

clonally with the techniques of *in vitro* reproduction. One objective: a Christmas tree that thrives well in plantations and grows with uniformly high quality.

In the BMEL cooperative project FastWOOD, in which eight partners participate, the objective is to assure the satisfactory cultivation of poplar, willow and locust trees and to improve the required conditions for large-area, reliable and cost-effective cultivation in short-rotation forestry. In addition to breeding, one major objective is to exploit the potentials of unused raw materials. In this way, and following the exceptional storm damages to forests over the past decades, tree cultivation stands have been established in many federal states in which pioneer forests consisting of stands of such trees as birches, alders and willows have developed. New trial approaches for the handling of such stands are being pursued: for example, in the PioWood project funded by the BMEL and coordinated by the Institute of Forest Science of Freiburg University.

Strengthening sustainable livestock husbandry

In addition to plants, livestock represent indispensable resources for supply of humans with high-quality food. Especially in view of the necessity of securing food for a growing world population, experts estimate that worldwide demand for high-quality food from animal sources will double by 2050. Climate change, dwindling resources and changes in consumer expectations give rise to further challenges. Resource-conserving and species-adapted animal husbandry is therefore of major significance in bioeconomy and also plays a major role in numerous and various research projects at universities, research facilities outside universities and in institutes of ministerial research. To enhance networking of expertise throughout German regions, the BMBF has since 2010 funded a number of Competency Networks in Agrarian and Food Research – which help to apply agrarian-science know-how in the solution of social problems. A network coordinated by Kiel University, for example, works with dairy research. These scientists closely examine the entire value-added chain, including animal feeding, dairy production and consumer health. These researchers collaborate with companies in the dairy and animal-feed industries.

Trout are widespread aquaculture fish.

Agrarian scientists in a network directed from Rostock concentrate in turn on research into characteristics of cattle and pigs that are interesting from the breeding standpoint, whereby their work is based on genome analyses and bioinformatics. Indeed: innovative approaches leading to more robust livestock more resistant to disease are increasingly in demand. In the Synbreed Cluster coordinated by Technische Universität München and funded by the BMBF, livestock geneticists have successfully searched through the genotype of Fleckvieh cattle to determine inheritance patterns that positively influence the health of an animal: for example, brown fur around the eye region. Such a “spectacle” pattern is a desirable characteristic for grazing cattle. Logically, it is understandable that reduction of solar radiation helps to ameliorate eye disorders. Within the framework of its innovation funding, the BMEL likewise supports numerous research projects for animal husbandry. Transnational projects in the European ERA Network include ANIHWA: Animal Health and Welfare, which is jointly funded by the BMBF and BMEL. These efforts are directed to imported pathogens, the prompt identification and isolation of diseased animals, as well as the development of new diagnostic techniques and vaccines. New avenues here concern antibiotics and alternatives to their use in animal husbandry. An important topic in livestock research furthermore consists of dedicated measures toward reducing emissions and preventing excessive fertilization. Cows, pigs and other farm animals emit climate-relevant gases such as methane, and their urine and faeces contain phosphorus and nitrogen. Concepts are now being systematically pursued within the context of bioeconomy to reduce these emissions and/or to apply them in an intelligent cycle as raw materials for other products.

Aquaculture on course for expansion

Aquaculture is a special form of animal husbandry that involves controlled breeding, raising and keeping aquatic organisms. This includes not only fish, but also other freshwater and seawater dwellers such as mussels and algae. Aquaculture is worldwide among the strongest-growing sectors in the food industry, with annual growth figures of 5 to 8 %. Good ecological performance makes aquaculture particularly interesting for sustainable production of animal protein. In Germany, aquaculture ranges from close-to-nature, extensively managed pond systems to flow-through systems and closed warm-water cycle facilities. German aquaculture companies are primarily family-owned. In 2012 the Federal Statistical Office reported production of approximately 20,000 tons of fish for human consumption. Germany lags behind, however, on the international market. German aquaculture experts from science and business have, following an EU directive, prepared a National Strategy Plan for Aquaculture (NASTAQ). This plan formulates measures to promote sustainable production increase in aquaculture in Germany as well.

Winter-hardy orchids for the garden – lovely blossoms with innovative reproductive techniques

Orchids are the royalty of ornamental plants. Their reproduction by seeds, however, is a loss-plagued effort and leads to plants of fluctuating quality. It was only with mass clonal reproduction in *in vitro* tissue culture that tropical orchids have become economically affordable. With laboratory engineering, plant researchers in Germany have transferred this reproductive technique to cultivated garden orchids: for example, the lady slipper from the *Cypripedium* genus (left photo). A team from the company Nextplant, a spin-off of Humboldt-Universität in Berlin, developed this technique as part of the BMBF funding measure KMU Innovative: Biotechnology, and has now specialized in the production and marketing of hardy orchids. In May and June, these plants with their purple-white blossoms are a real eye-catcher. Since these orchids are winter-hardy, garden friends can look forward to many years of returning splendour.

There is no lack of innovative approaches. At more than 30 German research institutions, scientists address issues for optimal, sustainable aquaculture. Approaches based on cascade operations are particularly promising: re-use of purified water and utilization of heat emitted from biogas systems have increasingly helped to move aquaculture cycle systems from water to land – and to make them economically attractive. Völkingen Public Utilities, in the state of the Saarland, constructed the first inland marine fish farm. This farm produces sea bass, gilthead seabream and sturgeon – the farm offered the first fish in regional supermarkets beginning in 2014. There are similar operations in the German states of Mecklenburg-Vorpommern and Schleswig-Holstein.

Aquaponics and urban farming

Entirely innovative approaches are being followed, however, to combine plant cultivation and animal husbandry in one circulation system: in aquaponics. Such systems are extensive closed facilities that re-use nutrients, metabolic products, carbon dioxide and water. With funding from the BMBF, the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IG), for example, has developed an emission-free system that allows joint cultivation of cichlid fish and tomatoes (see section “Bio-based production”). Other innovative concepts aim to integrate plant cultivation in urban space – for example, on roofs and on façades. This so-called urban farming is a futuristic vision to cover demand for regional products, and to systematically exploit waste, residual materials and waste heat. The Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT) is conducting work for combination of greenhouse technologies with new concepts, innovative process engineering and material research to meet the specific requirements of building-integrated agriculture and to enable technically, economically and ecologically beneficial results.

Tasty vegetarian diet for the turbot

© GMA Büsum

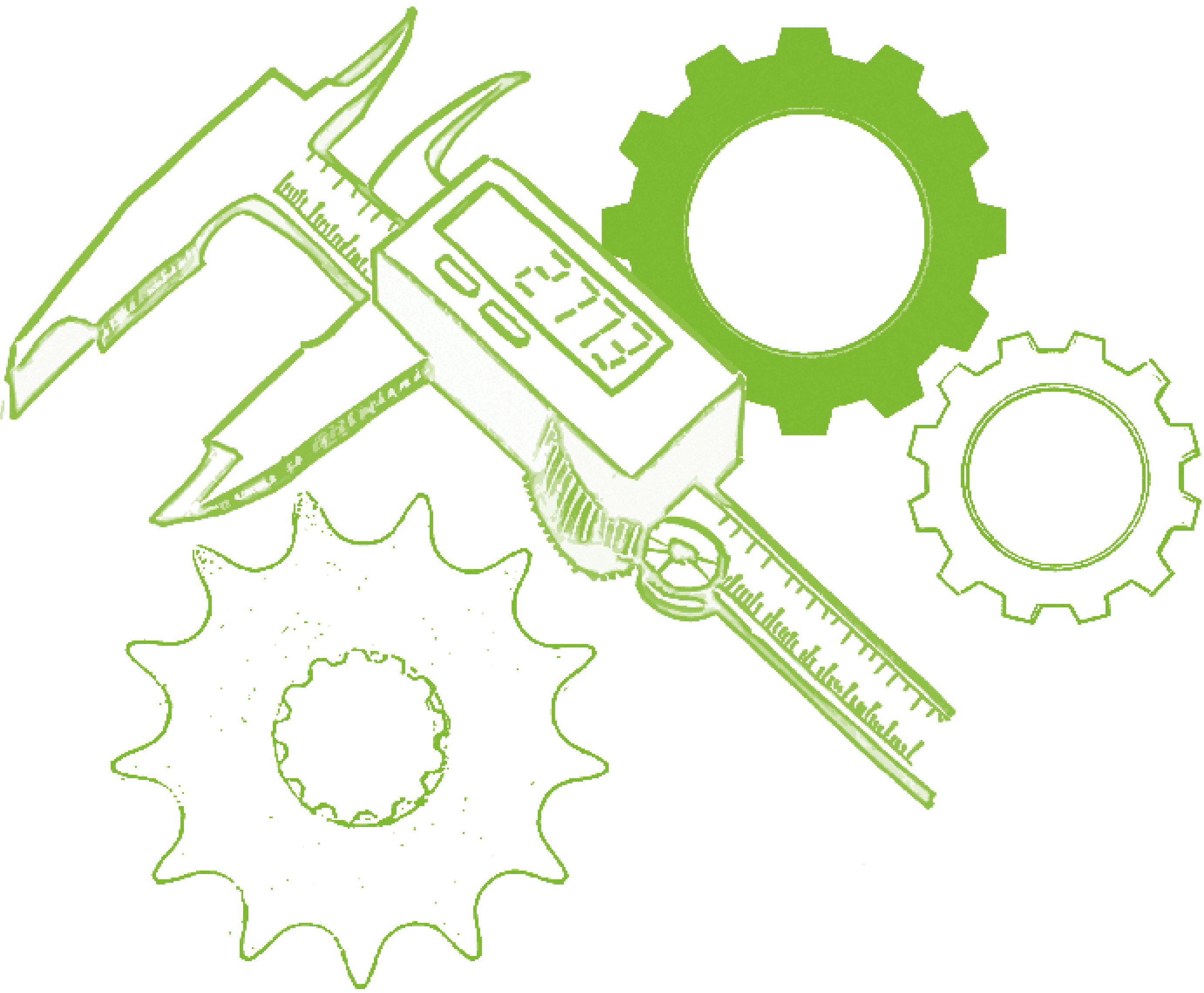
Normally, the turbot in aquaculture is fed with pellets made of fish meal. Now, however, plant raw materials are available as an alternative protein source. These pellets must be physiologically optimized from the nutrition standpoint such that they also taste good to the fish. Researchers from the Gesellschaft für marine Aquakultur (GMA), a research facility for marine aquaculture in Büsum, have for example succeeded in providing an effective additive to rapeseed protein pellets, which has significantly whetted the appetite of the fish for this food. The solution lay in obtaining lipoproteins from common mussels that would otherwise have been discarded as waste. The mussel protein returns the taste of the ocean to the vegetarian fish food. As part of its innovation funding, the BMEL aids cooperative projects that work with alternative feed, new species and sustainable production systems for aquaculture.

Mechanical engineering

Facts & Figures

No. of companies	6,227
Employees	978,000
Sales	€207 billion

Examples of bioeconomy:
Bioprocess engineering, agricultural engineering, measurement and control technology



Germany is one of the leading countries in mechanical engineering. Application of advanced machines, equipment and processes enables efficient and sustainable design of production processes – in all areas of industry and business. For further development of bioeconomy, innovations from mechanical engineering are key drivers.

Mechanical and plant engineering are among the traditionally strong pillars of Germany as economic location: more than 20,000 companies employ around one million people. Plant and machine as well as production and process engineering represent a key factor in a bio-based economy, in order to implement sustainability and resource efficiency. This applies especially with respect to energy requirements and efficiency, and also to lubricants and other materials applied. Engineers always face a special challenge when technical and biological requirements coincide. This particularly applies in the implementation of biorefineries in which various biological raw materials are processed in a single closed materials cycle (also see the section entitled "Bio-based production"). In accordance with specifications and equipment, plants and processes must be specifically developed for handling biological materials – from production of renewable energy in biogas stations to production and further processing of bio-based plastics in the chemical industry. Bioengineering and process technology, as well as plant engineering specialized for this context, play a special role here.

Expertise in mechanical engineering is also in demand when innovative development of agricultural machines, and intelligent measurement and control technology, are required for precision agriculture (see section "Agriculture and forestry"). Also essential here are new developments in the area of bio-based lubricants, and for applications of materials from regenerative raw materials for innovative composites – which, in view of growing demand for sustainable production and other industrial processes, are also increasingly pushing into the market. Here as well, engineers must adapt processes and production, and must assure that manufacturing is fit for series production. In addition, food processing depends on new developments from mechanical engineering. This applies above all to automation processes and to robot-aided procedures and production plants. In bioeconomy, mechanical engineering is therefore among those sectors that utilize many cross-linked networks in numerous and various economic sectors, and that must satisfy numerous and different requirements with respect to applied technical equipment.

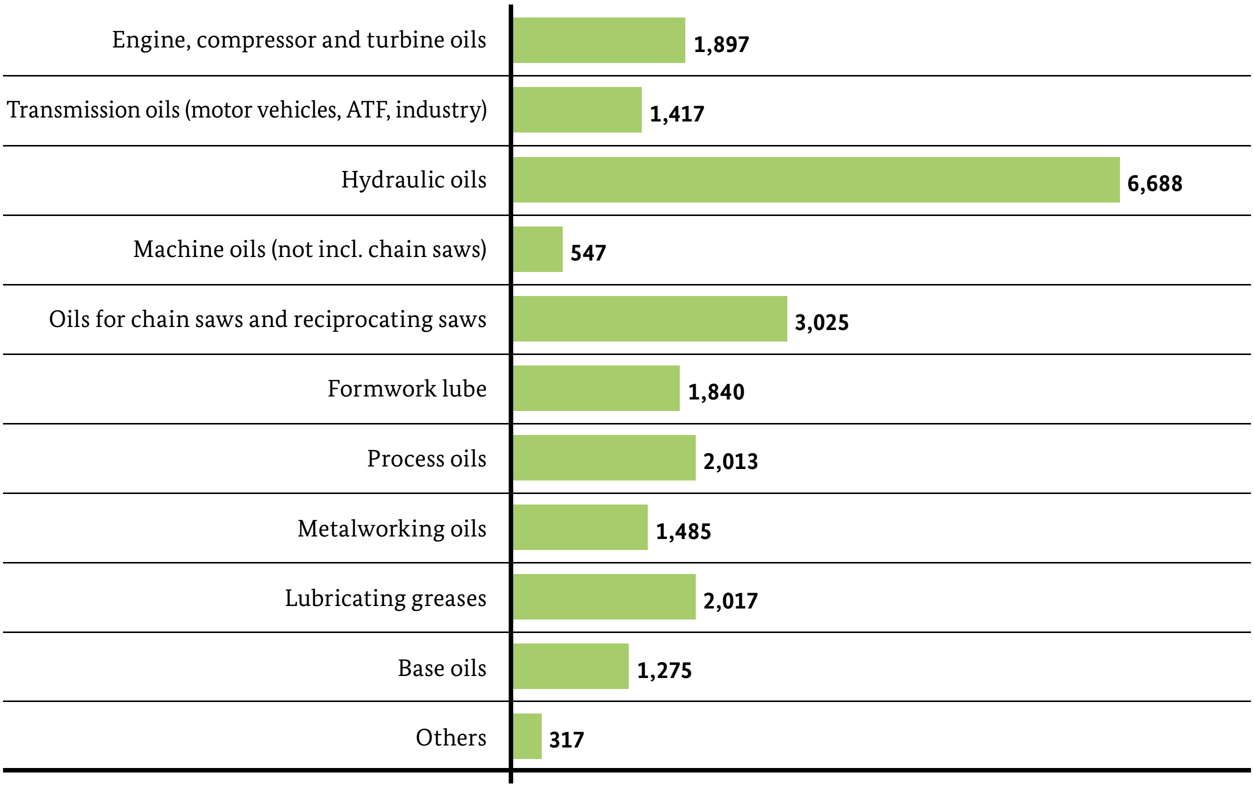
Ideal framework for the biological mini-factory

Great experience has been gained with application of natural resources in the construction of fermenters as they are used in industrial biotechnology. In these steel vessels – also called bioreactors – biological production helpers such as microbes and cells produce large quantities of highly diverse products such as bio-based chemicals, pharmaceuticals, food additives and cosmetic ingredients (see box on page 40). New insights in bioengineering deliver the basis here for designing especially efficient production plants – characterized, for example by low energy demand and high degrees of efficiency. Other important factors are special requirements that

Bioreactors – big home for little helpers

Bioreactors are the key elements in many bio-based production processes. In these vessels – usually giant units made of steel – microorganisms or cell cultures are bred and then employed on a dedicated basis to industrially create products for further use. These include pharmaceuticals as well as early stages of bioplastics. To offer these tiny high-performance manufacturers conditions as near the optimum as possible, numerous process parameters must be controlled. In addition to the type and concentration of the nutrients, such parameters as temperature, oxygen content, pH and many other factors play a role. Apart from the requirements for the organisms, additional technical, organisational and economic factors demand attention, since they influence the choice of operational parameters. As a result, engineers must, for example, assure that uniform conditions prevail in all parts of the reactor space, and that the culture material is not damaged by harsh treatment. It is only by satisfying all such requirements that an efficient, resource-economical process can develop.

Plant oils and grease used in 2011 (total: 22,500 tons)



In metric tons

Source: BMEL/Meo Caron Solutions GmbH 2014

result from new production cultures (microorganisms) and new producers such as algae. The latter, for instance, can supply the required content substances only if they receive sufficient light. With funding by the BMEL, such photobioreactors are currently being optimized for utilization in industry (see section “Bio-based production”).

Challenge for measurement and control technology

The greatest challenges associated with fermenters currently involve the continuous monitoring of the bio-based production process, as well as the demanding purification process at the end of the process chain. Not least owing to cost constraints, user industries are interested in minimizing resource consumption. The Alliance for Knowledge-Based Process Intelligence, funded by the BMBF, is involved in challenges such as these. The company Sartorius Lab Instruments GmbH & Co. KG in Göttingen coordinates alliance work in developing an innovative sensor and software platform (see section “Pharmaceuticals”).

