Bio-economy Council Report **2010**

Bio-economy Innovation

BioÖkonomieRat

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Research and technological development to ensure food security, the sustainable use of resources and competitiveness

Foreword

One of the greatest challenges of our time is to produce sufficient volumes of biomass while maintaining a sustainable approach to our terrestrial and aquatic, i.e. marine, resources. Both factors have a direct influence on markets and the price structures of bio-based products. Only by considering all aspects of sustainability can we secure food for a growing world population, and at the same time ensure that there is sufficient biomass for material and energy use in view of the changing general conditions – e.g. the local influences of climate change. Production techniques which are saving on resources are as important to sustainability as the efficient processing and use of the biomass produced. Here the bio-economy will play a key role.

To put Germany promptly on the right track in this seminal field, the Federal Government requested the German Academy of Science and Engineering (acatech) to establish a Bio-economy Research and Technology Council in conjunction with the BMBF and BMELV. The Bio-economy Council was founded in January 2009, and already after six months was ready to present its 'First Recommendations'. This first comprehensive report fleshes out those 'First Recommendations' with a wealth of technical detail.

The report is the result of a broad spectrum of work. Four work groups were set up, covering the areas of land, plants, animals and biotechnology, as well as two cross-discipline work groups focusing on issues of communication and acceptance, and international questions relating to the bio-economy. These work groups comprised Bio-economy Council members as well as further experts, to whom I extend my warmest thanks. The papers drafted by the work groups were reviewed externally, and I, likewise, wish to thank the reviewers for their assessments, some of which were produced at short notice. As is common practice with other acatech projects, the papers drawn up by the different work groups are published separately under the authorship of the members of the individual work groups. In retrospect, this pragmatic approach adopted by the Council to complete its tasks has proven to be very effective. In particular, the strategy has allowed proper consideration of the various subject areas within their specific contexts, from basic research to market-relevant aspects.

The total volume of exploitable biomass is limited. This is already the case today, both with regard to Germany and the world as a whole. Based on scientific expertise, the bio-economy combines the modern production of biomass with innovations in the creation of bio-based products. Research and development in the bio-economy unites traditional academic disciplines such as agricultural and food research with new areas of research such as white, green or red biotechnology. It is due to the broad nature of bio-economy that such links are easily formed.

The challenge for bio-economic research is to make greater efforts to instigate collaboration, reaching across traditional subject boundaries, so as to focus on the later marketing of products at the earliest – pre-competitive – stage as possible.

This report also considers the adaptation to current global challenges, combined with the search for new growth areas for Germany as a centre of science, research and business. Only with innovations based on science and research can the complex challenges of qualitative growth be addressed, while paying heed to sustainability in an increasingly volatile world.

As far as the bio-economy is concerned, this means that in the future bio-based products will have to be of good quality and in sufficient quantity, but also at reasonable prices. To increase yield volumes of biomass, we need to investigate and exploit all the technological possibilities for securing sustainable biomass production. Of key importance to research in the field of bio-economy is a fundamental openness towards technology. The scientific, business and political communities, as well as society at large, share the responsibility for this. And we also bear responsibility for the actions we do not take.

(Prof. Dr. Dr. h.c. Reinhard F. Hüttl,
Chairman of the Bio-economy Council)

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Summary

The bio-economy encompasses all those sectors and their related services which produce, process or use biological resources in whatever form. The bio-economy combines highly research- and knowledge-intensive economic activities in agriculture, forestry and the food sector with the innovative use of renewable raw materials for material and energy use. Because of its integrative function, the bio-economy will be important for Germany's future as a centre of business and technology. New and increasing demands on our biological resources, as well as radically changing production conditions (globalisation, scarcity of resources, climate change, the diversification of population development, increasing energy costs) mean that the bio-economy will make a substantial contribution to addressing the major global challenges of our time.

The bio-economy's potential for innovation, which needs to be strategically harnessed by the scientific and business communities, lies in the development of new types of production and production techniques, the creation and exploitation of synergies, as well as in raising the resource efficiency of the various interrelated value chains: from the production of biomass in agriculture and forestry, to the end products in the food and energy sectors, and areas of industry such as the chemical, textile, paper and pharmaceutical sectors. This is all to be based on the most up-to-date knowledge and findings about the fundamental processes within plants, animals and microorganisms.

The Council suggests that the development of the bio-economy in Germany should have the following **aims**:

1. To improve economic development, competitiveness, and thus value creation in Germany using bio-based approaches
2. To increase resource efficiency along the whole of the bio-based value chains
3. To secure the provision of public goods

The great challenges of our time can only be addressed and translated successfully into economic and social value if we manage to combine more closely the key technologies of the 21st century in the biological and life sciences with the agricultural sciences and engineering, and turn these into successful innovations. More than ever, business and science now need to act as a unified 'system'. By bringing together the various areas within science and business, which today still operate for the most part within their own sectors, Germany will become more competitive, and her leading position as a centre of business and technology will be reinforced. A better economic database to record the rapidly developing bio-economy is also needed to underpin this strategic alignment.

The stated goal of the current coalition agreement of the German government, namely, to develop an "internationally competitive strategy for a knowledge-based bio-economy", is the right way forward, and thus receives the full support of the Bio-economy Council. In the opinion of the Council, the primary objective should be to develop a research strategy whose findings can be used to devise a general strategy for the bio-economy overall.

To help formulate such a research strategy, the Bio-economy Council has outlined three key recommendations in this report, organised by subject area, thereby providing each of the main research fields with detailed recommendations for a programme. These are followed by a further recommendation on structural issues. In general, the Council advises that the following **measures** should be taken:

1. Development of efficient value chains, processes and products
2. Ensuring global food security, promoting health, and assuming Germany's responsibility for global issues
3. Sustainable use of natural resources
4. Appropriate integration of the bio-economic approach in the system.

Development of efficient value chains, processes and products

It is essential for the optimal development of all technologically feasible and economically relevant value chains that the processes or the resulting high-value products and energy sources are resource-efficient and cost-effective. One of the key innovations of bio-economic research will be not only to develop individual innovative value chains, but to link these chains in the system.

The breeding of plants and animals with higher yields/capacity and specific characteristics, including the ingredients for healthy nutrition, are central to a bio-economic research strategy seeking to optimise value chains.

Sustainable economic activity is dependent on an adequate provision of biomass and the efficient management of biomass, in a way which also protects resources.

Research into how the material uses of biomass can be extended by a combination of biotechnological and chemical conversion processes, as well as the use of improved enzyme systems to digest biomass and waste products, will deliver important contributions to efficiency. The field of industrial biotechnology must also focus on further developing its underlying research in order to maintain – and, where necessary, improve – the high level of innovation that currently exists.

Innovative biotechnological processes can reduce the consumption of raw materials and energy, and decrease the generation of undesirable by-products, secondary products and emissions.

Strategic development in the bio-economy should have a sound scientific basis and be geared towards the long term. To this end, the necessary socio-economic research and analytical basis must be strengthened. For example, dynamic system models should be used to investigate alternative scenarios to the bio-economy, taking into account socio-economic perspectives.

Ensuring global food security, promoting health, and assuming Germany's responsibility for global issues

Important value chains of the bio-economy can be found in the food sector. Our ability to feed the world's population is dependent on the efficiency and sustainability of these value chains, while their product and processing quality has a direct relationship to human health and the quality of life.

In this context, German research also has the responsibility to provide support to emerging and developing nations to secure sufficient volumes of good quality food for their populations, and to counter the volatility of food prices.

Local analyses of production systems that draw international comparisons are needed, especially in the sector of small farmers in developing and emerging nations, as this sector plays a key role in feeding the world's population.

To meet the growing need for food, feed and raw materials for material or energy use, and to strike a balance in the competition for biomass, there must be a substantial increase in the yields of food and feed plants, as well as in the productivity of livestock farming.

Research geared towards increasing the health-boosting properties of foods and healthy styles of eating must also be prioritised.

Sustainable use of natural resources

The geo-resources of soil and water, nutrients, and the biological diversity of plants, animals and microorganisms form the basis of bio-economic value creation. As the availability of these resources is limited, it is vital that we conserve them and use them sustainably.

There must be a better understanding of sustainable land use, soil quality and ecosystem services, and new verified findings must be translated more quickly into practice.

Technological solutions must be found to cope with changes in water availability and to improve the use of fertilisers and nutrients. This means developing optimised farming techniques and more efficient crop varieties which are more drought-tolerant and efficient in their use of nutrients.

There must also be consideration of the regionally specific effects of climate change. On the basis of the principle of resource efficiency, all potential uses of biomass must be prioritised and optimised. There is no doubt that a greater use of bio-based products can help the world meet climate targets as well as the aim of "combating hunger and poverty" as defined by the UN Millennium Goals.

For the strategic orientation of this bio-economic research there should be greater focus on the economics of resource use, including institutional regulations.

Part of the Bio-economy Council's work in the future will be to continue to prioritise the research goals within the recommendations cited above. The criteria here are: economic efficiency, competitiveness and sustainability. The Bio-economy Council has already identified suitable indicators to measure these.

Appropriate integration of the bio-economic approach in the system

Existing structures and parameters must be adapted to the new requirements so that the topics listed in the three research areas can be worked on effectively and put into practice.

It is important that research funding should be interlinked more closely, and overall funding volumes increased; the research infrastructure must continue to be adapted accordingly. New studies indicate that greater investment in research and development is absolutely essential if important agricultural resources are to be available in sufficient quantities, and that this must contribute towards ensuring global food security.

It is essential that research funding in the future is allocated to research in the economic and social sciences as well as that in the natural sciences and engineering. The maximum potential of the bio-economy can only be realised by means of these interdisciplinary approaches. On the one hand, we need to establish an economics of technological development, which can deliver as rapidly as possible an assessment of competitiveness and suggestions for sustainable technology paths. On the other hand, socio-economic research needs to analyse how the efficiency of the bio-economy can be improved by innovative control and incentive mechanisms.

The research strategy for the bio-economy proposed here is one based on innovation. It is a long-term, interdisciplinary strategy, oriented towards results and implementation. Taking into consideration the points outlined above, the Bio-economy Council strongly recommends the establishment of an **interdepartmental, national bio-economy research programme**, to allow the pooling and better coordination of research funding from the Federal Government.

Another prerequisite for the successful development of the bio-economy is the close linking of private research activity with that in the public sector. Legal uncertainties which hinder the commercial use of new research findings must be resolved. Cooperation and the synergy between public research institutions and industrial firms of different sizes and in the various business sectors are essential. New types of structures such as clusters and innovation alliances, e.g. open innovation projects and 'unusual' alliances between sectors that have seldom collaborated in the past, will play an important role here.

The bio-economy and its related research are not restricted to the national level. Particularly when international, primary objectives or global resources are at stake, Germany must act in conjunction with other countries. The Bio-economy Council believes that the **German bio-economy and national bio-economic research must make greater efforts to integrate themselves strategically and work as partners on the international stage**. Also important here are uniform, transnational principles, e.g. for the import of biomass and licensing of corresponding crops for farming. In technological decision-making, such as over the use of genetically modified crops, scientific assessment should not only consider the risks of use, but also those of non-use.

There needs to be more openness towards and communication with the public as far as the subjects of bio-economic research and its potential to secure sustainability, innovation and employment within Green Growth strategies are concerned. Ultimately it is up to the business community to introduce new products and processes, and to ensure that markets develop positively. In this area, there must be greater use of existing market knowledge to shape the strategic orientation of research programmes. Any system of government incentives and funding instruments ought to be no more than temporary.

In conclusion, the Council thinks it is crucial that the political, scientific and business communities cooperate more closely than in the past, and agree on the measures that need to be taken at the pre-competition stage. The Bio-economy Council thus recommends that a 'National Bio-economy Platform' be set up to carry out the necessary tasks of coordination.

1. Introduction

The bio-economy encompasses all those sectors and their related services which produce, process or use biological resources in whatever form (Bio-economy Council, 2009). The pillars of the bio-economy are the millennia-old procedures of crop farming, forestry, the domestication of livestock, and simple processes of bio-technological transformation of substances. Photosynthesis, which is used by plants to transform carbon dioxide amongst others into biomass, is the basis for life on Earth. The biomass thus produced is the primary raw material of the bio-economy. New demands on biological resources as sources of energy and materials, and radically changing production conditions (globalisation, scarcity of resources, climate change and population development) are presenting huge challenges to the bio-economy as an economic sector. These can only be mastered and translated successfully into economic, ecological and social value if we manage to integrate more closely the key technologies of the 21st century in the sectors of the biological and life sciences with those in the agricultural sciences and engineering, and turn these into successful innovations. It is very important for the future that science and business together take a leading role in this development. This idea also underpins the German government's High-Tech Strategy 2020 (BMBF, 2010c).

This is why the Bio-economy Research and Technology Council was established in 2009 as part of German Academy of Science and Engineering (acatech). By setting up this body at one of the two national academies of science, the German government broke new ground in the field of policy approach. This is the first time that a council has been established within an academy, and is thus able to make use of its competence network.

The Council's array of tasks includes analysing the scientific strategy objectives of the Federal Government, the administrations of the individual German Länder, the EU, and other international partner countries. It also has the job of helping the German government devise a bio-economy strategy. This requires a review of the corresponding activity in businesses and research institutions. The Bio-economy Council's conceptual approach is thus oriented towards value chains, combining elements of business and research, and delivering new stimuli which go beyond previous approaches.