The Strategy Process Biotechnology 2020+ was founded in 2010 by the BMBF in conjunction with universities, non-university research organizations, and polytechnics. This process focuses on innovative concepts for biotechnological production methods that extend far beyond the fermentation and biocatalysis processes in use today. Numerous research projects have been launched as based on a roadmap showing essential development and research milestones. The BMBF has funded this endeavour with a total of 60 million euros. In addition to five major projects conducted by research organizations, university and polytechnics researchers throughout Germany are at work in 35 alliances on a great diversity of ideas for future bio-based production. They include bio-based fuel cells, light-controlled biocatalysts and artificial photosynthesis – as well as micro-system engineering approaches intended to exploit metal nanoparticles for production of innovative manufacturing materials. The guiding principle of all projects is close collaboration between biologists and engineers.

International demand for biogas plant engineering

Expertise from bio- and engineering sciences is also in demand in the bio-energy sector, especially when involving the enhancement of efficiency in the engineering of biogas facilities. A primary key to profitable operation is particularly the extraction of a maximum of energy from a minimum of biomass (see section "Energy"). From the view of experts, there is still particularly great potential for improvements, especially in production and process engineering – above all in the interlinking of individual process steps. The further development of measurement and control technology, moreover, is also of great significance toward optimizing the fermentation process. An additional major technical challenge exists with respect to engines used in linked combined heat and power plants (CHP), where these facilities must operate also in interval mode and not in uninterrupted mode only. For these engines, change from idle to full-load operation is indeed technically challenging. Furthermore, owing to stagnation in demand for new plant facilities, many biogas plant engineers are focussing more on the international market. It is especially in Italy that this demand has sharply risen owing to state incentives. In France, Denmark, and a number of eastern European countries, to be sure, the demand for German biogas plant engineering companies as exporters is great.

Production of bio-based materials

In response to growing demand for bio-based plastics, production engineering has adapted to new requirements, which has led to further developments in injection moulding and related processes. This has involved, for example, composites with natural-fibre reinforcement, and wood-plastic composites. In 2012, 350,000 tons of these hybrid components were manufactured. Not least owing to these developments, Germany represents the most important European market for such products. It can also show a growing list of producers active in this market. Also involved here are numerous research institutions at work on new developments in plastics and wood technologies.

A major challenge involved in the production of bio-based and non-bio-based components is always the requirement for three-dimensional moulding of such parts. This is because wood and natural fibres are less dense than classic mineral fillers and reinforcement materials – a fact which must be considered especially for larger construction components and for light structures. Issues such as these are investigated, for example, at the South German Plastics Centre – one of the four Competency Centres funded by the BMEL in the context of the Biopolymer Network, for development of enhanced processes for treatment of bio-based plastics.

Together with researchers at Paderborn University, studies are underway to determine whether so-called sandwich injection moulding can be used to employ wood-plastic composites as core components in this process – which would thereby open a larger application spectrum to bio-based composites. Sandwich techniques enable production of moulded parts consisting of a core and a skin component. A dedicated injection moulding machine requires a separate injection moulding assembly for each of the two components – each of which must

Biogas plants

In 2013 approximately 7,700 biogas plants, with an installed electrical output of 3,300 MW, produced around 24 billion kWh of power in Germany. This represents about 4 % of total power consumption in the country – and approximately 12 % of power supplied from renewable energy. There are currently about 8,000 of these facilities in Germany. In plant engineering for biogas, Germany is internationally leading.

Biolubricants

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Although biolubricants currently cover only about 3 % of the market, experts expect positive development for the future. These lubricants, produced primarily from biologically degradable oils and greases, offer benefits above all for sustainable production processes. This slow access to the market is largely the result of prices higher than petroleum-based competitors. Presently, the largest shares of the market are in hydraulic oils, chain saw oils and formwork lube. In 2011, around 22,500 tons of plant oils –primarily from rapeseed, fats and palm kernel oil – were used for lubricants (see section “Chemistry”).

in turn lead to a common nozzle. If such a configuration could be employed without technical problems, wood-plastic composites would also emit less odour. This would in turn make hybrid components more attractive for new applications – for example, in the area of furniture manufacture. Researchers see a greater share of the market owing to the fact that a synthetic skin prevents water absorption – which would prevent deformation and expansion in the bio-component. There are also further developments in this field with press moulding and for dosing systems for machines used in the plastics industry for treatment and shaping operations. Already since 2009, the network alliance FENAFA, funded by the BMEL, has worked on various technical challenges involved in the use of plant-based natural fibres in the manufacture of moulded parts. These parts are widely used in the automotive industry (see “Automotive sector”), and in the consumer goods industry (see section “Consumer goods”).

Resource-efficient agriculture

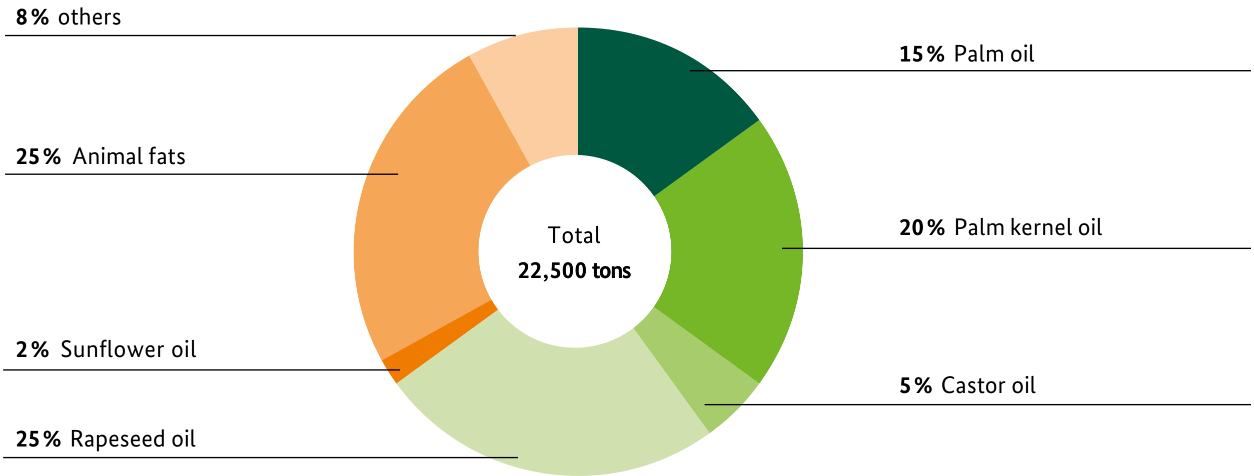
From the viewpoint of bioeconomy, mechanical engineering is significant not only in plant engineering and process technology. Indeed: the farming sector also benefits from the ingenuity of German engineers. During recent years precision agriculture has greatly gained in significance (see section “Agriculture and forestry” and “High-tech tools for bioeconomy”). To allow precision agriculture to exploit its benefits, numerous individual components are necessary that optimally interlink. Mechanical engineering provides innovations here from measurement and control technology and from automated processes that aid in optimizing work procedures in the fields and in the stalls – thereby contributing to sustainability (see section “Agriculture”).

A new development trend in agricultural machine engineering is likewise moving in the direction of field robots. They will primarily be used for heavy and monotonous work in which precise actions over long periods of time are necessary – for example, in fertilizing and sowing. Promising approaches of this kind are also evident in fruit and vegetable cultivation, in which robots can irrigate and harvest. Even sensitive fruit such as strawberries can now be picked by a robot. In addition, sensors are capable of differentiating between ripe and unripe fruits – a key advantage over human harvesters, since much fruit is still being lost in strawberry harvesting when just the right picking time is overlooked. Experts expect, however, that some time will pass before such harvesting helpers are active in German fields on a large scale. Many farmers are still unwilling to make such major investments. Demand is greater at the moment for automated processes in animal husbandry – for example, for milking and feeding animals. Such solutions help above all on large farms to more efficiently monitor applied resources – which contributes to greater sustainability in agriculture (see Section “Agriculture and forestry”).

The greenhouse of the future

Mechanical engineers work not only on the open field and in stalls: in greenhouses they are also working toward sustainable agricultural production – for exam-

Total amounts of oils and greases used for biolubricants (2011)



Source: BMEL/Meo Carbon Solutions (2014)

ple, in construction of greenhouses. The research centre Forschungszentrum Jülich, for example, is working on new glass types with diffuse light transmission. This means that such glass directs every incident beam of light in a different direction. The benefit here is that all leaves of a plant receive more uniform light than with conventional light. Especially with climbing or tall plants such as tomatoes and cucumbers, the leaves on lower levels lie partially in the shade of those above. With diffuse incidence of light in such cases, yield increases of up to 6 % are possible with the same energy input. By using low-iron solar glass with two-sided anti-reflex coating, advanced greenhouses achieve particularly great light transmission. Almost all the light usable by these plants for photosynthesis actually reaches the leaves, with the result that these light conditions in greenhouses are very similar to those on an open field. From the beginning of a plant under glass, this indurates the plants that will later be transplanted to the open, which prevents losses by ultraviolet burning. Enhanced light transmission not only increases yield but – for a number of plants – greater UV transparency also increases the production of flavour.

Robot-supported food processing

Food processing is also dependent on the expertise of engineers to assure resource-efficient and sustainable production processes. Intelligent automation processes, for example, are in demand – for which robotics offers an approach. At the German Institute of Food Technologies (DIL), for instance, intensive research is taking place to develop hygienic gripping techniques that can be flexibly employed. Process analytics is likewise of great significance in this field. It senses and determines the quality of manufactured products and of delivered goods, and provides the systematics for process tracking and control, data analysis and simulation of process procedures. Process analytics ranges from the assay of constituents, to recording of physical and functional characteristics, to tracking and tracing of food products, and finally to product evaluation by the consumer.

Food and beverage industry

Facts & Figures

No. of companies	6,000
Employees	555,000
Sales	€170 billion

Examples of bioeconomy:
Vitamins, aromas and amino acids, lupin ice cream, functional foods

The food and beverage industry plays a prominent role in bioeconomy. This industry processes raw agrarian materials to foods, beverages and animal fodder. Resource-conserving technologies help to manufacture healthy, high-value and safe products. For storage, preservation and transport of food and beverages, the bio-based economy also provides innovative processes.

With around 6,000 companies and 555,000 employees, the food and beverage industry is one of the largest German industrial sectors. According to the Federation of German Food and Drink Industries (BVE), total sales for 2012 were almost 170 billion euros, a European record. This sector is especially characterized by small and medium-sized enterprises, since 95 % of sector companies have fewer than 250 staff. These firms include many traditional family companies and internationally successful manufacturers of German specialties that are closely connected with company locations.

Leading sub-sectors of the food and beverage industry are the meat and meat-products industry, the dairy business, the sweets and bakery-products industry, the manufacture of alcoholic and non-alcoholic beverages and the processing of fruits and vegetables. These activities are reflected by the great diversity of products: more than 170,000 food and beverage products are currently on the market.

For the bioeconomy, the food and beverage sector is a key pillar, since about 80 % of agrarian products in Germany are processed by the industry to high-quality food and drinks (see section "Agriculture and forestry"). Innovative processes for production of high-value ingredients additionally provide an important contribution to making food healthier and safer. Resource-saving processes provide new and more sustainable materials and forms of packaging. Increasingly important, furthermore, are strategies that recycle waste products from the human-food and animal-fodder industries. As a result, the food and beverage industry is not only currently the user of agrarian raw materials, but in future can itself become increasingly a supplier of raw materials – for example, for the chemical industry (see section "Chemistry).

Enzymes and microbes as highly diversified upgraders

For food processing, resorting to nature's toolbox is not a new phenomenon. Indeed: beer has been brewed and wine produced for thousands of years with the aid of the baker's yeast *Saccharomyces cerevisiae*. Cheese likewise represents a traditionally bio-based product. For milk to turn to cheese the milk protein must coagulate – for which rennet enzymes are responsible. In earlier times, rennet was obtained from calves' stomachs. Thanks to advanced biotechnological processes, tailored microorganisms in large steel vessels today carry out the industrial production of these useful molecules, which are now an indispensable part of cheese production.

Alliance for natural food additives

Development of healthier food on a natural basis – this is goal of the consortium Natural Life Excellence Network 2020 – NatLifE 2020. This alliance consists of 22 partners and is coordinated by the biotechnology enterprise Brain AG in Zwingenberg, Germany. It investigates bioactive ingredients for food that have additive benefits. Technologies are employed here that are based on taste sensory cells. Brain AG biotechnologies have modified the function of these cells so that they can serve as test systems in the lab: for example, to identify taste and satiation modulators. Consortium members – which include Analyticon Discovery, Merck KGaA and AB Enzymes – collaborate along the entire value-added chain and apply an R&D volume of 30 million euros. The BMBF funds half this amount within the framework of the Innovation Initiative for Industrial Biotechnology.

Biotechnologists are also responsible for the fact that many foods today contain enzymes as natural biocatalysts. Since the 1960s, microbial processes in fermenters have become established as standard in the production of enzymes (see section "Bio-based production"). Currently, approximately 50 different industrial enzymes are in use in the food and beverage industry. Around 30 biotechnology companies in Germany – all of them small and medium-sized enterprises – have specialized in developing and implementing the resulting production processes. A number of these companies have had part of their technological development work funded by the BMBF and the Federal Ministry of Economics.

Enzymes are resource-friendly multi-talents as manufacturers of food products, since they carry out their work under moderate conditions. In the bakery industry, special enzymes assure attractive and stable bread crusts. Other enzymes in bakery mixtures aid in giving the dough volume and colour. The finish-baking of partially prepared parbaked dough, now widespread, would not be thinkable without such enzymes. Enzymes allow physiological enhancement and more efficient use of other raw food materials.

In this way, pectic enzymes aid in breaking down the plant cell walls when fruit is squeezed out, which increases the juicing yield – and they likewise degrade turbidity material in fruit juices. Other biological processes such as lactic acid fermentation help in the predigesting of animal fodder and human food: for example, in the production of sauerkraut and silage in animal fodder. Lactase is also an important enzyme in the food sector: it enables breakdown of lactose. This enzyme is sold in the form of tablets and capsules to enable humans with lactose intolerance to consume dairy products.

Aromas and amino acids

Enzymatic and fermentation processes also extensively serve as basis for production of natural aroma agents. Numerous flavouring agents are likewise manufactured with the aid of microorganisms. Mushrooms that grow on wood shavings, for example, produce strawberry aroma. Peach aroma is extracted from yeast. The first food additive biotechnologically produced on a large scale was citric acid. Whereas this substance was originally obtained from citrus fruits, the entire world production, to the amount of a billion tons annually, presently stems from a process using the fungus *Aspergillus*

Valuable ingredients for baby diets

Mother's milk is the ideal natural nourishment for babies. In addition to nutrients, it contains a rich mix of goodness – including human milk oligosaccharides. These complex polysaccharides support the development of healthy intestinal flora in infants and protect them from infection by pathogens. Medical experts assume that sugar molecules intercept viruses and bacteria that enter the gastrointestinal tract before they can attack a baby's cells. As a result, the World Health Organization recommends breastfeeding babies until their sixth month. Where this is not possible, baby formula can serve as alternative. The makers of such products have an ongoing interest in continuous improvement of their formulas. Researchers at the company Jennewein Biotechnologie GmbH in Rheinbreitbach, Germany, have accordingly developed a process that allows biotechnical production of human sugar molecules.

Microbes transformed to mini-factories in this way produce fucosyllactose – a sugar molecule that occurs in natural mother's milk. The BMFB funds this family-run company by its measure KMU Innovativ (SME Innovative).

Enzymes have by now become indispensable in the bakery industry. They assure attractive crusts and aid in finishing off parbaked products.

niger. Citric acid is used not only in lemonade drinks, but also wherever a sour taste is intended. An additional important group of food supplements is also biotechnologically produced: amino acids. There are approximately 20 amino acids, and they form the building blocks of which proteins consist. Some amino acids provide a sweet taste, and others add the fragrance of oranges or lemons. The salts of glutamic acid (glutamate) are used in turn as flavour enhancers – and not only in Asian cuisine. The bacterium *Corynebacterium glutamicum* aids in the production of glutamic acid on an industrial scale. Essential amino acids such as lysine, threonine and methionine are also of great importance as additives to animal fodder. Currently, more than one billion tons of lysine is internationally produced for the fodder industry. Such large amounts can be handled by chemical processes only at very great cost. As a result, bacteria re-programmed especially to function as cell factories are now likewise used here in production. The company Evonik is one of the largest producers of amino acids for animal fodder. This specialist chemical group, with headquarters in Essen, Germany, manufactures the four essential amino acids methionine, threonine, tryptophan and lysine. It is currently appreciably expanding its capacities around the world. Evonik is now aiming at annual production of more than 500,000 tons of biotechnologically obtained amino acid L-lysine.

No-calorie sweeteners

Even greater roles on the market are played by enzymatically produced carbohydrates such as glucose and fructose that are used as sugar substitutes. Glucose can be obtained from plant starch by enzymatic hydrolysis. Trends are also apparent toward use of sweeteners with fewer calories that less likely trigger civilization diseases such as obesity. Substances are in demand that taste sweet but that contain no sugar. Such an alternative is an extract from the tropical plant *Stevia rebaudia,* which already sweetens food and beverages without calories. The so-called steviol glycosides are almost 200 times sweeter than conventional sugar. Experiments are currently in progress on the production of stevia sweeteners by biotechnological processes. With the aid of yeast cells, the individual constituents of stevia sweetener can be separately produced with great purity in controlled and monitored fashion. The food industry has thereby enabled the possibility of varying stevia taste in accordance with application, and of entering new areas of use for this sweetener.