With its recommendations, the Council aims to demonstrate the potential of the bio-economy, anchor it within society, and make better use of it for Germany. The Council is currently identifying future areas where research is needed, developing ideas for the application of new, innovative technologies, suggesting areas for research funding, and making recommendations for the future development of research structures. The basic objective is to improve the general framework conditions for the bio-economy. This ties in with the Council's 'First Recommendations' (Bio-economy Council, 2009). [1)]

The Council is seeking to help Germany optimise its position in the international competition for bio-based markets. The recommendations in this report relate to a time frame of around 20 years. In the first

1) In its 'First Recommendations' of 2009, the Council already called for the bio-economy to be recognised as an essential and fundamental research area, and urged the setting up of overarching research structures.

instance they are addressed to the German government. The next step will be to integrate systematically the relevant parts of the dynamic business and science sectors into a bio-economy oriented to the future. This process must be actively supported by research, technological development and impact assessment. Thus the bio-economy is not only a major sector of the economy; it is also an important field of research and technology that concerns the whole of society.

The increase in the world's population from its current 6.8 billion to an expected 9.1 billion by 2050 (UN, 2008), in conjunction with changing dietary habits, including a higher demand for animal products, means that the bio-economy needs to devise new approaches to producing the necessary volumes and quality of food to meet these demands but which are also environmentally sound. The concept of 'sustainability' as understood by the bio-economy must be expanded to include the aspect of preventative healthcare. Sufficient food of good quality is a fundamental requirement for individual health, and thus for giving people the best chances of development from childhood.

Another important field of the bio-economy is how to raise biomass production in changing climactic and environmental conditions, with the increasing limitations on natural resources such as water and land. Modern processes in biotechnology and land use management, for example, can make a substantial contribution to reducing the regionally specific impact of climate change. It is the Bio-economy Council's belief that the use of biotechnology by industry, along the entire array of its applications, particularly in medicine, health, agriculture and food, but also in combining processes of biological and chemical synthesis for producing energy and raw materials, will fundamentally change many sectors of the economy.

In the long term, the bio-economy can become a cornerstone of a modern economy which is aware of its responsibilities towards the future, whereas at present the economy is still largely based on the consumption of fossil fuels. It offers Germany forward-looking solutions, such as an increase in the use of renewable raw materials, or the production of new goods and materials derived from biotechnological processes, thus offering a change to bio-based raw materials. Its social acceptance is crucial if these new processes and products are to be effectively marketed. The financial sector will also play an important role in introducing them to the market and seeing that they develop successfully. Notwithstanding the loss in confidence as a result of the financial and economic crisis, greater use must be made here of existing market knowledge than in the past for the purpose of establishing the strategic orientation of future research programmes. State incentives and subsidies should be no more than temporary necessities.

Humanity is facing another archetypal shift in its relationship with the natural world. A bio-economy allows existing biological resources to be exploited more sustainably than in the past by using innovative techniques; and their range of applications – as becomes clear from the example of synthetic biology – can be broadened by putting into practice new scientific findings. The long-term objective is to safeguard the foundations of life in the face of ever scarcer resources. In concrete terms this means:

- Ensuring food security
- Making energy provision more sustainable
- Making more efficient use of resources
- Producing new bio-based raw materials and agents

Throughout the world, Germany is currently seen as one of the leading pioneers in the fields of agricultural, biological, life and technological sciences. German research institutions are internationally renowned. Yet the combined potential of all this knowledge is far from being fully exploited. Only by mobilising and bringing together the forces which are currently operating within the confines of their sectors can Germany increase its competitiveness and Germany maintain its leading position as a centre of business and technology.

2. Bio-economy: recognising and exploiting the potential

The knowledge-based bio-economy comprises all the processes which aim to produce and use bio-based products competitively and sustainably. 'Knowledge-based' and 'bio-based' are thus the two core elements of this innovative and highly diverse area.

At present the bio-economy is not yet an economic sector in the traditional sense, but still a conglomerate of different branches of the economy in the process of becoming a new sector. The value chains of bio-based products in the various sectors are increasingly interlinked, or capable of being linked. This linking of value chains, which to a great extend does not lead to the waste of material but rather to reutilization in other production processes instead, is what characterises the bio-economy. The bio-economy's potential for innovation, which business and scientific policy need to tap into strategically, lies in the creation and exploitation of corresponding synergies, an increase in resource efficiency in value chains, and in the interlinking of well-established and brand new production processes, e.g. between agriculture and aquacultures, or forestry and industrial biotechnology.

The key elements of the bio-economy are biomass, its processing, and the resulting products. The basis for this is knowledge about fundamental biological elements, process techniques, and economic relations. Biomass, the primary raw material of the bio-economy, has an essential function as a food, feed, industrial raw material, and energy source. But the biomass which is not exploited by human beings has an important role, too, e.g. as a nutrient in ecosystems, as a habitat for the most diverse life forms, or in helping climate protection by storing large volumes of the greenhouse gas carbon dioxide.

As we move from an era characterised by a profligate use of resources and an increase in environmental pollution throughout the world, a fundamental paradigm shift has taken place within only a few years. It is likely that the availability of biomass will become a limiting factor in the long term. All possible uses of biomass must, therefore, be prioritised and optimised (RNE, 2008).

Goals of the bio-economy in Germany:

- Improve economic development and competitiveness
- Increase resource efficiency
- Provide public goods

2.1 Objectives for a competitive and sustainable bio-economy in Germany

In the Council's eyes, the development of the bio-economy in Germany should have the following objectives:

1. To improve economic development and competitiveness, and thereby value creation, in Germany, using bio-based approaches. An increase in international competitiveness by means of the export of high-value products and technologies will exploit Germany's strengths in research and development, such as mechanical engineering, plant construction,

the chemical and pharmaceutical industries, crop and animal breeding, and biotechnology. These form the basis for the bio-economy's position within the framework of an innovative Green Growth strategy.

2. To increase resource efficiency along the whole length of all value chains. Future economic activity must be more cost-effective, while taking care to protect the environment, including climate, as far as possible. We must also make ourselves more independent from fossil fuels, given the finite nature or limited availability of certain resources.

3. To secure the provision of public goods – also to guarantee that Germany makes an appropriate contribution internationally. These are those elements essential to life on Earth that need to be sustained in the long term, such as climate, biodiversity and global food security. The last of these must be given top priority. As a result of the economic and agricultural crisis, the global food situation has continued to deteriorate over the past few years (see Figure 1). This trend conflicts with the Millennium Goals set by the UN (UN, 2000).

It must also be noted, however, that in addition to the large number of humans facing undernourishment, there is an even greater number who are malnourished in some way. These contrast with a similarly large group who are overweight and obese (see Figure 2).

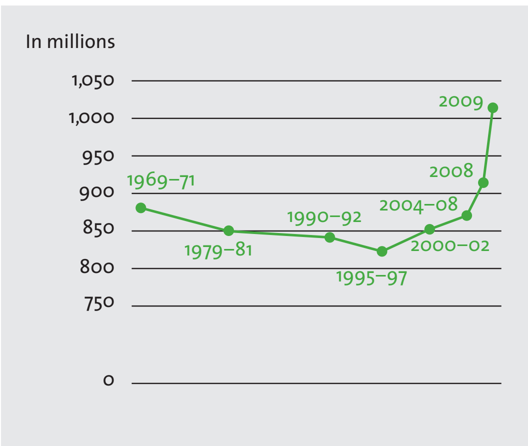

Figure 1: Increasing global starvation from 1969 to 2009 (FAO, 2009b)

It is one of the tasks of a sustainable bio-economy to create the conditions in which the global provision of foodstuffs can be guaranteed. Social and socio-economic behaviour must also be taken into consideration here, to restrict the thoughtless excess

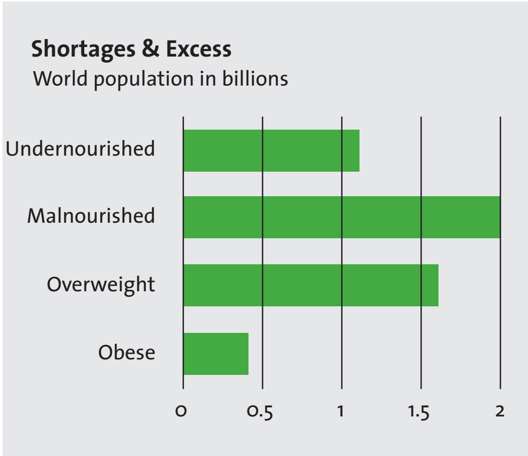

Figure 2: Number of undernourished and obese individuals (WHO, 2006; FAO, 2006a; according to DBank, 2009)

consumption of food and biomass. This is also important for promoting good health.

The strategic objectives of the bio-economy cannot be oriented to the past and present, but must be aligned to the challenges and opportunities of the future. Useful tools here are socio-economic scenarios of future developments.[2)] Existing scenarios cover aspects of the bio-economy, such as supply and demand trends for agricultural products, the increase in chemicals and materials produced biotechnologically, or the impact of changes in the energy sector and trade policy. But no comprehensive scenarios yet exist which address the bio-economy's complexity. Enhancing the facility to model scenarios (see also the following example) must, therefore, be an integral part of German bio-economic research (cf. Chapter 4).

Scenarios that examine the expected price developments for agricultural raw materials have produced a broad consensus. The long-term assumption is that prices will rise with increased volatility (IFPRI, 2009;

2) For an up-to-date example of the successful use of scenarios in developing action strategies, see: CGIAR (2009): Towards a Strategy and Research Framework for the CGIAR. Consultative Group on International Agricultural Research.

OECD/FAO, 2008). These estimates are not only relevant to the prices of biomass, but also of water and land, scarce resources whose costs are driven by the anticipated agricultural prices. These developments should not, however, be seen as immutable; in the long term they will be determined by, amongst other things, investment into research geared towards increased productivity. Research will be very important in helping reduce future shortages of biomass, and will thereby influence price developments.

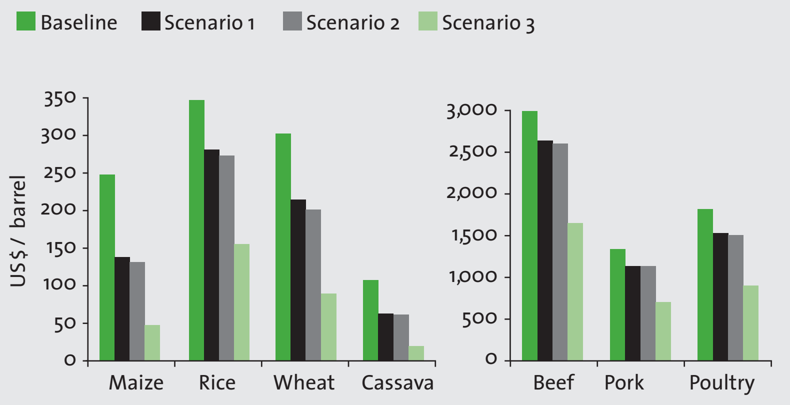

Figure 3: The impact of R&D investment on global agricultural prices in 2050 (IFPRI, 2009)

Comprehensive scenarios of alternative investment strategies[3)] show that R&D investment has a long-term influence on price developments (see Figure 3). Research on its own, however, can only have a limited impact. The greatest reduction in prices can be achieved by a combination of research investment and additional policy and management measures. Analyses that project these findings show that an increase in food prices will lead to deterioration in global food security (von Braun, 2008). To orient the bio-economy strategically, scientific policy in Germany needs to expand significantly its capacity to undertake scenario analyses in this area.

A bio-economy research strategy must, in essence, be based on the objectives already cited above. It should be seen as an element of the German government's High-Tech Strategy (BMBF, 2006) and link into other overarching Federal Government strategies, e.g. those relating to sustainability (Federal Government, 2002), biodiversity (BMU, 2007) and the 2020+ biotechnology strategy process (BMBF, 2010a).

Research and innovation are pivotal to resolving conflicts of interest. These conflicts, e.g. whether biomass should be used for food production or for material and energy use, will occur more frequently if they are not mitigated by efficiency increases. Overarching research strategies can be of particular help here. For example, a comparative study of concepts for using various energy sources in the energy sector is essential for making economically efficient and ecologically sound decisions in the bio-economy.

The research strategy for the bio-economy suggested here is a long-term one, and oriented to results. It is also vital that research activity in the private sector is closely linked to that in the public sector.

It is essential that appropriate indicators of the success of a results-oriented research strategy are defined to ensure that the three aims outlined above can be properly assessed and that the impact on results of investment in bio-economic research can be monitored. These are given below.

1. The economy in the national and international context
- Changes to the bio-economy's share of GDP
- Changes to the number of employees by educational qualification
- Investment volumes in individual sectors
- Number of businesses, number of new businesses
- Changes in market volumes and prices of bio-based products
- Changes in exports of bio-based products and technologies

2. Resource efficiency
- Changes in consumption of fossil versus bio-based fuels (or bio-based products with a degree of substitution), changes in productivity per unit of resource used
- Consumption of inorganic resources (e.g. phosphorus or nitrogen) per product

3) These scenarios highlight the fact that, without a significant increase in R&D expenditure, prices for all important foodstuffs will move significantly upwards across the globe in the years to 2050 (compare the dark-green bar with the others in Figure 3).