Foods with functional ingredients

In the food and beverage sector, functional foods represent a further trend for which bio-based processes can prove useful. This development concerns products that

Greater sustainability in the food chain

How can food be produced and consumed with greater sustainability? Researchers are investigating innovative approaches within the network ERA-Net SUSFOOD (Sustainable Food Production and Consumption). European research activities are being funded here, with inclusion of all relevant players along the value-added chain from the farmer's gate to the consumer. In addition, alliance projects are being launched, and both the BMEL and the BMBF fund German project partners within the European network. In the initial round in 2013, focus was thereby placed on projects targeting resource-efficient and environmentally friendly food processing that lead to products with greater added value and less waste. Nine translational research alliances have already been initiated, in seven of which German research institutions or companies are participating.

www.susfood-era.net

have positive and above all prophylactic influence on health owing to special bioactive ingredients. Prebiotic substances, for example, are considered to be functional constituents, which include special dietary fibre that has positive effects on intestinal flora. Probiotic dairy products, in turn, contain specially bred and vital strains of bacteria that, ingested with food, help to maintain balance among intestinal flora. In order, however, that food and beverage producers can make health-related claims for their products, they must provide scientific evidence of efficacy in accordance with the EU Health Claims Directive: a complicated and expensive procedure.

Certain phytochemicals such as polyphenols and glucosinolates are likewise considered candidates as health-promoting constituents. As such, their effects can include reduction in the risk of malignant disease, regulation of blood pressure, lowering of blood cholesterol level and strengthening of the immune system. In addition, they can demonstrate antibacterial, antiviral and anti-inflammatory effects. BMBF-funded research projects in Germany are currently investigating how polyphenols can be cost-effectively obtained from citrus fruits, and how glucosinolate content can be increased in broccoli. Retailers are already offering an unusual combination of seafood and meat: one supermarket chain offers sausage types that have been enriched with omega-3 fatty acids from fish oil. Food researchers from the Fraunhofer Institute for Process Engineering and Packaging (IVV) have developed these products to the point of marketability.

Plants as high-quality protein sources

Nutritional science has recently been more closely examining alternative protein sources, in efforts toward more sustainable development of domestic agriculture and at the same time toward reduction of the consumption of animal protein. The lupin is one of the most striking protein plants in Germany; its seeds have a protein content of 35 %. Until now, however, the high content of bitter constituents has prevented lupin use in the food industry. Decades ago, researchers discovered that the blue lupin *(Lupinus angustifolius)* was a species that contains little alkaloids and is resistant to many plant diseases. In addition, the legume is relatively undemanding and thrives very well, especially in Northern Germany. In its storage of nitrogen, the lupine improves soils and requires no fertilization. To assess the market opportunities of innovative lupin-protein products, the BMBF funded in the state of Mecklenburg-Western Pomerania the project Regional Growth Core PlantsProFood: Food from the Blue Lupin. Partners in this innovation initiative were ten companies and four research institutions in the Rostock vicinity – including researchers from Fraunhofer IVV and the split-off company ProLupin GmbH in Neubrandenburg, which by now have developed various lupin-based food sorts. The first commercial product has been ice cream, which is now available in supermarkets. In addition to lupin proteins, it contains rapeseed oil, additional plant constituents as well as polyunsaturated fatty acids. This ice cream is interesting for vegetarians and for allergy sufferers. Lupin proteins have also been processed in a vegetarian liverwurst, in which proteins replace most of the fat: whereas a conventional liver sausage has 30 % fat, the lupin sausage has only 5 %. The BMEL also funds an alliance project that is experimenting with how innovative foods can be manufactured from other domestic legumes: for example, from peas and field beans.

Technologies for safe food

Further technologies can enhance the sustainability and the resource economy of the food chain – and can thereby make foods safer. These efforts include processes for lengthening the shelf life of foods. In the same way, the latest in sensor systems can contribute toward enhancing product safety for the consumer. As part of its Program for Encouraging Innovation, the BMEL has funded a series of research projects in which, for example, optical methods have been developed for evaluating the freshness and the quality of meat. Other researchers are testing innovative packaging with anti-microbial effects – products planned for use in chilled-food displays of supermarkets.

Better use for food remnants

In the food and beverage industry, there is a great deal of untapped potential for bioeconomy in heretofore discarded parts of food. One example is citrus albedo, the white layer of tissue in citrus fruits. Until now, it has been considered waste by the industry, usually with no further use. Researchers from the college Hochschule Ostwestfalen-Lippe are working to produce a natural opacifying agent from the albedo. These substances would be added to lemonade to preserve its murkiness. With several industrial partners, the biotechnologists engaged here are developing an enzymatic process to enable extraction of the suitable constituents from the albedo layer. In the bakery industry, many tons of waste accumulate every year. These remnants represent valuable organic resources for researchers at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim. In an EU project, they also want to use stale buns to obtain molecular building blocks for bioplastics from which bags can be produced. The use of waste in the food and beverage industry is therefore an example in the bioeconomic cycle of how various sectors can, through interlinking, more efficiently use resources and thereby contribute to greater added value for Germany as an economic location.

Lupin seeds are a rich source of protein. Vegan ice cream with a creamy consistency can be produced from them.

Pharmaceuticals

Facts & Figures

No. of companies	923
Employees	135,773
Sales	€41.4 billion

Examples of bioeconomy:
Biopharmaceuticals, medicinal plants

For thousands of years, medicinal herbs have helped to relieve illnesses. Nature, in addition, offers a huge selection of therapeutic agents that serve as basis for advanced medications. Increasingly, biotechnological processes are employed in the production of medication. These biopharmaceuticals have become indispensable in the therapy of widespread diseases such as cancer and diabetes.

Especially with respect to production of medicinal preparations, pharmaceutical companies are increasingly resorting to biological insights. Although chemically produced medicine still represents the largest share on the German pharma market, so-called biopharmaceuticals are increasingly gaining ground. Their sales of 5.6 billion euros are currently 21 % of the market, with a rising trend. These drugs consist of biomolecules that are so large that they cannot be manufactured by man – or only at prohibitive cost. These medications include antibodies against cancer and against auto-immune diseases such as multiple sclerosis, hormones such as insulin for treatment of diabetes and enzymes against metabolic diseases. Techniques from advanced biotechnology developed in the 1980s are applied for their production: living microorganisms and cells can thereby be re-programmed as mini-factories (see section "The high-tech tools of bioeconomy").

Biotech-drugs on the advance

The development of biopharmaceuticals began in the late 1970s. US researchers from the company Genetech succeeded in 1978 in isolating for the first time the genetic information for the hormone insulin gained from human cells and in inserting them by gene transfer into bacteria cells. Previously, patients were forced to use insulin from pigs or cattle. Production was not only tedious and expensive, but the therapy was also not tolerated by all patients. Ultimately, the human body reacts against animal hormones as it does against pathogens. In 1979 Frankfurt researchers at the Hoechst pharmaceutical complex likewise developed a biotechnological process for production of human insulin with the aid of genetically modified microorganisms. In 1987 the Eli Lilly pharmaceutical group in Germany obtained licencing for human insulin developed on the basis of the Genentech principle. It was originally produced in Strasbourg, France, and exported to Germany. In 1984 the Hoechst company attempted to obtain a licence for its experimental plant in Frankfurt, but Joschka Fisher, the Environment Minister in the state of Hesse, refused an operating licence. It was only in 1994 that Hoechst obtained the licence, and in 1996 approval followed for production of human insulin. In 1998 biotechnological production officially began. It would not be possible to supply the present number of insulin patients without insulin produced by genetic engineering.

Despite these initial reservations, medication for man and animal manufactured by genetic engineering is generally accepted. Today, more than 200 medications available in Germany are produced in this way. In 2013 an additional 14 were approved – the largest yearly number until then. In addition to the Frankfurt location – which now belongs to the French company Sanofi—the Swiss pharmaceutical group Roche at its plant in Penzberg has implemented comprehensive production capacities for

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Biopharmaceuticals are produced in steel vessels under sterile conditions.

Knowledge-based process intelligence

The latest production and process engineering technology is applied to enable optimal control of industrial production processes in a bioreactor. Presently, however, batches generally undergo quality testing only after production – which is tedious and often leads to considerable losses. Biotechnologists place importance on being able to assure the quality of bioproduction and to influence it during the production process itself. Under direction of Sartorius Lab Instruments GmbH & Co. KG in Göttingen, 20 partners allied to construct a sensor and software platform that combined innovative measuring principles with advanced methods of data analysis. By continuous supervision of production, the partners expect greater process reliability and uniformly high product quality. The strategic alliance Knowledge-Based Process Intelligence will concentrate here on two pilot processes for food biotechnology and for production of biopharmaceuticals. Industrial users will then transfer the accumulated know-how to their own in-house processes. These users include Chr. Hansen, the brewery group from Bitburg, as well as Rentschler, the independent contract manufacturer. The BMBF funds the alliance, launched in 2014, for six years to the amount of approximately 9 million euros, as part of the Innovation Initiative for Industrial Biotechnology.

biotech medications. Additional German companies with significant production facilities include Bayer in Leverkusen, Merck in Darmstadt and Boehringer Ingelheim in Biberach. A number of small and medium-sized biotechnology companies have furthermore specialized as service providers to carry out bio-based production, or to support the development and market-dedicated implementation of the relevant processes.

Germany leads European countries in this field. In 2008 the production volume for biopharma was assessed at 675,000 litres. At that point in time, Germany was the second largest producer in the world, after the USA. Several expansion processes have taken place since: Sanofi has continuously expanded its production facilities in Frankfurt, with addition of a cell culture plant for 30 million euros, for production of antibodies used in clinical development. In 2013 Roche in Penzberg announced investment of 280 million euros for further expansion of its pharma plants. The Bayer Group in March of 2014 announced investments of 500 million euros for its complex in Wuppertal, to offer more protein-based drugs for haemophiliacs.

Antibodies in the focus of interest

During recent years, a certain class of biotechnologically produced medicines has especially moved increasingly to the focus of interest: antibodies. A number of white blood cells in the human body produce these molecules. They are seen as tracers and as guided missiles of the human immune system, because each of them bonds to only a certain individual other molecule – the surface protein of a virus, for example, or the toxin from a bacterium. By this bond, an antibody renders its target molecule harmless and prepares its degradation. Since the mid-1970s, processes have been developed by which human antibodies can also be produced with the aid of cell cultures. Today, immune molecules are not only an indispensable medical tool: they also represent an increasingly important medication class. With many diseases such as cancer and autoimmune disorders, they help not only to relieve symptoms, but also to attack the cause of disease – especially by significantly improving the struggle against cancer and autoimmune disease. By now there are more than ten different officially approved antibody-based medications, with many others

Efficient purification at the focal point


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In production of biopharmaceuticals, experts decide between upstream and downstream procedures. For upstream, it is essential to tailor a biological production system – such as microorganisms and mammalian cells – such that the desired proteins are eventually produced. This process must also be designed so that it can take place on an industrial scale in fermenters with capacities of 500 to several thousand litres. In the downstream process, the active substances must be purified to the extent that they are suitable for therapeutic application. This is because the microorganisms or mammalian cells initially create a kind of brew in which – apart from the desired substances – numerous other by-products are contained. Mechanical and thermal techniques such as centrifugation and crystallisation are therefore essential for assuring fast and successful purification.

in advanced stages of development. In Germany, research is taking place for many innovative forms of antibody molecules, in order to further improve their action. Other classes of medication – for example, antibiotics and vaccines – are currently as a rule being produced by biotechnological technologies. Globally, pharma companies produce approximately 4.7 billion vaccine doses (EVM). In Germany, they produce vaccines against influenza and avian flu, tick-borne encephalitis (TBE), diphtheria, whooping cough and rabies – in addition to adjuvants for vaccine production around the world. These companies are continuously expanding their production capacities: the British group GlaxoSmithKline, for example, has invested 100 million euros in production of influenza vaccine in Dresden. In Marburg, Novartis has built an innovative plant for production of flu vaccines and vaccines against TBE and rabies.

Intelligent process control

Intelligent process control is indispensable for producing all these medications in the required amounts. With its technical know-how in bioprocesses, Germany is leading in the world. Work funded by the BMBF is additionally taking place on meeting current and future challenges in this field. These efforts include optimized process control based on intelligent sensor technology (see box page 62). For biotechnologically produced medication, ongoing enhancement of purification processes is a key task – which is why the BMBF has funded further targeted development here. Current research efforts are also focused on effective production organisms. In the initial years of biotechnology – as for insulin – these organisms were initially bacteria; currently, mammalian cells are primarily being used. An example is human cell lines and CHO cells that initially originated from hamsters. In contrast to bacteria, these cells are capable of producing certain molecules that are essential for the efficacy of medications.

Unconventional pharma producers

Unconventional sources are also being used now as biological producers of medicine. For example, attention has focused on plants that produce innovative active pharmaceutical agents. In 2012 the regulatory agency US Food and Drug Administration (FDA) approved an enzyme produced by carrot cells for treatment of Gaucher's

Sales developments by pharma segment in accordance with approval classes, for 2010 – 2012 (in millions of euros), on the pharmacy market

	2010	2011	2012
Human medicine	19,144.1	19,345.2	19,443.3
Biopharmaceuticals	3,915.8	4,184.4	4,656.3
Others *	851.3	925.1	922.1
Phytopharmaceuticals	777.0	758.5	748.7
Diagnostic agents	646.3	667.1	675.3
Homoeopathic medicine	252.8	253.3	256.3
Anthroposophic medicine	49.3	52.8	53.8
Total	**25,636.6**	**26,186.5**	**26,755.7**

* Body and dental care, injection accessories, disinfectants, peripheral product range, drugs, medicinal products, chemicals, veterinarian medicine, nutritional/dietary/food supplements

Source: BIP, based on data from Insight Health 2013

disease. Work is also being carried out in Germany on such plant-made pharmaceuticals. Scientists at the Fraunhofer Institute for Molecular Biology and Applied Ecology (IME) in Aachen, for example, have succeeded in producing an HIV vaccine in tobacco plants. Bayer, the pharmaceuticals group, is also conducting tests with tobacco plants in special plant facilities and under controlled conditions. This work, based on a process developed by Icon Genetics, a biotech company in Halle, Germany, is intended to enable production by plants of a new vaccine against cancer of the lymph nodes. These plants are by no means found in normal agriculture. Intensive research work here has resulted in the required production and purification processes, and the new active agents must pass clinical studies. On the basis of research work carried out by plant researchers at Freiburg University, the biotech company Greenovation is likewise working on a production method for medicine based on the moss *Physcomitrella patens*. Plans are for the first active agent to go into clinical testing in 2014.

There are also plants whose constituent substances are interesting as active medicinal agents. The substance paclitaxel, found in the Pacific yew *(Taxus brevifolia)*, for example, is employed as a cancer drug. The restricted habitat of this plant, and its low content of active agent, however, means that it is not possible to meet worldwide demand for this drug by conventional means alone. For some good time, this drug has therefore been partly manufactured synthetically from certain plant/herbal active-agent precursors. In 2002 the British pharma group Bristol-Myers Squibb developed a process for cultivation of isolated yew cells on culture media in fermenters, for the purpose of obtaining this active agent. Biotechnological production takes place in the state of Schleswig-Holstein, in Ahrensburg, at the company Phyton Biotech GmbH, which offers one of the world's largest fermenter capacities based on plant cells.

Cultivating the tradition of medicinal plants

In addition to the advanced biotechnological processes that have appreciably improved medical possibilities in recent years, traditional medicinal plants continue to play an important role. Cultivation of medicinal herbs has a long history in Germany. A total of 440 medicinal plants are indigenous to Germany, with about 75 of them commercially cultivated on an area of about 12,000 hectares. Most of this area is in the states of Thuringia, Bavaria, Hesse and Lower Saxony, which together cover more than 70 % of domestic demand for medicinal plants. Chamomile represents the greatest share of all plants cultivated (more than 1,000 hectares), followed by plants such as flax, lady's thistle, peppermint and buckthorn (each from 500 to 1,000 hectares). Domestic cultivation, however, represents only a niche: 90 % of processed medicinal plants are imported. Medicine from nature enjoys great and growing respect in Germany: in the early 1970s, only 52 % of the population used such products, and in 2002 it had increased to 73 %. The use of natural remedies has proved especially effective in treatment of minor disorders such as colds.

Some medicinal plants today are still harvested in the wild: these especially include plants that are used only in small amounts, or that cannot be cultivated domestically. In comparison to commercial agriculture, however, the quality and the quantitative composition of their constituents fluctuate. As a result, attempts are being made in Germany to cultivate such new or not yet cultivated medicinal plants. These efforts, however, are difficult: for herbs it can take at least five years to render these plants suitable for commercial cultivation, and for trees and shrubs even longer. For this reason, the BMEL funds research work in this field (see box). Throughout Europe, companies established in Germany are market leaders in the production of plant-based drugs. Nevertheless, domestic pharmacy sales of phytopharmaceuticals are declining. With 2012 sales of almost 750 million euros, though, it is still the third-most important sub-segment on the German pharma market. In addition to applications in medicine, medicinal plants are gaining importance for cosmetics and dietary food supplements.

Promoting domestic cultivation of medicinal plants

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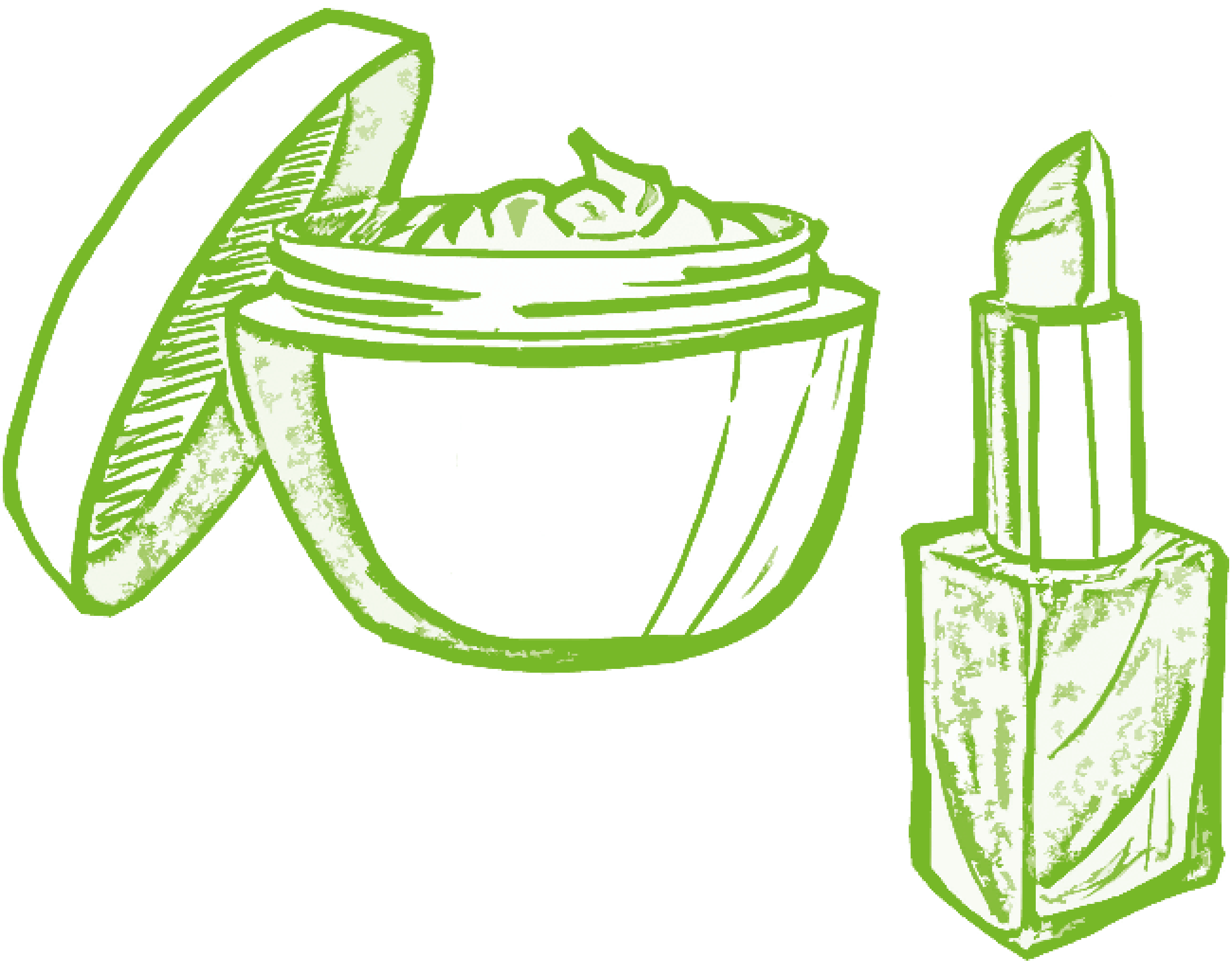
To enable German agriculture to profit more from the market for medicinal plants, the BMEL has funded the demonstration project KAMEL. The attempt has been made – for example, with chamomile, valerian and melissa – to improve the profitability and the product quality for these species by research and development work and thereby to intensify their cultivation in Germany. Emphasis has been placed on optimization of breeding and on improved drying, cultivation, harvesting and after-crop techniques

Consumer goods

Facts & Figures

No. of companies	no data
Employees	no data
Sales	€203 billion

Examples of bioeconomy:
Bio-based tensides, bioactive constituents for cosmetics



For cosmetics, washing agents and home appliances: bio-based processes find application in manufacture of a great number and variety of products used in everyday life. These processes make an important contribution to greater sustainability in industry and enable innovative products with novel properties for the consumer.

In the consumer goods industry, it is obvious that bioeconomy has long since found its way into daily life. Not only for long-life purchases such as appliances, but also for quickly consumed products such as washing agents, toothpaste and body care cream – natural raw materials are in demand in many areas, and bio-based processes are widely used in industrial production. Every year in Germany, the average household spends around 26,000 euros for private consumer goods. In addition to clothing and food, body care and cosmetics are among the areas with leading sales. In Germany in 2012, approximately 13 billion euros in sales was earned with these products – with around 4 billion euros additionally spent in the areas of washing and cleaning agents. This amounts to per capita spending of 53 euros for Germany.

Tensides from regenerative raw materials

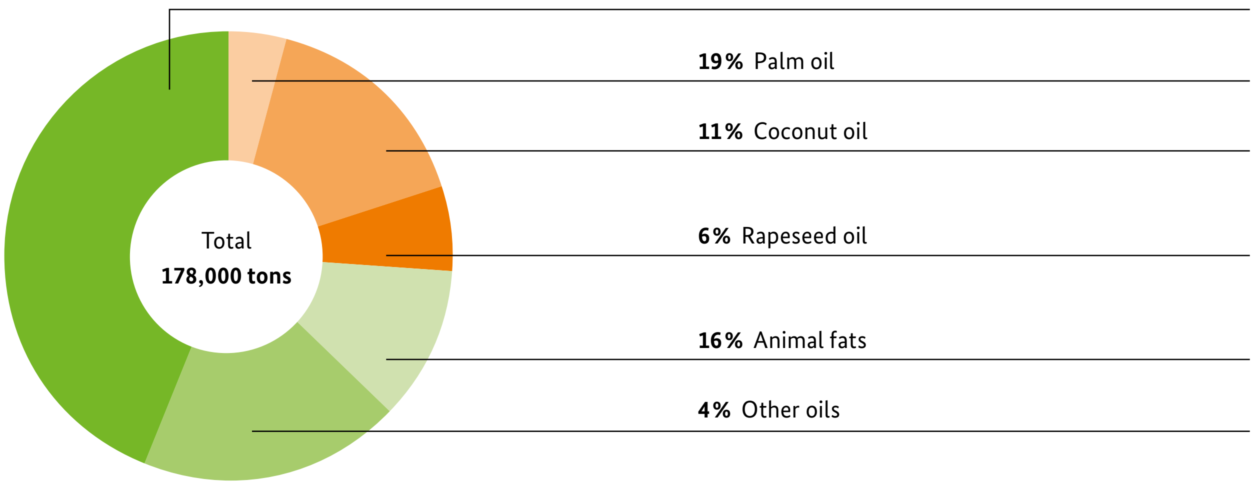
In these two sub-segments of the consumer-goods industry today, the application of bio-based processes is already relatively great. About 40 % of the constituents in the 600,000 tons annually produced are completely or partially bio-based. This includes tensides, alcoholic solvents and citrates. Production of citrates today is already completely bio-based, with the aid of molasses – a waste product from the production of sugar from sugar cane. In 2011 the share of bio-based and mixed tensides was 72 %, for which plant oils and animal fats are primarily used (see page 68). Moreover, work carried out here includes efforts by the chemical group BASF – funded by the BMBF – to develop innovative biotensides manufactured with the aid of microbes. Production of alcoholic solvents used for cosmetics is around 30,000 tons yearly, of which 100 % is bio-based. The share for washing and cleaning agents is 50 %. Sugar and starch plants serve as raw-material basis for production of these alcohols, whereby sugar beets with 50 % represent the greatest single resource. Funded by the BMEL, BASF has for example developed a process to use the dianhydro sugar alcohol isosorbide, obtained from starch, in washing and cleaning agents.

Bioactive molecules in body-care cream

For some good years now, manufacturers of body-care products have resorted to special bioactive constituents – and thereby meet growing demand for natural cosmetics. According to current consumer analyses, 31 % of Germans approve the absence of chemical additives from body-care products, and welcome their production on a natural basis. For more than 30 years, lipid-replenishing natural substances such as ceramide, vitamins such as folic acid and special enzymes such as Q10 have been contained in cosmetics and body-care products. To make them available for industrial application, it was necessary to develop their production with the aid of biological mini-factories such as cells and bacteria, which produce the respective substances in large steel vessels (see section “The high-tech tools of bioeconomy”). These processes, also called fermentation, have become widely established today as standard in the cosmetics sector. The enzyme Q10, for example, was still extracted from bovine hearts in the 1970s: with a price of 1,000 US dollars for one gram of the enzyme. Production in yeast by fermentation caused the price to fall to only a fraction. Today, Q10 is also found in affordable cosmetics. The alliance NatLifE 2020 – funded by the BMBF and directed by

Plastic shopping bags, children’s toys, ballpoint pens and catering cutlery: bioplastics are found today in many and various products.

Application of plant oils and animal fats in production of tensides in Germany (2011)



Source: BMEL/Meo Carbon Solutions (2014)

the biotech enterprise Brain AG, in turn a shareholder in the cosmetics company Monteil – counts on completely new technologies for the development of bioactive substances for cosmetics. The cosmetics industry, furthermore, is concentrating on new approaches that retard the process of skin ageing.

The first types of toothpaste are now available with probiotic microorganisms. The Berlin biotech company Organobalance has developed a process that allows the use of natural lactic acid bacteria. These bacteria, integrated in the toothpaste, attach themselves to caries pathogens in the mouth, where they agglutinate and can be easily rinsed away by tooth brushing. These probiotic microorganisms help to remove caries pathogens better than conventional products. The natural microorganisms of the species Lactobacillus casei are manufactured according to the standards of the food and beverage industry and therefore satisfy strict requirements for safety and tolerance. After production, they are stabilized, dried and added to a prepared toothpaste mass.

Natural cleaning aids

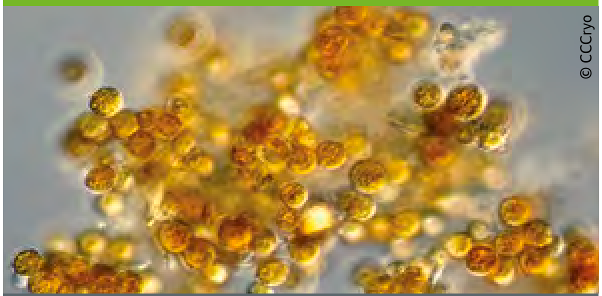
Bio-based processes have likewise become routine in the cleaning sector, in the production of additional active-cleaning, natural-based substances besides tensides. Here as well, enzymes – biocatalysts produced with the aid of microbes – have by now become the option of choice. The largest market share of industrial enzymes, 40 %, is used in the cleaning and washing segment of the consumer goods industry. By virtue of their many years of application in washing machine agents, these natural helpers have already made an essential contribution toward rendering washing machine cycles more environmentally benign – after many years of excessive consumption of energy and water. Unlike chemical molecules, enzymes frequently become active at mild temperatures. We can also thank them for enabling a reduction in average clothes-washing temperature, down to 46 °C now – in 1972 this temperature was at 63 °C. Today, only about 7 % of all washing takes place at 90 °C – whereas it was still around 40 % more than 40 years ago. At the same time, the use of biocatalysts has enhanced the efficiency of cleaning agents: years ago, 220 g was necessary for 5 kg of washing; now, 75 g suffices. According to the German Cosmetic, Toiletry, Perfumery and Detergent Association (IKW), in 2010 almost 6,000 tons of enzymes was produced annually as constituents of washing and cleaning agents, up from less than 3,600 tons in 1994. By the same token, 80 % of all washing agents today contain proteases: these are enzymes that degrade protein molecules. This property makes them highly effective in removing stains consisting of blood, cocoa or egg. Work funded by the BMBF succeeded several years ago in disclosing a protease that is particularly cold-active and that can remove stubborn chocolate stains even at 20 °C.

Bioplastics in everyday life

Around 14 million tons of packaging material is produced annually in Germany, with approximately 40 % – around 5.5 million tons – consisting of plastics. This packaging material is so popular because it keeps packaged goods clean and fresh, weighs little and can be shaped into almost any required form. Plastics, however, are primarily made from a raw material that is diminishing: petroleum. Bio-based alternatives have therefore become increasingly interesting – also for the manufacturers of large domestic appliances, smaller appliances and domestic heaters. According to data from the German Electrical and Electronic Manufacturers' Association (ZVEI), around 12,700 companies in this area achieved sales of almost 8 billion euros in 2012. Since styling, material and energy efficiency are gaining in importance as purchase criteria, also for small appliances, manufacturers are increasingly turning to bioplastics, which are being offered in increasing diversity by the chemical industry (see section "Chemistry"). One of the greatest challenges here is proper handling of the materials during production. With regard to their heat stability and their fire behaviour, they may exhibit properties that must be considered for their application in technical facilities. With funding by BMEL, the company Efbe Haushaltgeräte GmbH has developed a new injection moulding process for biopolymers reinforced by natural fibres. These innovative materials are designed for casing parts in hair dryers and are now available for sale – but at prices still higher than for conventional materials. Bio-based casings for toasters, water boilers and coffee machines are likewise already being tested.

Bioplastics have by now found good sales opportunities on the beverage market – with US manufacturers strongly pushing so-called plant bottles. Until now such producers consumed around 20 million barrels of oil annually to manufacture plastic bottles. These bottles typically consist of the plastic polyethylene terephthalate (PET), which in turn is composed of two components: terephthalic acid (PTA, 70 %) and monoethylene glycol (MEG, 30 %). It is already now possible to produce monoethylene glycol from bio-based alcohol obtained from natural resources such as sugar cane. This production saves around 20 % of carbon dioxide emissions in comparison to petroleum-based processes. The objective here is to produce terephthalic acid, the main component of PET, from biological raw materials: a goal set for 2020. There are no differences in chemical characteristics between conventional and bio-based PET; only the raw materials sources are different. Bio-based PET is therefore a typical drop-in solution, for which production can be converted from petrochemical to natural sources without further adaptation (see section "Chemistry").

Algae for the cosmetics industry


© CCCryo

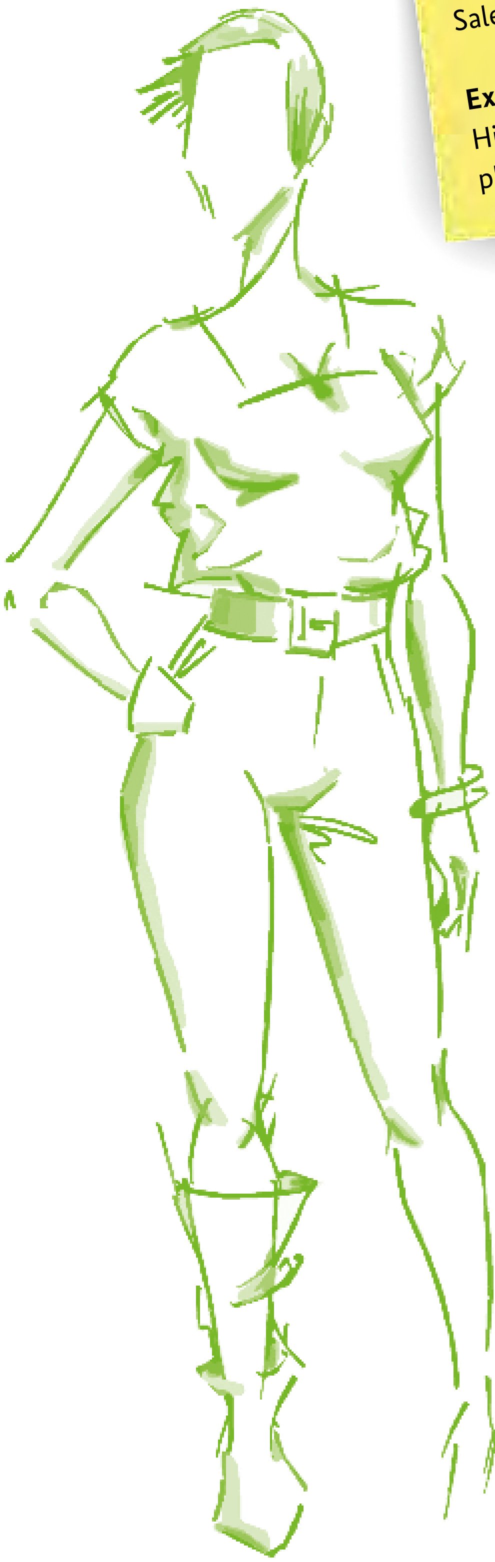
Algae contain numerous natural constituents that are interesting for the cosmetics industry. Plant researchers, for example, have discovered freshwater algae that have adapted to extreme habitat conditions: snow algae, which thrive in the cold. They can be used to produce an extensive palette of pigments, vitamins and antioxidants that can be used in the cosmetics and food industries. Researchers from the Fraunhofer Gesellschaft have assembled a species catalogue – the Culture Collection of Cryophilic Algae – CCCryo – with 370 isolates and 125 species. This collection is a freely accessible bioresource. For a number of years now, an industrial collaborative has produced snow algae strains for application in cosmetics, in photobioreactors especially developed for this purpose at the Fraunhofer Institute for Biomedical Engineering.

Textiles

Facts & Figures

No. of companies	1,300
Employees	111,313
Sales	€11.33 billion

Examples of bioeconomy:
High-tech fibres made from spider silk, plant tanning agents



For the textile industry, application of regenerative raw materials is a matter of daily routine. Plant fibres such as linen and cotton, as well as animal products such as wool, silk and leather – natural products are used in many textile areas. With regard to sustainability and resource efficiency, however, unconventional ideas are now being implemented. New high-tech fibres with previously unknown properties, for example, are now being produced from formerly discarded materials from the food and beverage industry.

Natural products have been used for thousands of years to make clothing. The Egyptians and Romans of antiquity used flax fibres to make linen fabrics. Leather, which is tanned animal hide, was a favourite material even in the Stone Age, as a material for making shoes and belts. It has been only in recent decades that inexpensive petroleum-based synthetic fibres have predominated over leather. In the recent past, however, a return to traditional natural fibres has become particularly apparent.

In 2012, world production of textile fibres was approximately 83 million tons – of which cotton represented one-third. Cotton is the most commonly used natural fibre for textiles used at home and for clothing. It is produced from the seed fibre from plants of the genus *Gossypium*, and is harvested manually or mechanically. It is not, however, only the extensive global use of cotton that makes it a symbol for bio-based economy: almost the entire plant can be used sustainably. The seed fibres are used to make textiles, and cottonseed oil pressed from the seeds is a basic material for the cosmetic industry. The oil cake remaining after pressing the oil is in turn often used as protein-rich animal fodder. Once the cotton plant has withered, it is frequently ploughed under, where it serves as fertilizer.