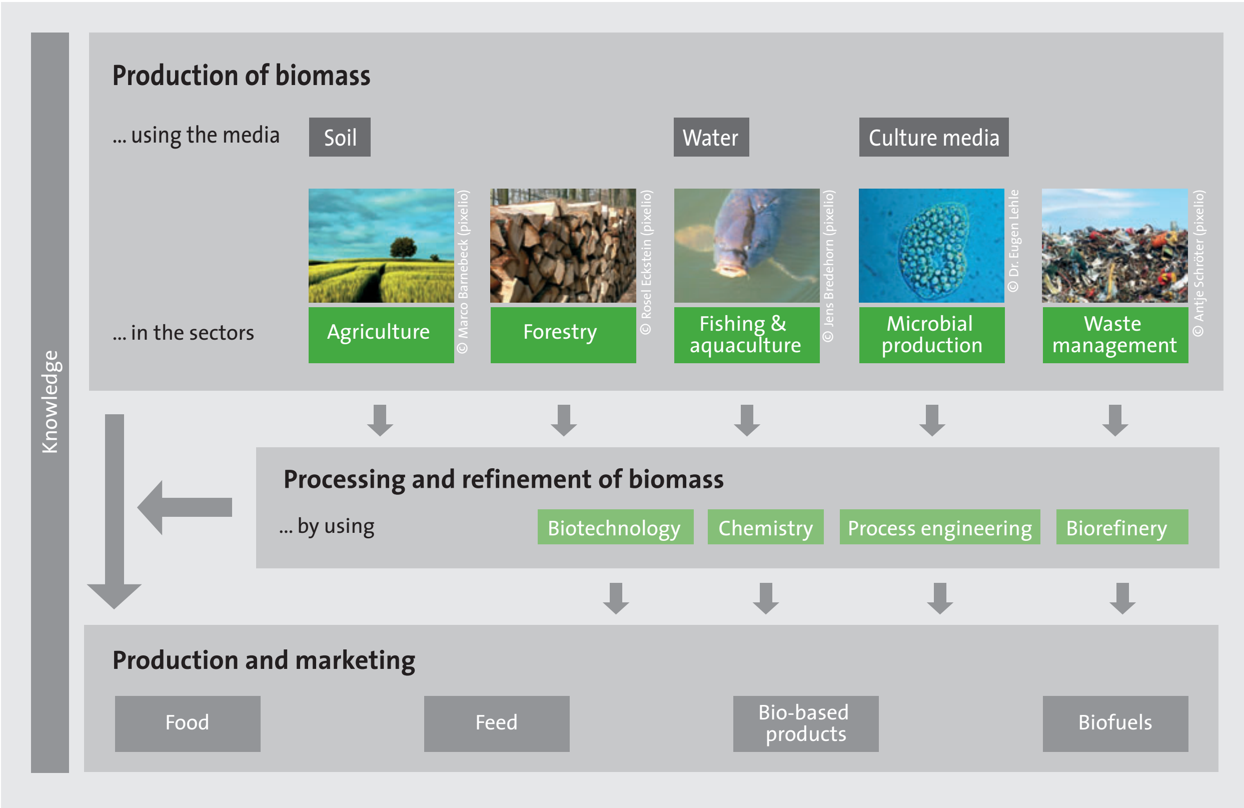

Figure 4: The bio-economy – a system with interlinked value chains, adapted from EC, 2006

3. **Global benefits**
- Degree of global agricultural and biomass provision
- Changes in number of starving people and in the incidence of nutrition-related diseases
- Changes in CO_2 emissions and other gases that effect climate
- Changes in water consumption
- Extent of soil sealing, expansion of agricultural land through recultivation
- Extent of biodiversity loss

An analysis of these indicators allows measures to be validated and, if necessary, adjusted as part of a research strategy.

2.2 The significance of the bio-economy for Germany

The value chains begin with primary production in agriculture, forestry and aquaculture, and continue via the processing industries for basic foods, high-value foods, and feeds, sections of the chemical, pharmaceutical, cosmetic, paper and textile industries, to the energy sector based on renewable raw materials (see Figure 4).

In a large number of sectors, biogenic raw materials are being processed to produce bio-based primary, intermediate and end products using a very wide variety of physical, chemical and biotechnological processes, the last of these playing a key role here. In principle, all biological resources are suitable for technological exploitation. Correspondingly, there is a very wide range of products that can be created. The different process technologies must, therefore, be systematically analysed and assessed. These aspects are embodied in the concept of the biorefinery, for example (see also box on p. 22). This idea is currently being put into practice in simple production systems such as oil or wheat mills, sugar factories and bio-ethanol plants. In future, however, more complex raw materials and material flows will be transformed into more complex products in biorefineries using interlinked processes.

According to the most recent comparative figures available at a European level, dating

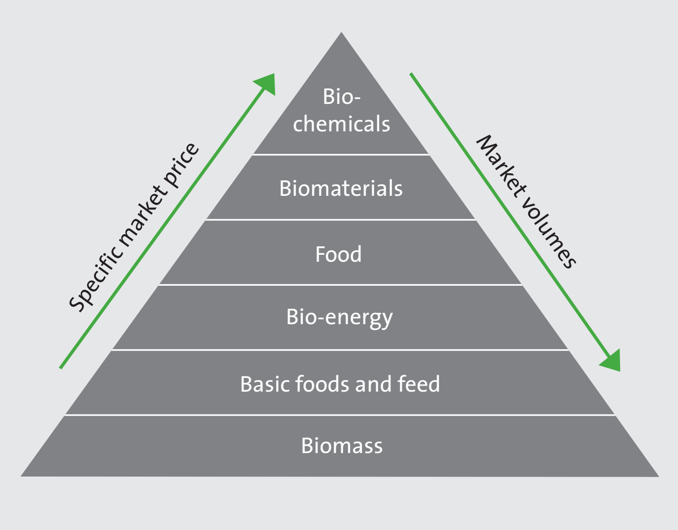

Figure 5: Specific market prices versus market volumes of bio-based products (adapted from Langeveld et al., 2010)

to 2005, sectors of the economy which either produced or processed biomass, or in which biotechnological processes were used, accounted for around 3.9 % of German gross value added. The figure for the EU-25 as a whole was around 4.9 %. In Germany these sectors employed 5.2 % of the working population, and the corresponding figure was 6.3 % in the EU-25 (EU KLEMS, 2008).[4] By far the largest share of value added is currently generated – both in Germany and across Europe – by food and feed production (see box). This is also the case for the rest of the world.

The intrinsic value created by bio-based products is in inverse proportion to their market volumes (see Figure 5) and usually correlates to the number of processing stages. As in every other sector, the relative importance of individual bio-economy products determines whether these are produced in Germany and in what volumes. The optimal production structure, i. e. the relative proportions of the various bio-economy products manufactured in Germany, is ultimately determined by the comparative advantages of the various products. In the long term, research into innovation has considerable influence over these comparative advantages. R&D investment must not neglect any of the product groups roughly depicted by the pyramid in Figure 5. Otherwise the bio-economy would be systemically weakened.

The potential for innovation in the development of new products and processes is high at all levels of this pyramid, particularly with regard to the responsible management of all resources used either directly or indirectly.