Unlike cotton, the stems of other textile plants are further processed: for example, flax, hemp and jute. Global production of such bast fibres, however, is much less – around 2 million tons annually. After the bast fibres have been separated, their further processing is similar to that for cotton. Yarn is spun from the individual fibres, which is then processed to textiles. Their areas of use, however, are different: bast fibres are used primarily as so-called technical textiles for industrial applications, and not so often to manufacture clothing.

The capability for cotton to cover the enormous international demand for textiles continues to decline. In 1990, 19 million tons was internationally available, which amounted to a share of 49 %. Although 20 million tons was available in 2000, this amounted to a share of only 40 %, since the international market for all fibres had grown. Currently, cotton has a share of 31 %.

Synthetic fibres with a green coat

The majority of materials used by industry, however, consists of synthetic and chemical fibres made of synthetic polymers such as polyester, Teflon™, Lycra®,

Synthetic fibres dominate the market

The German textile and clothing industry consists of 1,300 enterprises, virtually all of them small and medium-sized. They employ around 111,000. The share of exports in the textile industry is about 40 %, and this sector represents the second-largest consumer goods area in Germany. In 2013, these companies earned a total of 11.33 billion euros with textiles. These data stem from the Federal Statistical Office. Chemical and synthetic fibres are still the most important raw materials here, especially in the clothing industry. In 2012, approximately 121,000 tons of these fibres were processed, in addition to 21,000 tons of cotton and 17,000 tons of wool.

Enzyme tricks for enhanced processing of synthetic fibres

After being washed several times, cotton fibres form tiny knots, and the textiles attain a grey hue. Enzymes from the cellulose group counter these disadvantages when added to washing agents. The biotech company evocatal GmbH in Dusseldorf intends to exploit this potential for synthetic PET fibres as well. Under the umbrella of the alliance Functionalizing Polymers (FuPol), work is conducted to find enzymes that help to prevent knot formation in PET fibres. This alliance consists of nine members: four from academic research and five from industry. Another example is development by Coats, makers of textile yarns, of functional textiles such as are needed to seal seams in outdoor applications. Over the coming five years, this alliance intends to invest around 8 million euros in several research projects. The BMBF contributed half the funds from the Innovation Initiative for Industrial Biotechnology.

Trevira, nylon and others. Today there are also other examples of natural polymers that are used as raw materials for fibres, but that are produced by chemical processes. These include viscose, made of cellulose. Unlike cotton fibres, viscose fibres are characterized by greater variation in their fibre geometry: in length, crimp, fineness and cross-section form. As a result, they have more extensive application. Although energy and water consumption in production and processing of viscose is less than for cotton, its processing creates unhealthy and environmentally harmful toxins such as hydrogen sulphide (H_2S) and carbon disulphide (CS_2). Other chemical fibres made from cellulose do not present this problem. As a result, a direct-dissolving process was developed for the production of Tencel® and lyocell fibres, which features a non-toxic solvent and which functions in a closed materials cycle. In addition, the required cellulose is obtained from eucalyptus or beech wood. Since these trees grow rapidly and offer appreciable yield per land area, their environmental balance is better than for cotton. Recent research work has additionally revealed that flax, hemp, bamboo, banana plants and soya are suitable sources for the cellulose pulp.

Breeding of new fibre plants

Recently, interest has again been focused on plants that had virtually lost public attention: for example, the stinging nettle. In addition to hemp and fibre flax, the stinging nettle was among the most important domestic fibre plants until the Second World War. Afterward, it was forgotten. Thanks to new processing methods, however, it is today possible to make textiles from the stinging nettle with the fineness of cotton and with excellent textile properties – and to make fleece for technical uses. The usual propagation by or from cuttings, however, is less suitable for large-scale cultivation, and with the fibre content of existing cultivated varieties, increases in yields are still possible. With funding from the BMEL, the Institut für Pflanzenkultur (IFP) in Wendland, Germany, and the Faserinstitut Bremen e. V. (FIBRE) have now developed new breeding lines of fibre nettle characterized by fine yet strong fibres and by large fibre content.

Plant tanning agents reduce environmental pollution

The textile industry offers not only plant raw materials: wool, silk and leather and other animal products also play a major role in the current assortment of raw materials. Whereas wool and silk also represent fibres, leather production entails tanning the hides of animals to preserve them. Of all the hides processed in the world, over 95 % of them originate from cattle, calves, sheep, goats and hogs: by-products of the food industry. In earlier time, tanning agents from wood and bark were primarily used; in more recent years, tanning based on chrome salts and other minerals has come to be used. Although these methods are cheaper and less labour-intensive, they have earned criticism owing to their environmental impact.

For this reason, recent years have seen increasing development of plant-based tanning agents. The company Wet-Green GmbH, for example, has developed an extract of olive leaves as tanning agent – an active agent that intrinsically protects trees from herbivores. During olive harvest and pruning of the olive trees, around 10 % of the harvest by weight consists of leaves. Earlier, these leaves were frequently burned on site – but now they serve as raw material for production of plant tanning agents. As a result, they improve the environmental balance of a great variety of products such as cars, shoes, couches and watchbands. This economic potential of olive leaf waste is great: theoretically, up to 40 % of world leather production could be processed in this manner.

From waste product to raw material

The sports article manufacturer Puma also emphasizes sustainability. The remake of its classic Suede models is now being marketed as a complete eco-shoe. The upper material of the shoes is synthetic suede developed by Toray, a Japanese company. It consists of 100 % recycled polyester fibres transformed from production waste into synthetic material by a chemical recycling process. The rubber part of the shoe soles consists partly of rice hulls obtained from food-production waste – which reduces the share of petroleum-based rubber. Production of this remake saves 80 % of the CO_2 emissions produced by conventional shoe manufacturing. Production and sales of the recycling shoe, 140 g lighter than its 1968 predecessor, protect the environment: according to Puma, savings of 15 tons of CO_2 emissions result for every 10,000 Suede pairs that leave the factory.

The company Qmilk Deutschland GmbH in Hanover has specialized in the profitable use of waste from the food industry. Qmilk is developing a biopolymer consisting of the milk protein casein, which the company obtains from no longer marketable raw milk: of which 1.9 million tons is available annually. Already in the 1930s there were approaches to use this waste for textile manufacture – but excessive chemistry was required in those days. This is no longer the case. Currently, production of these biopolymer fibres takes place in collaboration with the Bremen Fibre Institute (FIBRE), without chemical additives. The product is used not only for clothing and home textiles but also as technical fibres:

© Qmilk GmbH

Anke Domaske at Qmilk Deutschland GmbH helps produce textile fibres out of waste from dairy production.

In Mediaeval times, clothing was dyed red with dyer's madder *(Rubia tinctorum)* – and today natural dying processes are experiencing a renaissance.

for example, for use in medical technology and in automobile construction.

Enzymes enhance environmental balance

For the textile industry, however, importance is being placed not only on regenerative raw materials. In order to improve the environmental balance of industrial production and processes heavily based on chemistry, biotechnological approaches are also currently receiving greater emphasis. One example is the bleaching of textiles, for which hydrogen peroxide (H_2O_2) is still widely used. This oxidant, however, must be completely removed from the textile material after each bleaching process. In the conventional method, this takes place by rinsing the textile material at least twice with water at 80 to 95 °C. This procedure lasts about two hours and consumes large quantities of water and energy, but since it does not completely remove the bleach, various other chemicals are necessary for post-treatment. The biotechnological variant exploits the natural power of biocatalysts, for example, of the enzyme catalase. This enzyme allows removal of the hydrogen peroxide with warm water (30 to 40 °C) within a few minutes, in only one rinse step. This reduces costs for cooling water, process water and steam – and protects the environment by use of less energy.

Biotechnological processes on the basis of enzymes are also used in production of jeans. Traditionally, pumice is used to achieve the so-called stonewashed effect: an uneven colour structure. This costs water, energy and product quality, since the pumice treatment is harsh on textiles. For each pair of jeans, this also produces 600 g of stone abrasion, which damages the machines and must also be disposed of. But there is an alternative – without pumice but with special enzymes. The stonewashed effect achieved with cellulase is the same, but this alternative reduces environment-related costs by 54 %, and there are virtually no pollutants released into effluent water (-97 %) and into the air (-86 %). Another example shows the environmental relief and the cost-reduction potentials in textile dying. By use of the enzyme catalase in dying pre-treatment of cotton, it was possible for each ton of treated textile to reduce climate-adverse carbon dioxide emission by up to 120 kg, water by up to 19,000 l and power by up to 500 kWh. Enzymes also play an important role in the cleaning of textiles. Even with old household agents such as bile soaps, enzymes already showed their cleansing effects.

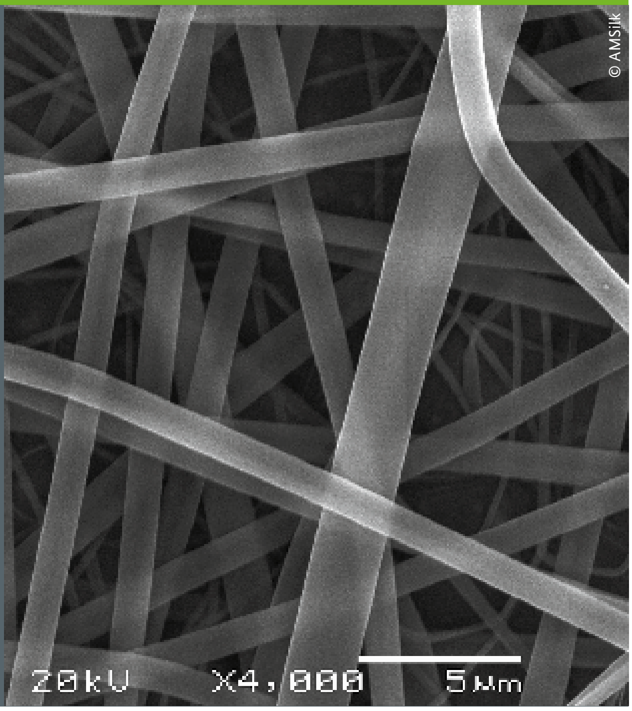
The enzyme cocktails used today for washing agents are usually produced by microbes (see section “Consumer goods”). They serve not only to remove soiling from textiles, but also perform many and various other tasks: for example, cellulase removes small protruding individual fibres and thereby assures that no lint forms on the textiles.

Natural dyes for exclusive textiles

To enhance the sustainability of textile dying, producers now resort to an old tradition in the textile trade. As early as 4,000 years ago, Europeans dyed natural fibres with plant dyes. Since Mediaeval times dye plants have been cultivated: for example, dyer’s woad for blue, dyer’s madder for red and reseda for yellow. With the development in the nineteenth century of synthetic dyes based on coal and petroleum, these substance lost significance: until their renaissance in the 1990s. Upon the initiative of the state of Brandenburg, the domestic plants madder and reseda began to be cultivated again: to be sure, only on small, job-order scale. The greatest challenge was to obtain standardized extracts. The company Spremberger Tuche GmbH, in a project funded by the BMEL, has now developed a functioning process. The extracts can now be processed in advanced dying machines and dosing systems. A total of 120 colour shades can be produced from two extracts. Owing to the high price, these producers cannot serve a mass market; their customers come primarily from the area of exclusive textiles.

High-tech fibres from spider silk

Spider silk is a true wonder of nature – one-tenth the diameter of human hair, yet twenty times stronger than steel and at the same time more elastic than rubber. This natural material would therefore be ideal for a whole range of applications: for example, for high-tech textiles. Until now, production of spider silk has been problematic, since these animals cannot be bred in large numbers or “milked”. The company AMSilk GmbH in Martinsried has taken a biological approach here. After many years of experimentation together with material researchers from Bayreuth, and with funding from the BMBF, AMSilk – a spin-off of Technische Universität München – has tailored bacteria such that they can produce spider silk proteins. In addition, a process has been developed to process these molecules to fibres. In March of 2013 the first biotech fibres were spun that are suitable for use in high-text textiles and medicine. The next step is to move the technology from the lab to the pilot scale.



© AMSilk

Raw materials sources for bioeconomy

Plants, animals and microorganisms provide the many and various raw materials sources for the bio-based economy. This involves not only biomass that is newly created in agriculture, forestry and fishery – increasingly, focus is on organic remnants and waste materials as valuable resources for material and energetic use.

The unique aspect of bioeconomy is its regenerative raw materials basis. Biological resources – living organisms such as plants, animals and microorganisms – grow and thrive and produce through their metabolisms a great diversity of organic substances. The proper generic term for such regenerative resources of plant or animal origin is "biomass". Biomass is used for many and various uses in bioeconomy, primarily as food and fodder, but increasingly also as supplier of material and energy for industry. Sustainably produced, regenerative raw materials contribute to the preservation of fossil resources and reduce the emission of gases harmful to the climate. At the same time, they create jobs and added value in rural areas.

Biomass from fields and meadows

Plants are the most important biomass producers in the world: they perform photosynthesis and convert carbon dioxide from the air and sunlight into oxygen and organic compounds. Biomass contains a complex mixture of carbohydrates, fats, oils and proteins. Green plants supply the chief quantities of primary biomass production on the earth's surface. Plants are located at the beginning of the agricultural value-added chain and therefore possess fundamental importance for bioeconomy. Plant cultivation in Germany is extensive and broadly diversified: it ranges throughout the fields of arable farming and plant cultivation, forestry, horticulture, orcharding as well as specialized cultivation involving plants such as grapes and hops. Farmers cultivate and manage almost half the land area of Germany. Crops are primarily cultivated for use as food and fodder. For human consumption, agriculture produces – in addition to animal products – bread cereals, potatoes, sugar beets, fruit and vegetables.

Today, grain is the most important plant product in German agriculture. Grain grows on just over one-third of agriculturally used land in Germany, with most grain used for fodder for farm animals. Wheat is by far the most extensively cultivated grain in Germany. Barley follows, which is especially used for livestock fodder, as well as in the form of brewing barley for making beer. Rye likewise has a traditional place in Germany, sometimes called the land of bread. Sugar beets are the most important industrial suppliers for starch and household sugar (sucrose). Further significant starch plants are potatoes, wheat and maize. Plant oils and fats gained from rapeseed are extensively used in Germany, primarily by the food industry. Crops such as soya, wheat and rape are additionally important sources of protein. Recently, lupins, field beans and peas have enjoyed greater attention. Associated research efforts have been directed to improve the output of these domestic protein suppliers, toward reducing dependence on international imports. Within bioeconomy, approaches are being especially pursued to manage the cultivation and use of plants for greater resource efficiency and sustainability – in the sense of optimal coexistence of conventional and ecological agriculture, and under consideration of new possibilities for plants as regenerative raw materials beyond the food, beverage and fodder industries. In this way, grain, rape, sugar beets and other cultivated crops likewise play important roles for production of renewable energy (see section "Energy") and as raw materials for the chemical industry (see section "Chemistry").

Overview of German agricultural land

© Jan Jansen/Fotolia.com

In Germany, 46.8 % of the entire land is used for agriculture, including 6 % organically farmed. Two-thirds of all agriculturally used land is used to supply animal fodder, with 27.5 % for human food. Cultivation of energy crops takes 12.6 % of all land, and 2.4 % supplies plants for industrial uses. Fallow and unused areas account for 1.2 %.

Snow algae are microalgae that have adapted to cold. They are gaining increasing attention as producers of constituents of cosmetics and food.

Whereas plants play the dominant role on land as producers of biomass, algae and other primary producers perform this task in aquatic areas. In the ocean and in fresh water: algae produce large amounts of sugar molecules and oil and can therefore be used to supply interesting constituents for industry. In Europe, algae are applied in the food and beverage industry as emulsifiers, thickening agents and dietary supplements. Algae can be cultivated in open or closed systems on degraded and infertile land. This production does not therefore directly compete for land usage in production of food and fodder. Algae enable biomass production ten times that of crops; their cultivation in the context of photobioreactors, however, demands great availability of sunlight. To better exploit this resource for Germany, efforts include domestic research to develop undemanding microalgae (for example, snow algae) as producers of dyes and ice-structuring proteins (ISP) that are used in the cosmetics and food industries (see section "Consumer goods").

Wood – sustainable raw material for bioeconomy

An important source of regenerative raw materials in Germany is its forests. Approximately 3.4 billion cubic meters of forest wood is available in Germany – leading in Europe. Forests are at once valuable ecosystems, carbon sinks, restorative environments and essential suppliers of raw materials. Wood is a plant tissue consisting of cells with cell walls. They in turn consist of a supporting structure in the form of the long-chain sugar molecules cellulose and hemicellulose. During lignification, lignin is additionally incorporated into the cell walls, where it acts as a binding agent. The resulting chemical supporting structure is also known as lignocellulose. The significance, the demand and the use of wood as a regenerative raw, construction and basic work material continues to increase owing to its positive material properties and its favourable ecobalance. Domestic use of wood as raw material has continually risen over the past two decades. In addition to wood from forestry origins, the other raw wood materials such as sawdust, wood shavings, bark

Focus on regenerative raw materials

With its funding program Regenerative Raw Materials, the Federal Ministry of Food and Agriculture (BMEL) has pursued the goal of promoting the industrial use of plant and animal raw materials from agriculture and forestry. This includes both material as well as energetic processes and encompasses a number of focal points: for example, bioplastics, biofuels and energy crops. The projects are supported by the Fachagentur Nachwachsende Rohstoffe (FNR). At present alone, around 650 research and development projects are being executed, with annual funding of around 60 million euros for these projects.

and forest wood remnants likewise represent important raw materials for wood-based added value, as well as an important source of employment in Germany. In 2011 the federal government adopted its Forest Strategy 2020 to safeguard forests as natural and economic space over the long term, and to strike a viable balance between the increasing demands placed on forests and their sustainable output capability.

The focus of interest here is on the search for cascade usage that enables resource-efficient use of wood as environmentally friendly and regenerative raw material. Numerous research efforts are also being made in the area of forest breeding (see section "Agriculture and forestry"). This also applies to fast-growing trees, which have gained increasing attention, especially for construction (see section "Construction"). With the aid of the latest in technologies, furthermore, attempts proceed to further improve the possibilities for wood as source substance for use as an industrial material.

The forest as supplier of raw materials

There are currently 11 million hectares of forest in Germany: 31 % of its total land area, with continuously increasing wood reserves. Forested area has increased by 1 million hectares over the past four decades. Annually, a total of 135 million cubic metres of wood as raw material is harvested as material for construction and other uses, and as energy carrier.

Biomass from stalls and pastures

An important basis for bioeconomy is livestock. In animal products, German agriculture occupies top position: no other country in Europe produces more milk and more pork. Germany, following France, is the second largest European producer of beef, veal and poultry. There is a total of 170 million head of livestock, which in turn consume 80 million tons of fodder. As users of plant biomass, livestock in Germany play a significant role. Animal husbandry and agriculture are therefore closely associated. Fodder cultivation – subdivided into the two forms of arable feed crop cultivation and grassland use – thereby provides a major part of the basic fodder for livestock, including grass and maize silage. By-products additionally result from food production in sugar factories, grain mills and dairies, and are likewise processed to fodder. Sufficient supply of protein-content fodder is assured for the most part by supplementary imports, since sufficient protein-rich plants are not produced in Europe. Meadows and pasture also represent a significant factor in the system: they supply cattle with fodder and are thereby a key pillar in the dairy industry. With their great biodiversity they also contribute to environmental protection. In the context of bioeconomy, a prime objective is to set animal breeding and husbandry, food and fodder production, as well as sustainability and environmental protection in harmony with each other (see section "Agriculture and forestry").

A further biological resource – hardly visible to the naked eye – consists of microorganisms such as bacteria, yeasts and fungi. These organisms occur in highly diversified form and have been used for thousands of years: for example, as tiny helpers in the production of food and beverages such as beer and cheese. In sewage treatment plants and biogas plants, microorganisms also degrade organic substances. In the chemical and pharmaceutical industries, microbes are now important "beasts of burden" (see sections "The high-tech tools of bioeconomy", "Chemistry" and "Pharmaceuticals"). These microbes include the bacteria *Escherichia coli* and *Corynebacterium glutamicum,* used in production of amino acids, and the fungus *Aspergillus niger,* an important supplier of citric acid. Microorganisms also open highly promising perspectives in conjunction with the extraction and processing of conventional raw materials reserves such as ores and mineral resources. For many years now, bacteria have been used in metallurgical mining to separate metals piece at a time from the earth and

Research for organic farming

The Federal Organic Farming Scheme and other Forms of Sustainable Agriculture (BÖLN) has set as its goal the improvement of the basic conditions for organic farming and food economy and for other forms of sustainable farming in Germany – and to satisfy the prerequisites for balanced growth in supply and demand. This programme is funded by the Federal Ministry of Food and Agriculture (BMEL) and is coordinated in Bonn by the BÖLN offices in the Federal Office for Agriculture and Food (BLE). By now, over 750 research and development projects have been executed, with annual funding of around 9 million euros

from mining tips. There are now initial approaches for recovery of rare earths from solutions – also with the use of microorganisms – to enable more efficient use of reserves in Germany.

Closed-circle economy as a challenge

One of the additional special hallmarks of bioeconomy is that not only those biomass shares are used that have been produced, harvested and primarily processed by agriculture and forestry – in addition, attention is also being focused on the previously and largely unexploited potentials in harvest waste and other agricultural remnants such as straw, wood remaining from forest harvesting, and manure slurry. Of additional importance are waste materials produced in industrial manufacturing and further processing: these include traditional waste such as rapeseed cake, algae remnant biomass, fermentation remnants, whey and fruit shells. Also included here are waste products such as carbon dioxide, even though research has only recently enabled their re- and further processing.

The concept of bioeconomy especially includes efforts toward the establishment of closed materials cycles and the employment of existing resources as efficiently as possible in the sense of cascade use. A key objective here is the multi-use of biomass: the initial step is material use of the carbon dioxide originally bound in bio-based products, with its release again at the end of the material utilization phase, in the process of energetic employment. With wood, this principle is already being applied: cellulose becomes paper, used paper is processed to insulation and it is then burned as energy source once the insulation is no longer serviceable. Similar cascade uses are also feasible in the employment of straw – which was produced in Germany in the amount of approximately 35 million tons (fresh mass) in 2010. Between 20 and 40 % of produced straw is available for energetic and material exploitation, but this potential has not yet been fully realized. With animal residue, in contrast, existing materials cycles are already closely interlinked – although further potential is available here with a view to higher-quality applications and multiple material use. The National Research Strategy Bioeconomy 2030 of the federal government has set as objective the modelling of a future bio-based industry on the carbon cycle as found in nature. Which means: it is not simply a matter of replacing fossil resources by regenerative raw materials. Instead, it is more essential to appreciably and more effectively exploit the potential hidden in biomass, and to make available the resulting material flows – with sustainability and resource efficiency – for the various sectors of industry. There are already highly promising approaches in these sectors (see section “Bioeconomy in everyday life”). Biorefinery concepts are presently in trial stages on the process level (see section “Bio-based production”).

At the same time, it is necessary to carefully consider biological resources in their entirety. The ideal closed-cycle

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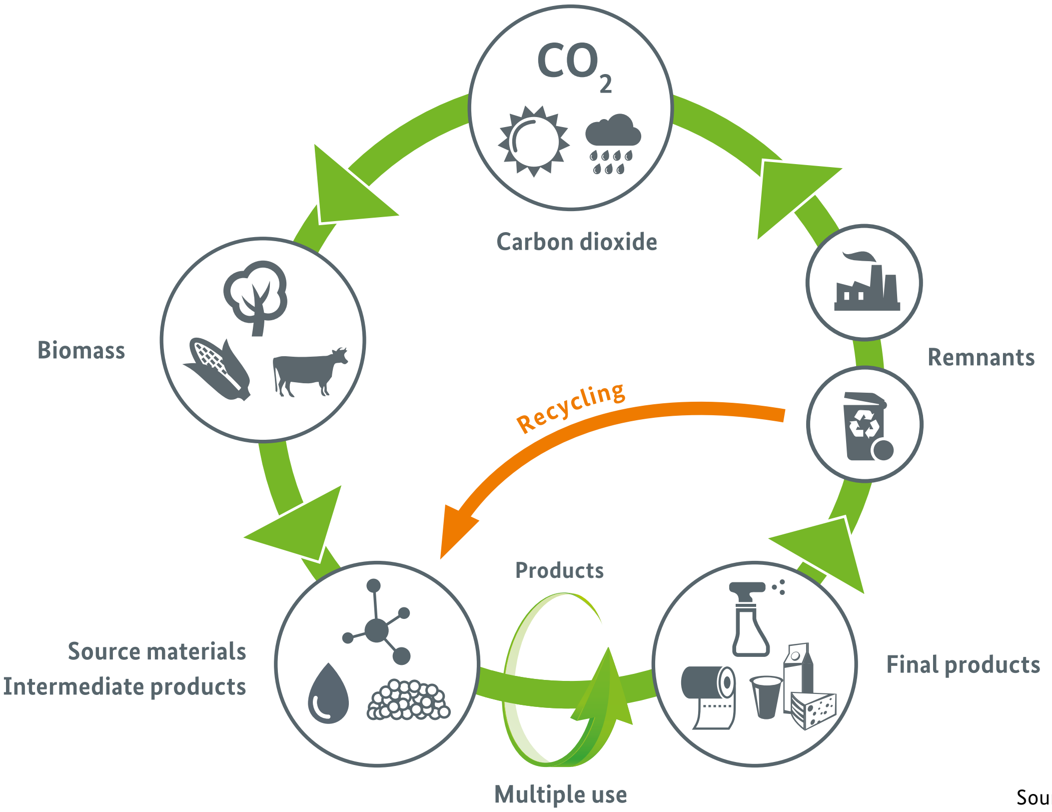
Carbon cycle in industrial processing



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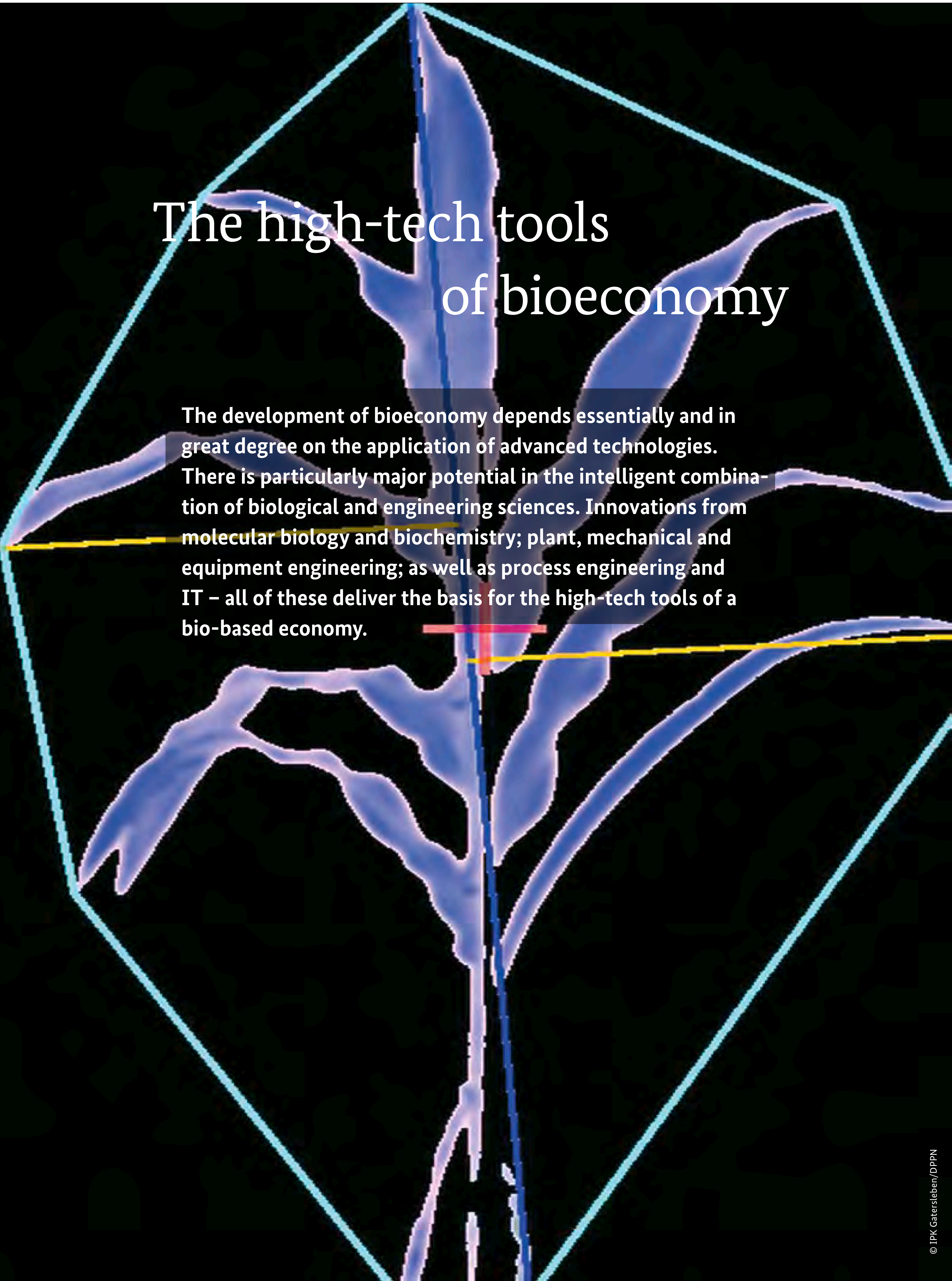
Source: BIOCOM AG

economy, to be sure, places great demands on all participants. For example, the material and energetic use of biomass places requirements on the quantity and quality of raw materials, the details of which are different than for their use in the food and fodder areas. In addition, other relevant parameters must be taken into account: not only in comparison of the material and energetic use of biomass, but also in the various and different usage routes themselves that exist there. A key aspect is land availability: since biomass is principally renewable, but is limited owing to limited cultivation space. And there is demand for intelligent handling of biomass. Bioeconomy provides the framework – on the basis of high-tech tools and bio-based production processes (see section "The high-tech tools of the bioeconomy" and "Bio-based production") – for modelling the aspects of resource efficiency and sustainability in the economy. Only in this way is it possible to succeed in assuring competition among the various usage routes for regenerative resources, and coexistence of organic agriculture with conventional agriculture and forestry. At the same time, bioeconomy offers the opportunity to increase the added value produced by biomass in Germany, and to enable sustainable further development, for rural areas as well.



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The high-tech tools of bioeconomy

The development of bioeconomy depends essentially and in great degree on the application of advanced technologies. There is particularly major potential in the intelligent combination of biological and engineering sciences. Innovations from molecular biology and biochemistry; plant, mechanical and equipment engineering; as well as process engineering and IT – all of these deliver the basis for the high-tech tools of a bio-based economy.

Advanced technologies are important engines for bioeconomy. During recent years, and especially in the life sciences, there have been pioneering advances that have given powerful impetus to the concept of bio-based economy. Insights into biological diversity, basic molecular principles and the metabolic behaviour of organisms – as well as innovations in plant engineering, mechanical engineering and sensor systems – have led to new processes and applications that can be industrially applied in many and various ways. (see section “Fossil raw materials in everyday life”)

Knowledge advances of recent decades have transformed methods of breeding crops, industrial production in bioreactors as well as the machine technology used in agriculture and forestry. Increasingly greater success has been achieved in the efficient use of regenerative raw materials and in the manufacture of bio-based products, as a result of high-tech developments in plant engineering and equipment technology, as well as by the use of latest sensor, energy and process engineering. This development enables increases in yields from field and forest, in addition to conserving resources at the same time. The combination of innovations from many and various disciplines moreover offers the potential of further development of closed-cycle-based concepts such as the biorefinery to the extent that efficient multi-use and re-use of biomass can be carried out on a cost-effective basis.

Modern breeding: faster and more efficient

For several thousand years now, mankind has tilled the fields and bred animals according to human requirements. On their way from wild forms to high-yield cultivated plants, and to high-performance farm animals, farmers over the centuries traditionally chose plants and animals toward improvement of their useful characteristics. It was only in the early twentieth century that this tradition gave way to systematic plant and animal breeding. New techniques combine the latest in insights from applied genetics and molecular biology with advanced farming and animal husbandry, and with sustainable management of soil and other resources. In classical breeding, there are many and diverse ways to achieve the desired genetic variations. The most common form is the crossing of varieties and breeds to combine interesting characteristics. In further steps, it is possible to select the desired characteristics. Enormous advances in molecular genetics over recent decades – especially in genetic analysis – have enabled major further development of this classical form of plant and animal breeding. Genome deciphering has enabled fast and cost-effective sequencing of even complex and giant genomes, as they are typical for many crops. Such databases allow breeders to control and advance selection processes appreciably more efficiently than before. At the same time, biologists and animal breeders can resort to a great selection of analysis tools, by which they can exactly investigate dynamic processes in cells, metabolic products and even the functioning of individual genes. In this way, microbiologists can associate interesting characteristics in plants and animals with certain sections in their genome and study

Inventory of genetic diversity

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For poultry and cattle, wheat and maize, algae and bacteria: study of genomes allows research and industrial exploitation. Molecular genetics has made tremendous advances in recent years. Novel techniques allow genetic analysis much faster and much more exactly than ever before – and thus advance the genetic inventory of crops and livestock. Once genetic diversity has been catalogued, this also accelerates the breeding of plants and animals with enhanced characteristics. Gene libraries are important resources here to maintain agricultural biodiversity. As part of the National Research Strategy Bioeconomy 2030, BMBF and BMEL fund research in new methods in plant and animal breeding, as well as in the creation of gene libraries.

www.biooekonomie.de
www.genres.de

These plants in orderly ranks at the IPK in Gatersleben enable exact study of the growth of maize plants.

them in detail. Moreover, knowledge of the exact construction of a genome supports breeders in using genetic markers, which are molecular landmarks. As a rule, such markers are inherited together with a commercially important characteristic.

These salient sections are therefore of paramount significance for smart breeding. The progeny of crossed plants and animals are investigated here in molecular biological tests; if certain markers can be detected, this indicates that the tested progeny have in fact inherited a gene variant. A targeted genome check can determine, even with young organisms, which are suitable for further breeding. For agriculture and animal breeding, these advances have paid off: in recent years, with significant reduction in labour and costs for breeding.

Some breeding goals, however, cannot be achieved by crossing, since the desired characteristics may not exist within a species or breed. In such cases, molecular biological methods offer alternative techniques: for example, by precisely inserting genetic material into the genome of animals or plants. Genes from the same, related or different species are suitable for gene transfer. In this manner, it is possible, for example, to transfer interesting characteristics from wild plants into modern, high-output varieties. The development of plants with high yields, even under extreme weather conditions such as drought or cold, is possible with the aid of such techniques, since the desired characteristics often exist among microorganisms. There is strong opposition in the European Union to the commercial cultivation of genetically modified crops, and such plants are cultivated only by a few members of the EU. The cultivation of genetically modified crops continuously increases throughout the world: also significantly in countries that export genetically modified raw agrarian materials to the EU – for example, from the USA, Brazil, Canada and Argentina. In 2013 approximately 175 million hectares of genetically modified crops were cultivated, by 18 million farmers. In countries outside the EU, there is already cultivation approval for genetically modified crops such as cotton, soya, maize, rape, sugar beets, potatoes, rice, pumpkins, melons, papayas, tomatoes, sweet peppers, radicchio, plums, alfalfa, flax, flowers and poplars. As current research and development projects make apparent, this list will continue to increase in coming years. Globally, already around 80 % of soya harvests and around 70 % of cotton harvests are genetically modified.