With the liberalisation of EU agricultural policy, agricultural production in Germany has registered a positive growth over the past 25 years for almost all domestic products, particularly milk, cereals, meat, fruit and vegetables. Besides increasing food and feed production – Germany is the fourth largest agricultural exporter in the world – it has been possible to allocate 30 % of agricultural production to material and energy use. It should also be noted that in 2004 the net proportion of land producing agricultural goods for export was 20 % (UBA, 2009). In addition to agricultural production there is

The bio-economy in Germany – an increasingly important sector

Figures for the individual parts of the bio-economy are to a large extent already embedded in the statistics relating to the established sectors of the economy. It is thus still difficult to determine precise details relating to their development and significance within the German economy as a whole. Some trends in the bio-economy are reflected by those in the production of food and feed, drinks, leather, wooden goods, paper etc., as well as of basic pharmaceutical goods. Over the past decade, these six sectors have experienced very different developments.
Overall, turnover in the bio-economy has grown by 16.1 %. The food and feed sector has been responsible for the greatest share of this positive development, with a growth in turnover of 28.5 %. Biotechnology (including the dominant red biotechnology) showed an annual increase in turnover of 9 % between 2005 and 2009 (a total of 42 % over these five years). This growth is stronger than that in the bio-economy overall (+11.3 %) or in the food and feed sector (+17.7 %) over the same period.

Sources: BMBF, 2010b; StatBA, 2009

4) These calculations take into account agriculture (including hunting, forestry and fishing), the food, drinks and tobacco industries, the textile industry (inc. leather and shoes), and the wood, cork, paper and fibre industries. No data are available for the chemical industry which allow a differentiation between conventional and biotechnological production.

also a growing wood sector, with an annual increase of forestry land of around 20,000 hectares (Federal Government, 2009).

Trade in biomass and bio-based products will be dependent on the competitiveness and relative importance of individual areas. The competitiveness of all segments of the bio-economic value chains must be strengthened. With this in view, the Bio-economy Council emphasises that the national supply of biomass for material and energy use is limited. The German bio-economy should, therefore, concentrate on high value/low volume segments. Besides greater efficiency in the production of biomass, the focus ought to be on more refined products in the value chain, such as foodstuffs, biochemicals and pharmaceutical goods (see Figure 5).

Thorough knowledge of biological systems is vital for the production and use of bio-based products, and the ongoing development of the technologies needed for these. Different scientific disciplines must also cooperate along all stages of the value chain down to the end product. Expanding the knowledge base and its application is a prerequisite for increasing productivity. By methodically developing systems biology, Germany will acquire the potential to take a leading role globally in this area.

The sectors of the bio-economy are labour intensive. In addition to the production side, a large number of services are involved and this also promotes the creation of highly skilled jobs. This is already the case with crop and animal breeding, as well as industrial biotechnology, which have the highest levels of R&D funding amongst the various sectors.

In a report on a detailed study of industrial white biotechnology undertaken by the Fraunhofer Institute for Systems and Innovation Research (ISI) using an input–output model, it is stated that: “The greatest impact on employment... is at the university and non-university R&D institutions, followed by IWBT suppliers”. The report continues: “The importance of services is comparatively high: in most instances (i.e. subsectors) they account for between 40 % and 60 % of upstream jobs; at universities / R&D institutions and small and medium-sized IWBT firms this figure rises to between 75 % and 80 %. The role of IWBT in consolidating future-oriented service sectors is thus an important one.” (Fraunhofer ISI, 2009)

To strengthen the bio-economy as an economic sector in Germany and increase competitiveness, the first thing that is needed is a detailed analysis of important areas in an international comparison.

The food chain is of particular importance to the bio-economy, given the bio-economy’s global standing thanks to the interlinking of value chains, bio-based raw materials and technologies, and also the central role played by the increasingly global food sector. In general terms, the food sector can be said to be comprised of the following four segments: the input sector, agriculture, the processing industry and the food retail sector (see Figure 6).

Figure 6 provides an overview of the global food chain in diagram form. At present, this chain is predominantly governed by the consumer side. Communication plays a key role here. In view of the market power of the actors positioned on the right-hand side

Competitiveness and global perspectives

With an ever greater availability and application of new technologies, the competitiveness of the German bio-economy will increasingly be governed by investment strategies in private and public research and development. Within the OECD, figures relating to this differ radically. For bio-technology, for example, the annual growth rates of R&D investment range from 1 % in Italy (2002 – 06) to 52 % in Spain (2004 – 06). For the four countries with the highest private investment in the field of biotechnological R&D, the growth rates vary from 10 % in Canada (1999 – 2005) to 20 % in Germany (2005 – 07), with 16 % in the USA (2004 – 06) and 18 % in France (2003 – 06). The competitiveness of the German bio-economy is dependent on the interlinking within and between the various value chains. The importance of this interlinking is clearly demonstrated by projections.

Sources: Fraunhofer ISI, 2009; Nusser et al., 2007; OECD, 2009

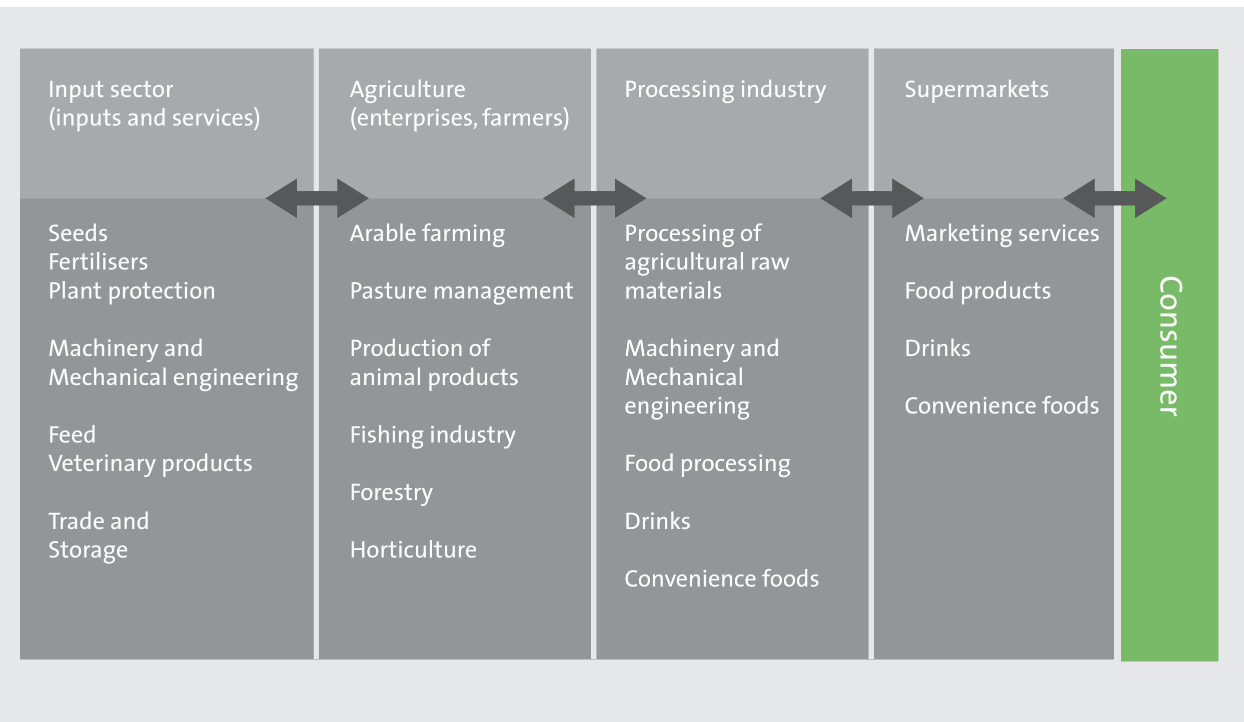

Figure 6: The global food chain as a key element of the bio-economy (von Braun and Díaz-Bonilla, 2008)

of the diagram, an expanding bio-economy will not fundamentally change this state of affairs, but it is expected to create greater value than the actors on the left-hand side of the diagram.