Preserving agricultural biodiversity

In the past, there was sometimes neglect of the great importance of genetic and biological diversity for the efficient and simultaneously sustainable breeding of plants and animals. Upon first use of a plant variety or animal breed, only a few species were often domesticated and selected for ongoing breeding. Accordingly, the Federal Office for Agriculture and Food (BLE) has reported that only eleven livestock species form the basis for animal production in Germany. In addition, of the 74 domestic breeds subject to animal breeding laws, 52 (from five species) are endangered. It is furthermore assumed that internationally 75 % of the genetic diversity of cultivated plants has been lost. Such constriction of the genetic pool leads to the extinction of original domestic varieties or breeds. Within this context, breeders and scientists have begun to compile gene libraries toward assuring genetic diversity. The Gatersleben gene library, for example, contains around 145,000 seed samples from crops collected from around the world – including 20,000 from barley alone. There are additionally also gene libraries – funded by the BMEL and coordinated by the BLE – for wild and ornamental plants. Funding by the BMEL has likewise enabled creation of the German Gene Library for Livestock, to promote the preservation of domestic livestock breeds.

Phenotyping: automatic screening

Examination of genotypes, however, affords only partial disclosure of the genetic constitution of a plant or animal. For this reason, modern breeding takes a closer look at the phenotype as well – which can reveal how genetic "interior design" is manifested in specific characteristics. This benefit is highly important for plant breeders: for example, with regard to the interaction of a plant with its environment. Researchers have set up so-called phenotyping platforms to enable analyses with a great number of plants. Such facilities fully automatically screen plants in great numbers, in accordance with particular characteristics. Ideally, non-invasive techniques are used here that scan the plants without damage. These methods are similar in principle to positron emission tomography and nuclear magnetic resonance spectroscopy (NMR), familiar from medical diagnosis (see section "Agriculture"). This fully automatic scanning of plants and their individual components – such as roots, stalks, leaves and fruiting bodies – is the key to gaining new insights into breeding and agricultural practice, as well as to forwarding ecological research. On the basis of this data volume, computer-aided techniques and intelligent algorithms can model future breeding results in the computer and, to some extent, predict them. The closer linking of genome research, phenotyping and breeding, in order to contribute to building the agrarian system of the future, will represent an essential building block for future development of bioeconomy in Germany. This process will be funded by measures of the BMBF and BMEL toward sustainable agrarian production.

Visions for high-tech tools of the future

In addition to the methods and processes already being employed, researchers are at work on entirely new ideas for even stronger interlinking of biology and technology for bio-based production of tomorrow. As part of a BMBF initiative launched in 2010 – The Next Generation of Biotechnological Processes – there are, for example, deliberations directed toward simulating biological processes for material and energy transformation. Microbial fuel cells, artificial photosynthesis and universal production organisms – there are ideas enough for industrial production of the future. The first 35 projects for basis technologies have by now been funded to the amount of 42 million euros. Additional major projects in research organizations are also underway and are partially funded by BMBF.

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Smart technology on the fields

For crop and livestock husbandry, high-tech tools are important not only for breeding. Innovations in plant, equipment and machine engineering are increasingly

Intelligent farm robots inspect the fields

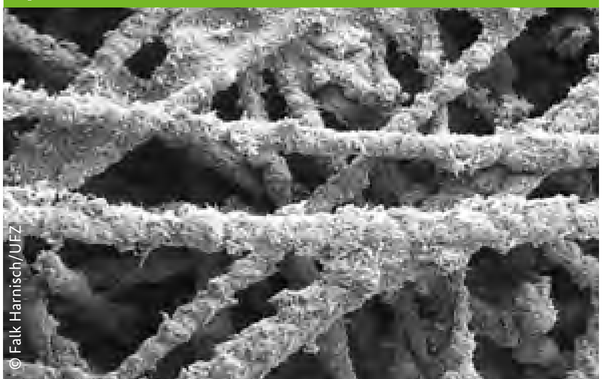
The BoniRob is an extraordinarily versatile and, at the same time, exacting agrarian robot. This machine, which has already received several awards, was developed at Hochschule Osnabrück, in conjunction with the car component supplier Bosch and the agricultural machine maker Amazone, as part of a project funded by the BMEL. With its individually controlled wheels, BoniRob autonomously finds its own way through the fields. Equipped with laser scanners, light grids, spectrometers and other sensors, it scans every individual maize plant and determines how well the plants are being supplied with nutrients and water.

© Hochschule Osnabrück

entering work in fields and stalls. So-called precision agriculture is linking the latest automated agricultural technology with sensors and systems for data processing, to ensure that production can be demand-driven, sustainably managed and optimally oriented to fluctuations in agrarian eco-systems. In this way, farm management measures within one field or in an animal herd can be organized with intelligent agricultural machines such that they are individually adapted to local conditions and to individual animals. This enables more efficient use of fertilizer and fodder and reduces environmental burdens at the same time.

Many farm tractors today are filled with high-tech: with sensor technology, computers and satellite navigation on board, they move over fields, record the condition of growing crops, combine their measurements with geodata, exactly derive nutrient requirements for plants and react with coordinated dosing of fertilizer. Automated harvesting robots perform field work in difficult terrain (see box on page 85). Innovation funding by the BMEL is an example of continuous promotion of innovation. It is characteristic for the advanced agriculture of today that the farm machines being used are not only more intelligent, but that they are also more closely inter-coordinated. Modern sowing machines, for example, can plant seeds down to centimetre precision: exactly where another machine has earlier placed the fertilizer. Automatic driving control guides tractors and harvesting combines down the rows, with precision of a few centimetres. High-tech tools are also integrated in animal husbandry. Advanced sensor systems in the stalls precisely check the state of animals' health – which enables farmers to diagnose and treat diseases faster than before.

Electro-bacteria: production of material with power



It was only a few years ago that discovery was made of bacteria that degrade organic molecules and generate electric power at the same time. With their help, researchers have developed so-called biofuel cells. The reverse case was also discovered: if power is specifically applied to electro-active bacteria, this will activate their metabolism and they begin to produce high-quality organic compounds. Electro-biotechnology is a field of the future with which more and more scientists also in Germany are becoming involved. As part of a funding initiative – The Next Generation of Biotechnological Processes – Biotechnology 2020+ – the BMBF is funding a number of research projects that investigate electrosynthesis by microbes.

Interaction of biology and technology

In addition to plants and animals, microorganisms and cells – as well as the biomolecules obtained from them – represent essential building blocks of bio-based farming economy. Whether for the chemical, pharma or food industries: already today they are being employed in greatly diverse and numerous ways as biological mini-factories in the production of chemicals, medication and fuels (see section "Bioeconomy in everyday life"). The industrial and commercial application of microorganisms, cells and enzymes for a great diversity of sectors is called industrial (or also "white") biotechnology. Natural scientists and engineering scientists can especially complement one another here. One effort involved is to exploit the diversity of microorganisms and their capacity for industrial production.

Huge collections of microbial samples from many and various areas of life, as well as so-called metagenome libraries, represent one way toward archiving and accessing this diversity. Bacteria are tracked down, for example, that can dissolve metals as well as rare earths from ore, or that can obtain electric power from waste water (see box on page 86). Increasingly precise analysis and lab techniques additionally track and monitor these proficient little helpers "live" at their work. Other research approaches such as systems biology apply holistic investigation to the complex metabolic processes of cells.

These insights can be used to equip cells and biological systems, according to engineering principles, with complex new characteristics and functions. The application of living organisms and cells as mini-factories for bio-based production demands a great deal of expertise in production and process engineering – at which extensive and varied research is taking place (see sections “Bio-based production – an overview”, “Mechanical engineering” and “Pharmaceuticals”).

In many production systems in bioeconomy – including biogas plants, aquaculture and biorefineries –system cycles are applied that combine material and energetic use or employ innovative recycling technologies (see section “Bio-based production”). Also apparent here are the latest trends in bio-process engineering, in which smaller and mobile disposable (or one-way) bioreactors are replacing conventional stainless steel tanks in order to simplify elaborate sterile production conditions. All these challenges demand not only engineering skills and expertise in plant engineering, but also in molecular biology. A great number of BMBF-funded measures pursue the objective of supporting research and development projects in this area. This particularly applies to small and medium-sized enterprises, and for companies in sectors that have previously had no extensive experience with bio-based processes.

Intelligent combination of innovative materials

Essential impetus originates, moreover, from the material sciences and from production engineering. Materials researchers, for example, have transformed wood, a traditional raw material, into a high-tech material – one that

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also satisfies contemporary requirements for high-rise construction (see section “Construction”). Sophisticated production methods have created innovative wood materials that exhibit building-physics performance characteristics similar to those of reinforced concrete.

Construction with wood exemplifies an additional aspect that is typical for the application of bio-based materials of the future: they can be effectively combined with conventional, petroleum-based material building blocks. The production of hybrid products and composite materials enables savings in energy and carbon dioxide: which also applies to the growth market for bio-based plastics (see section “Chemistry”). The high-tech tools of bioeconomy from regenerative raw materials help to create building blocks and intermediate products that allow intelligent combination with other source materials from the petrochemical industry. In progress toward bioeconomy, it will be necessary to integrate bio-based techniques, step by step, into existing infrastructures.

Bio-based production – an overview

Resource-efficient and sustainable production processes are the key elements of bioeconomy. Tiny living beings such as microorganisms play their parts, as do highly complex technical facilities in which multi-utilization of regenerative raw materials takes place. Ideally, bio-based production is intrinsically a closed cycle.

Production and process engineering play a decisive role in every sector of the economy, in the preparation and processing of raw materials of many and various kinds. In a bio-based economy, sustainable and resource-efficient production engineering is crucial. It represents an essential building block toward reducing the emission of carbon dioxide and toward enhancing the environmental compatibility of industrial processes. One of the most important objectives expected of bioeconomy consists of lowering the consumption of fossil raw materials such as coal, petroleum and natural gas in industry. The diversity of bio-based production systems is great. Cultivated fields, meadows and forests accordingly also play major roles here, just as do biological mini-factories in the form of bacteria, fungi and cells. Also involved is the entire bandwidth of plant systems in which biology and engineering go hand in hand: they range throughout aquaculture, biogas facilities and biorefineries. A further goal of bioeconomy is to establish intrinsically closed-cycle system in which raw and waste materials are not only prepared and processed, but in which they ideally can be multiply used and further processed.

Sustainable soil management

The production of the required biomass is located at the very beginning of value-added process chains. Whatever is involved in production – whether food and beverages, animal fodder or industrially used raw materials – sustainable cultivation of the necessary plants can take place only on fertile soil. Around 50% of the entire area of Germany is used for agriculture, with an additional 30% occupied by forests. With its area of 27.8 million hectares, soil is therefore the most important production factor for agriculture and forestry (see section "Agriculture and forestry"). Soils, to be sure, are also sensitive ecological systems that perform their own so-called ecosystem services. These include the storage of water and carbon, which has direct effects on climate changes. The changes possible here are currently being analysed in the first National Agricultural Soil Survey to cover all of Germany. This survey, financed by the BMEL, is the first consistent and representative inventory of carbon resources in the top 100 cm of agriculturally used soil. Researchers from the Thünen Institute, who conducted the survey, submitted initial findings in 2014 – which more clearly reveal the role played by agriculturally used soil for climate protection.

Working with soils in agriculture or forestry demands a great deal of patience: soils are created in long-term processes and cannot be quickly renewed or replaced. Under these conditions, it is hardly surprising that science repeatedly confronts the issue of how the serviceability of agrarian soils can be maintained and enhanced over the long run. The BMBF systematically funds such projects with support focus on the project BonaRes: Soil as Sustainable Resource for Bioeconomy. The associated activities take place additionally within the Federal Organic Farming Scheme and other Forms of Sustainable Agriculture (BÖLN).

Researchers are additionally addressing the issue of how it is possible to enhance the nutritive efficiency of plants through plant roots. Around 95% of all land plants intake their required inorganic nutrients through fungi, with which they form a symbiotic association called mycorrhizia (from Ancient Greek "fungus" and "roots"). Deeper insights into this symbiosis are an inestimable factor for sustainable agrarian systems. Currently, around 70 % of potentially available potable water in the world is used for agriculture, and costs for nitrogen and phosphate fertilizers will sharply increase in the near

The fungus *Aspergillus* niger is, in its natural state, capable of producing a variety of technical enzymes. This capability is systematically used by industry.

future. Under these circumstances, the application of efficient fungus-plant symbioses will play a growing role. The effective functioning of these symbioses allows significant enhancement of the resistance of plants to pests and to drought and salt stress – and reduction of the accumulation of heavy metals in plants. In a BMBF-funded project, researchers from Ludwig-Maximilians Universität München (LMU Munich), as part of a spin-off, intend to market a promising root-coating technique for agriculture. A prognostic, intelligent soils management programme is in turn under development in the Platform for Protection of the Natural Resource Soils, initiated by the BMEL, in which representatives of the federal government, states, communities, associations, science and investors are participating.

Microbes as mini-factories

Microorganisms such as bacteria and fungi likewise represent important production systems for the bioeconomy. These microscopic organisms thrive in an astonishing diversity of very different habitats. They live in soils, but also in locations subject to extremes of heat, cold, radiation, pressure and darkness. In a bio-based economy, microbes represent the smallest bio-based production units. Mankind has always exploited the capabilities of microorganisms. In many cultures, methods were employed for the fermentation to alcohol of sugar-containing nutrients, by using yeast and lactic acid fermentation with use of *Lactobacillus* species – and for production of vinegar with the aid of special *Acetobacter* species. This was long before the discovery of microorganisms themselves, and before insights into the fundamental processes involved. Today, industry systematically exploits these natural capabilities. Microorganisms, for example, carry out complex material conversions, with high yields at room temperature and standard pressure – in contrast to chemical processes that require high temperatures and pressures (see section "The high-tech tools of bioeconomy"). In large fermenters, these high-performance microbes produce a great diversity of industrial products: for example, basic chemical building blocks, washing agent enzymes, bioplastics and active pharmaceutical agents (see section "Bioeconomy in everyday life").

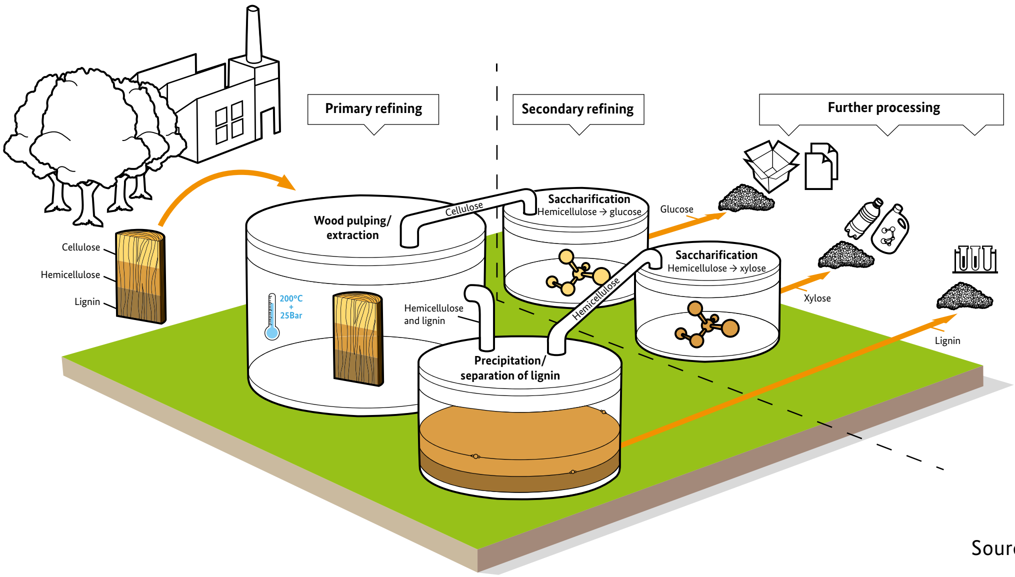
Carbon residue as raw material

Sewage sludge and industrial waste water contain a great amount of carbon that has until now gone unused. As part of the strategic alliance Zero Carbon Footprint (ZeroCarb FP), funded by the BMBF, 21 partners from industry and science have joined to advance process development for exploitation of flue gas and waste water as raw materials suppliers. Objectives involve the use of microorganisms that – fed with carbon-rich waste – produce valuable building blocks for industrial production. Project participants intend to concentrate on product involving bioplastics, aircraft de-icing agents, bioleaching in mining and additives for high-tech oils and fats.

Recycling – a second life for biomass

There are by now a number of bio-based processes for the production of heat, electric power and fuels (see section "Energy"). Many such processes are based on the exploitation of remnant, residue and waste materials. They include biomass district heating power plants in which cordwood is fired that cannot be used for alternative purposes, or that cannot be utilized at competitive prices. Animal products such as solid and liquid manure are employed in biogas plants. German engineers are world-leading in the development of the latest biogas processes. Future plans also include the use of mixed matter such as left-over food. Experts in bio-process engineering conduct ongoing work on further developments – to further shorten production steps and to increase production yield. On the basis of its long tradition in mechanical engineering, Germany has access to extensive know-how (see section "Mechanical Engineering").

Function schematic of the lignocellulose biorefinery at the CBP in Leuna



Source: BMEL/FNR

Within the context of bioeconomy, efforts are being additionally directed to finding new ideas for waste recycling that interlink materials cycles leading through and beyond various sectors. The strategic alliance funded by the BMBF and under direction of the company Animox GmbH, for example, is working to extract valuable technical protein building blocks from rapeseed waste – which can in turn be used downstream to make such products as paints and pigments.

The integration, however, of bio-based production processes into a complex infrastructure – one that has become established over the past decades on the basis of petroleum-based industries – is by no means a simple matter. So-called drop-in solutions are easy to integrate if the bio-based variants are employed as substitute for fossil products. In the chemical sector, this includes chemical precursors from bio-based production that can be used downstream in the following traditional production sequence – because, in their chemical properties, they harmonize with products from petroleum. This applies, for instance, to bio-based succinic acid (see section "Chemistry").

Biorefineries – production concept for the future

Appreciably greater challenges arise with technical facilities based on a number of production steps that consequently must be organized on a completely new basis. Engineers have major expectations here in conjunction with the concept of the biorefinery. Analogous to present oil refineries, biomass as raw material would be broken down as efficiently as possible into its individual chemical constituents and profitably employed. A biorefinery is a plant with an integrative and multi-functional use concept: regenerative raw materials are converted with the aid of many and various technologies into a broad spectrum of intermediate products and products – ideally, with complete use of all biomass building blocks. This would, in ideal cases, involve the linking of material and energetic usage avenues.