The input sector includes all areas of seed and fertiliser production as well as plant protection. In 2009 the seed industry had a global turnover of 36.5 billion US$ (Phillips McDougall, 2009b); in 2007/08 the fertiliser industry produced 170 million tonnes of fertiliser worth about 85 billion US$ (IFA, 2009); and in the plant protection sector alone, 40.5 billion US$ of products were used (Phillips McDougall, 2009a). Over the same period, the global gross product of agriculture was 1,592 billion US$ (von Braun and Díaz-Bonilla, 2008).

By comparison, the gross product of the ten largest food companies in the world came to 409 billion US$ in this period (von Braun and Díaz-Bonilla, 2008). Over the same time, the ten largest supermarket chains across the globe had a total turnover of 1,091 billion US$. Consumers, meanwhile, spent 4,000 billion US$ on food (von Braun and Díaz-Bonilla, 2008). By comparison, total global expenditure on electricity in 2008 came to 1,820 billion US$ (EWG, 2010).

Significant progress in the bio-economy is dependent on increased efficiency in the relevant value chains. Of key importance here is the elimination of loss and wastage, and reduction of ecological 'footprints' along the entire value chain. Consideration must be given to the advantages of local production compared to goods produced and sold transnationally.

To increase competitiveness there needs to be greater and targeted cooperation which is efficient and which meets the specific requirements of the value chains. Targeted subsidies are also needed to help adapt existing structures to the all-embracing nature of the bio-economy system. In the past people have largely taken a traditional approach to the available technological options in the areas cited above, and thus have pursued them in isolation: i.e. by means of individual input; in production areas such as animals, crops, land, industrial biotechnology; or fields of application such as food or biofuel production. The economic value of the bio-economy will be principally realised through complex substitution and synergy effects in the system. Hence the cited need for greater interdisciplinary cooperation.

3. Recommendations

One of the principal features of the bio-economy is the use of biological resources in value chains, some of which are complexly interlinked. Changes in consumer behaviour, shifts in demand, and the increasingly limited availability of resources mean that we need to develop new products and production techniques. To ensure that these development processes are as profitable as possible, but also do not put at risk our natural resources, it is essential that we create new, systematic research programmes which are oriented to value chains.

It is important that economic and social science research also benefits from future research funding, in addition to the natural sciences and engineering. Within this field we can identify two core areas:

– Technology-related economics
  Fundamentally, this should focus on evaluating competitiveness, market potential, employment impact and structural effects, and develop suggestions for sustainable technology paths. It must also investigate the consequences of not exploiting technological opportunities, and how obstacles to innovation can be overcome.

– Socio-economic research
  This should assess how the efficiency of the bio-economy can be improved by innovative control and incentive mechanisms. These include developing ideas for eliminating competition over use of resources, optimising climate protection strategies, reducing price fluctuations, and for political support of globalisation processes in the bio-economy sector.

Models, such as those outlined in Chapter 2.1, are suitable for use in such research projects. The appropriate data sets are required if valid information is to be obtained from these models about suitable courses of action. Only then will it be possible to provide an economic assessment of developments in Germany, and give these financial support. It is thus necessary to analyse the performance of the German bio-economy in an international context on the basis of reliable data, demonstrate the potential that can be created by investing in innovation, and give an idea of the expected net gains of these investments. This is the only way of providing a sound evaluation of results achieved and, if applicable, of adapting the strategies of public and private research funding and policy. Until now it has not been possible to draw up a sufficiently accurate economic picture of the elements of the bio-economy, as the statistics we have are based on the traditional sector structure (e.g. agriculture, energy) and do not relate adequately to the system-orientated bio-economy. For this reason, the recommendations outlined below are derived using conventional methods, and are not yet based on models.

Research findings can only be put into practice successfully if the external framework conditions are orientated accordingly. It is also important that the various actors have clearly defined tasks. Public research funding should in future be related more closely to the economic application of research findings and the interests of the users – i.e. of the enterprises operating in Germany. Thus, there ought to be funding for research which creates basic knowledge and technologies, and which has potential for future application with a high level of value creation.

The following recommendations by the Council are predominantly based on the findings of the soil, animal, plant and biotechnology work groups (Hüttl et al., 2010; Schwerin et al., 2010; Müller-Röber et al., 2010; Treffenfeldt et al., 2010). They focus on three important research areas as well as considering what changes need to be made within the system:

1. Develop efficient value chains, processes and products
2. Ensure global food security, promote health, and assume global responsibility
3. Use natural resources sustainably
4. Ensure appropriate integration of the bio-economic approach in the system

If we consider the first three recommendations relating to key research areas, it is apparent that certain technological processes can be applied across the board. These cross-discilpinary technologies (see Figure 7) are a necessary basis for many of the research topics listed. Funding for these is especially important, therefore, as they can produce synergy effects benefiting several research areas at the same time.