In order to exploit biomass sustainably and to avoid entry into competition with food production, research is especially concentrating on second-generation biorefinery concepts. Operations here would be based on remnant material such as straw, grass and waste wood. At the Fraunhofer Center for Chemical-Biotechnological Processes (CBP) in Leuna, German researchers are working on biorefinery concepts based on wood as raw materials; funding is by the BMBF; the BMEL; the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB); and the state of Saxony-Anhalt (see box p. 92).

The Biorefinery Research Centre at the Leuna chemical complex


© Gunter Binsack/Fraunhofer CBP

Work is progressing on new biorefinery concepts at the Fraunhofer Center for Chemical-Biotechnological Processes (CBP), which is embedded at the industrial-chemical park in Leuna. A total of 53 million euros has been invested into this research centre, as showcase project, by the federal government, the state of Saxony-Anhalt and the Fraunhofer-Gesellschaft. The CBP, which opened in October of 2012, offers its partners from research and industry five different process plants on 2,000 m² of space in which the industrial plant modules can be separately operated or combined as needed. Emphasis here is on wood as raw material – especially on the material and energetic exploitation of lignocellulose. Early in the process chain, wood chips are broken down into their constituents cellulose, hemicellulose and lignin in something resembling a pressure cooker (see graphic, page 91). Lignin can be used as a binding agent or as an engineering material. With the aid of enzymes, cellulose and hemicellulose are broken down into the sugar molecules glucose and xylose – which can be used to feed microbes that produce various chemicals. The CBP is the heart of the BioEconomy Cluster launched in 2012 and funded by BMBF with 40 million euros. Sixty partners from the region pool their forces to set up an optimal exploitation chain supplied from the plentiful beech wood in the region – by systematic interaction among the chemical, paper, cellulose, automotive, construction and textile industries. The French company Global Bioenergies recently set up facilities in the industrial part. In a pilot plant at the CBP, plans are to produce up to 100 tons annually of the gaseous carbohydrate isobutene. Additional partners in the BioEconomy Cluster are Linde, Total, Vatenfall as well as many small and medium-sized enterprises such as Homatherm. The Deutsches Biomasse Forschungszentrum (DBFZ) is integrated into the network as a research institution.

www.bioeconomy.de

Besides Leuna, an additional biorefinery centre has been established in Straubing, in Bavaria. In 2012 the specialty chemical company Clariant opened operation at the largest demonstration plant in Germany until now for biotechnological extraction of second-generation biofuel. In the 28 million euro building complex, Clariant produces the fuel ethanol from agricultural waste, including wheat straw that contains lignocellulose. The BMBF and the Bavarian state government each funded this pioneering project with 5 million euros (see section “Energy”). Another biorefinery approach for exploitation of residue biomass such as straw is being pursued at the Karlsruhe Institute for Technology, together with five industrial partners. This four-stage process produces from biomass a syngas that can be converted into fuel – a so-called biomass-to-liquid fuel (see section “Energy”). These examples show that work on biorefinery concepts in Germany is in progress at numerous sites. The pilot and demonstration plants must evidence that they are not only sustainable and efficient, but that they can also function effectively on a major industrial scale, and that they can cost-effectively operate. The Biorefinery Roadmap published by the federal government summarizes the challenges associated with establishment of biorefineries. This strategy paper was prepared by experts on behalf of the BMEL and the BMBF and now serves the federal government as basis to advance further development of biobased economy in Germany.

Aquacultures today and tomorrow

New avenues have now opened in the development of aquaculture. In Germany, aquaculture is centred on facilities in open ponds or in flowing waterways. Since the 1980s, integrated systems have been developed that combine fish breeding and plant cultivation. The ancient Aztecs knew that rice plants yield more when fish live around them. By now, aquaponics systems have recently emerged as a new trend in aquaculture: the combination of aquaculture and hydroponics (plants cultivated without soil). Aquaponics represent a natural materials cycle consisting of plant, bacteria and fish cultures.

From economic and ecologic perspectives, such a circulatory solution operates more efficiently than systems that utilize only a smaller section of the biological cycle. The excrement of the fish, for example, simultaneously nourishes vegetables, and nutrients are not lost. Other useful substances are also produced, such as sewage sludge for biogas facilities. Funded by the BMBF, the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) is currently working on such a closed system. Since the species involved here – tomatoes and tilapia cichlids – harmonize so well, the project has been called “Tomato Fish”.

The first commercial facility has recently been built in Berlin by the company ECF Farmsystem GmbH, and a demonstration facility is planned for the Müritz Waterway. Major aquaponics systems already in operation in the USA combine, for example, cichlids with lettuce and revitalize abandoned industrial sites. Experts associate aquaponics with the hope of reducing fresh water use in agriculture. Aquaponics would therefore be particularly interesting for regions otherwise too arid for agriculture. Thanks to advanced technical systems such as LED plant lighting or plasma lamps, aquaponics operations can take place without regard to natural daylight. Aspects of vertical gardening can also be integrated here. Successful applications in aquaponics can additionally influence developments in building-integrated agriculture in urban areas – also called urban farming. In the sense of local nutrition culture, this futuristic vision involves exploitation and networking of local synergism in the use of resources. The next step involves adapting technologies from traditional agriculture – for example, from greenhouses – to fit these new applications (see section “Agriculture”).

Industrial uses of algae


© FZ Jülich

In addition to microorganisms, algae also serve as sources for energetic or material exploitation by industry. Plant engineering specialists have developed tailored, transparent reactors for such purposes: so-called photobioreactors. One challenge here is to utilize incident solar radiation as efficiently as possible, to achieve sufficiently high yield of the desired final product. Algae are already manufacturing constituents for the food and fodder industry and for cosmetics. Photobioreactor systems are in development that, according to the principle of circulation systems, input various material flows and further process them to the form of algae biomass. At the research centre Forschungszentrum Jülich, Germany, the BMEL is funding an algae plant intended for production of biokerosene as aircraft fuel. With funding from the BMBF, biotech companies such as Subitec GmbH and IGV Getreideverarbeitung GmbH are working on technologies for the exploitation of algae biomass.

Outlook – bioeconomy in social dialogue

The implementation of bioeconomy is a process for the entire society: not one that can be implemented alone by expert circles in science and economics. A bio-based, sustainable economy has a chance to become reality only if the desired goals and the possible conflicts in objectives are discussed with all players in society.

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As bioplastics in the bonnet of an automobile, as material for parquet flooring or as fabric in a jogging shoe: many regenerative raw materials have been integrated into the products of our everyday life. Many bio-based processes have become integral parts of various industrial sectors – and have become the expression of incipient structural economic transformation toward bioeconomy. The value of regenerative resources has therefore become recognized, and application of bio-based techniques and processes of all kinds is increasing. The examples presented in this brochure confirm this development.

Experts, however, agree that it will not suffice simply to shift from a basis of fossil to regenerative raw materials, or to merely employ biomass for industrial applications. It will likewise not prove adequate only to integrate, by individual innovations, biological knowledge into existing process technology. To meet the challenges of the twenty-first century, successful structural transformation must take place throughout all of society: changes that effectively link economic growth and ecological compatibility and take social issues into account. The economy must satisfy growing requirements placed on the manner in which production takes place: these issues are founded on protection of our environment, nature and animals – and on the maintenance of social standards. Further challenges are likewise associated therewith: especially since the availability of regenerative resources and climatic conditions vary widely according to geography. These circumstances lead to development of new production centres, to new patterns of the flow of goods and, accordingly, to possible new competitive and conflict situations that must be treated within the context of international collaboration. This transformation process in economy and society can therefore take place only on a holistic basis.

Goal: bioeconomy in extensive application

The first three years with the National Research Strategy Bioeconomy 2030 have shown that the realization of a bio-based and regenerative economy is greatly dependent on whether all participants can be integrated: researchers, producers of regenerative raw materials, industrial users and the entire society. Transformation must be oriented to sustainability and must be accelerated. There must be an increase in sustainable and bio-based products and production methods – which must then be successfully marketed.

Many factors influence the development of a bio-based and sustainable economy. Scientific and technical innovations, as drivers, play a key role – just as do interrelationships among economy, environment, engineering and society. Moreover, objectives linked to bioeconomy can compete with each other. Systemic research approaches are therefore of prime significance for ongoing development of Germany as a land of bioeconomy.

It is also apparent that bioeconomy in Germany will continue to advance only if broad sectors of the population support changes in economic and behavioural structures. It will be crucial to expose the concept of bioeconomy

News and background on the Web

What is bioeconomy? What new research trends are apparent? Where is research on bioeconomical issues taking place in Germany? Which projects does the federal government support? What are the current funding initiatives? The information platform of the BMBF – biooekonomie.de – provides the answers to these questions. In generally understandable form, this platform publishes the latest news from science, economy and politics – as well as thematic dossiers and examples of funded projects. Profiles give insights into the everyday work of men and women researching in bioeconomy. In addition, the site publishes overviews of bioeconomy activities in other countries, as well as current funding measures. Numerous video clips help students and teachers discover the world of bioeconomy. Site visitors can order informative material free of charge.

www.biooekonomie.de

Sustainable agriculture in the city – associated with the concept of urban farming. Here, an example of Kreuzberg, in Berlin.

more to public perception and to enable fact-based discussion among research, industry, society and politics – so that economy and society can sustainably continue to develop.

Extensive political support has been granted in Germany to prepare the way for a bio-based economy; nevertheless, large shares of the population are still unacquainted with bioeconomy as such, or with its methods and sub-areas. The vision of a bio-based economy accordingly calls for extensive explanation. Social dialogue and understanding for the challenges and opportunities of bioeconomy play a decisive role in the demand for new products and services, and for the associated innovations and technological developments. It is only if citizens are actively incorporated into shaping this social transformation that bio-based economy has a chance.

Dialogue with the broad public

The German Bioeconomy Council is an autonomous consulting body of the federal government on the topic of bioeconomy. As such, this council has begun to conduct an open-ended dialog with the broad public (see box at the right). Its initial events have shown that citizens are highly interested in meeting the challenges of a sustainable structural transformation. Discussion focuses above all on questions of everyday life: What influence will changing mobility behaviour bring? How will new infrastructural and architectural concepts look? Topics of discussion also include dealing in critical fashion with one's own consumer behaviour. All of this reveals that bioeconomy is part of an overall social transformation process – one that covers the entire range of highly diverse trends and initiatives that include green economy, sharing economy, citizen science and urban farming. With a view to bio-based and sustainable structural transformation of the economy and society, the numerous and various approaches to bioeconomy will deliver key incentives.

The players in bioeconomy in Germany will in the future face the challenge of considering industrially relevant innovations in an intra-contextual manner. It is no longer a matter strictly of scientific expertise and technical feasibility, but also of integration of broader perspectives – arising from society, politics and science. It will indeed be more important than before to take into consideration the needs and wishes of consumers and users in the development of new products, services and processes.

Second half for the National Research Strategy Bioeconomy 2030

Above all within the context of innovation funding, the federal government – with its National Research Strategy Bioeconomy 2030 and its Political Strategy Bioeconomy – will provide the required impetus. The federal government has set the objective to promote participation of all social players for development of bioeconomy in Germany: the federal states, research organizations, colleges and universities as well as non-governmental organizations. Bioeconomy as a process throughout society can thrive only if joint action succeeds.

It will at the same time prove essential also to consider national developments within an international framework. Bioeconomy is on the advance throughout the world. Bioeconomy will play an essential role in Horizon 2020, the Eighth EU Framework Programme for Research and Innovation. Here as well, all participants are called on to make an active contribution and to help build bioeconomy.

The German Bioeconomy Council

As an autonomous consulting body for the federal government, the German Bioeconomy Council was set up in 2009 with the Federal Ministry of Education and Research (BMBF) and the former Federal Ministry of Food, Agriculture and Consumer Protection (BMELV). With their individual expertise, the 17 members active in the second period (beginning in 2012) of work for the Bioeconomy Council cover the field and content of bioeconomy in its entire extent. They search for ways toward sustainable solutions and place their findings in a global context. The council holds open dialogue with society. It furthermore provides recommendations on how basic and ongoing training, as well as research and development, can be optimally promoted. The activity of the council is oriented not only to long-term goals but also to current political requirements.

www.biooekonomierat.de

Glossary

Amino acids
Organic compounds that provide the molecular building blocks of protein. Of proteinogenic amino acids, 23 have been identified until now.

Aquaculture
The controlled breeding, husbandry and reproduction of aquatic organisms, including mussels, crayfish and algae in addition to fish.

Aquaponics
Aquaponics denotes a method of combining the techniques of aquaculture and the cultivation of crops in hydroculture in a closed water and nutrient cycle.

Bio-based
On the basis of biological resources

Bioenergy
Regenerative energy source; the energy carriers are obtained from biomass. Bioenergy can provide electric power, heat and fuels.

Biomass
Mixture of organic material bound in living organisms or derived from them.

Biocatalyst
Biocatalysts are biomolecules that accelerate or retard biochemical reactions in organisms by retarding or (less frequently) promoting the activation energy of the reactions. They are not changed by the reactions and can therefore catalyse many consecutive reaction cycles.

Bioeconomy
Knowledge-based production and use of regenerative resources to provide products, processes and services in all economic sectors in the context of a future-capable economic system. The concept of bioeconomy encompasses all sectors of the economy and their related services areas that produce, prepare and process, use and therefore treat regenerative resources such as plants, animals and microorganisms and their products. Synonym: bio-based economy.

Bioreactor
A bioreactor is a vessel in which especially bred microorganisms or cells are cultivated under as nearly optimal conditions as possible in a culture medium, in order to obtain either the cells themselves, parts of them or one of their metabolic products. Bioreactors are also called fermenters.

Biorefinery
Integrative overall concept for the processing of regenerative raw materials to produce chemicals, biomaterials and other material products, as well as fuels, with maximum exploitation of biomass (comparable with an oil refinery, which however produces a great number of different substances from petroleum).

Biotechnology
The application of science and technology to living organisms and their constituents, products and models, for the purpose of modifying living or non-living material, to produce goods, materials and products, including knowledge increase and provision of services.

Bulk chemicals
Bulk chemicals or bulk products are basic chemicals produced in amounts of more than 10,000 tons annually.

Cascade use
Single or multiple material use of a raw material in products (for example, by paper recycling), as well as subsequent energetic use.

Cellulose
Long-chained carbohydrate fibres that are constituents of plant cell walls; raw materials for the production of paper, plastics and fibres.

Coupled production
Simultaneous production of more than one product in one single production process.

EEG
The Renewable Energy Act, which controls since 2000 in Germany the input into and the output from power mains, as well as the use of and payment for electric power produced from renewable energies.

Energy crops
Plants cultivated and used for producing bioenergy; in addition to maize, rape, grain and sugar beets, also poplars, the cup plant *(Silphium perfoliatum)* and other wild plants.

Enzyme
An enzyme is a protein molecule that can catalyse a chemical reaction. The majority of biochemical reactions in living systems are catalysed and controlled by enzymes.

Fermentation
Fermentation is an energy-releasing metabolic process that decomposes organic material and that takes place anaerobically (under the exclusion of free oxygen).

Fermenter
Another designation for a bioreactor.

Fine chemicals
Substances with a great degree of purity, as required for example for pharmaceutical ingredients.

Functional food
Food with functional ingredients that promote health.

Lignin
Constituent of plant cell walls, with network structure. Enables lignification of the cell.

Lignocellulose
High-molecular regenerative raw material consisting of cellulose, hemicelluloses and lignin. Constituent of the cell walls of lignified plants.

PET
Polyethylene terephthalate, a thermoplastic.

Phenotyping
Collection of information on key functions and structures of organisms and biological systems and of their fundamental physiological, molecular and genetic causes.

PLA
Polylactide, a bioplastic made of polymerized lactic acid.

Precision agriculture
Agriculture on the basis of latest technology, which combines sensors, IT systems and automation systems, with the objective of adapting and optimizing production of food to local differences in the agrarian ecosystem.

Regenerative raw materials
Agricultural and forestry products that serve as raw materials for industrial products, or for producing energy, but not for food or fodder.

Short-rotation forestry (SRF)
Plantations in which rapid-growing trees such as poplars and willows are cultivated. The permanent cultures are ready for harvest after a few years.

Smart breeding
Breeding methods based on molecular markers, to enable faster selection for a certain characteristic of plants, animals or their progeny.

Special chemicals
Chemicals with a great degree of functionalization. Internationally, less than 10,000 tons a year are produced.

Sustainability
Concept of a permanently future-capable development of economic, ecologic and social dimensions of human existence. Sustainable development satisfies the needs of the present without risking that future generations will not be able to supply their needs.

Funding measures

An overview of funding measures of the Federal Ministry of Education and Research (BMBF) and of the Federal Ministry of Food and Agriculture (BMEL) that are relevant to bioeconomy

BMBF

National

BonaRes
PLANT 2030/PLANT-KBBE
Innovative Plant Breeding within the Cultivation System (IPAS)
Competency Networks in Agrarian and Food Research
German Plant Phenotyping Network (DPPN)
Fraunhofer Center for Chemical-Biotechnological Processes (CBP) in Leuna
BioEconomy Cluster
Innovation Initiative for Industrial Biotechnology
Initiative Biotechnology 2020+
SME Innovative: Biotechnology
Founding Push Biotechnology GO-Bio

International

International Bioeconomy
Global Food Security (GlobE)
ERA-Net ANHIWA
ERA-Net FACCE-JPI
ERA-Net SUSFOOD
ERA-Net Industrial Biotechnology
ERASynBio
ERA-Net EuroTransBio

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BMEL

National

Programme for Innovation Funding in the Areas of Food, Agriculture and Consumers
Funding program Regenerative Raw Materials
Federal Organic Farming Scheme and other Forms of Sustainable Agriculture (BÖLN)

International

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ERA-Net FACCE-JPI
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ERA-Net ICT AGRI
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