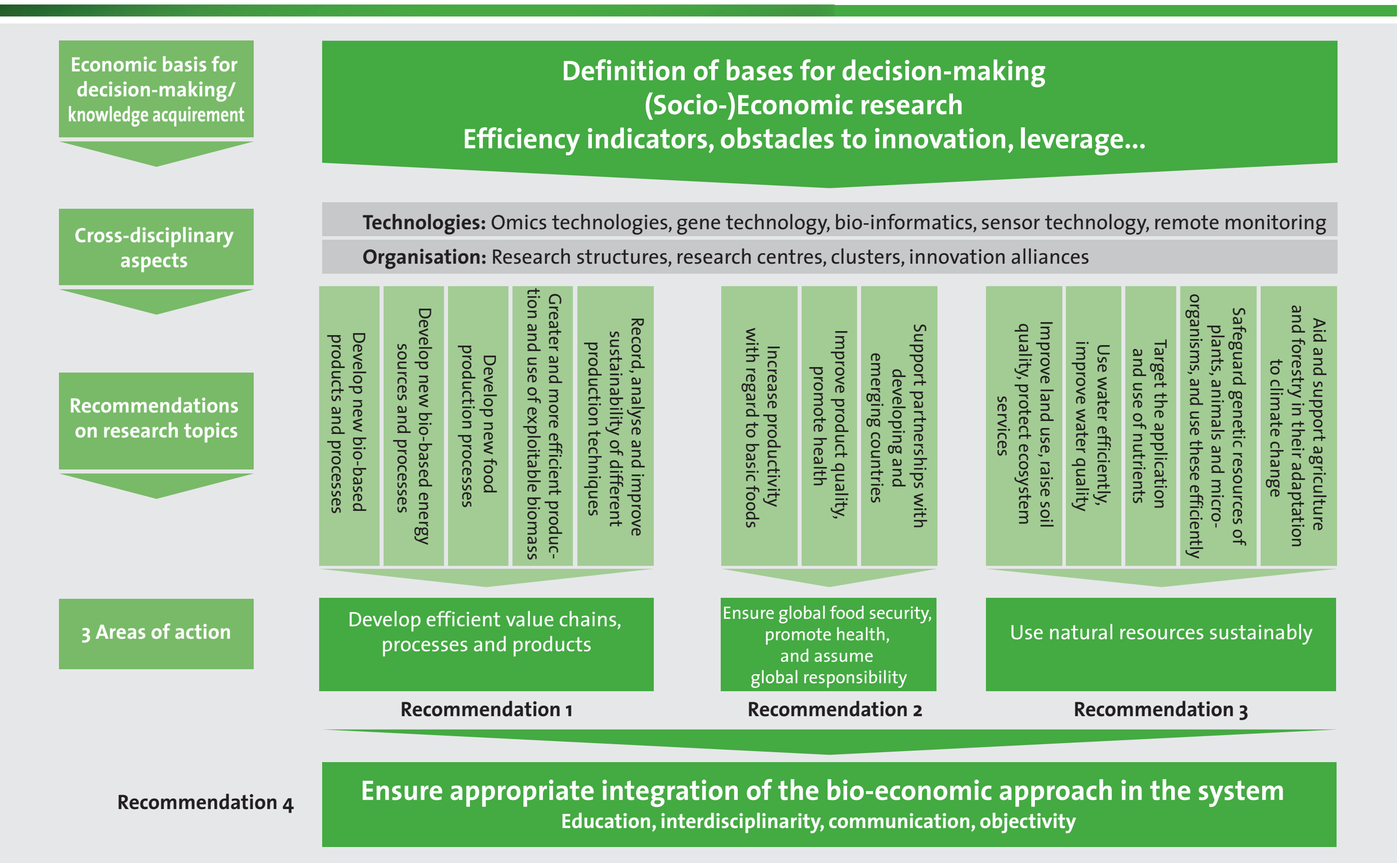

Figure 7: Cross-disciplinary technologies, research topics and recommendations for bio-economic research

Recommendation 1:

Develop efficient value chains, processes and products

The prerequisites for an optimal development of all technologically feasible and economically relevant value chains are resource-efficient and economic processes, or the resulting high-value products and energy sources. In addition to the production of materials, the processes of ensuring food security and energy conversion are important research areas here. Sustainable commercial activity depends as much on the efficient and resource-saving use of biomass as on an adequate supply of biomass for the areas cited above. Dynamic system models that examine socio-economic perspectives can help highlighting the advantages of biotechnological procedures in comparison to conventional methods. Innovative biotechnological processes can reduce the consumption of energy and raw materials, minimise the generation of undesirable by-products, secondary products and emissions, and reduce the use of toxic and non-degradable substances.

a) Develop new bio-based products and processes

For a long time biomass has been used as raw materials in many branches of industry, such as the wood-processing sector, paper and wood pulp processing, the chemical industry, the textile industry, and the pharmaceutical and cosmetic sectors. Using biotechnological processes a large number of intermediate chemical products, such as platform chemicals and end products (e.g. refined chemicals and specialty chemicals) can be generated. In most cases, however, these processes are not yet competitive. Although this segment currently accounts for 5% of global turnover in the chemical sector (Bachmann et al., 2004), it is nevertheless exhibiting over-average growth.

Biotechnology also allows us to create highly complex and valuable substances which either cannot be produced using chemical processes or are very expensive to manufacture using these means, such as enzymes, active substances in pharmaceuticals, and agricultural pesticides. However, research in this area is still very much in its initial stages. To exploit the full potential, greater funding is needed for genome research, bioinformatics and synthetic biology.

Because the value chains for the material use of biomass are much more complex and longer, the potential for value creation is usually higher than if these are used for energy production (cf. Figure 5). Sequential use ('first material, then energy') would be a particularly efficient way of employing biomass associated with optimal value creation. This would allow us to both minimise resource use and reduce competition between different uses (food and feed, chemicals, materials and energy generation e.g. fuel, biogas or heat). Priority must therefore be given to the further development of sequential use.

Because some agricultural raw materials have a complex chemical composition, processing them can require expensive preparation, conversion and separation procedures. In addition to the actual target products, an array of by-products is created, varying in quality. These are used as feed, fertiliser or for energy generation. In this way wastage is reduced to a minimum. Such practices are already employed today in modern grain and oil mills, sugar factories and bio-ethanol plants.

In the future, biotechnological methods in particular will make it possible to create higher value end products from these by-products. Appropriate industrial biotechnology techniques will be used for the degradation of these substances. These new processes, still to be developed, will help enable the economic exploitation of substances such as primary and secondary metabolites. In addition, substances such as lignocellulosic raw materials can be prepared by fermentation processes in such a way that they will be of commercial value. The plants that carry out these processes need to be managed in association with primary production, and situated at the same locations. The biorefinery is a key concept here in connection with the preparation of biomass or organic waste for further processing (see box). The development of localised and integrating concepts for the use substances is an important research area. The biorefineries of the future will be characterised by integrated processes which allow the use of more parts of crops in the manufacture of various types of products, which can then be integrated into existing processes or value chains in the chemical industry.

Biorefineries

are integrative process concepts designed to promote the sequential refining of renewable raw materials to obtain bio-based products and biogenic energy sources. The array of products ranges from basic chemical substances (organic acids, artificial monomers), foods and feeds (proteins, amino acids), fuels and combustibles, to fibrous products that can be used as insulating materials.

Source: ECN, 2006

At present, however, this form of biorefinery is only in the initial stages of development, which means there is an even greater need for research and development. To fill the current gaps in our knowledge, there must be funding both of basic research as well as processing, technological and product development (VCI / DIB, 2010).

The complexity and diversity of biomass and of the resulting intermediate products for further processing present major challenges with regard to the generation and use of biorefinery products. This is why new techniques for the degradation of substances are needed, together with the corresponding microorganisms or enzyme systems. There must be greater use of recent findings from genome research, bioinformatics, systems biology and synthetic biology. Considerable research is also needed in methods of improving space-time yield, the energy-intensive reprocessing of high dilution products, and the separation of complex mixtures of substances.

The Council recommends a two-stage approach. First, new processes must be developed to ensure more efficient use of by-products in existing processing plants such as oil and grain mills, sugar factories, and bio-ethanol plants. Then, building on the experience and knowledge thus gained, the relevant processes should be optimised conceptually so that a multi-purpose biorefinery can be devised which can process and combine a very wide variety of raw materials. Studies will need to be carried out beforehand, setting out the technological and economic feasibility of these ideas in detail. As a rule, new processes are not put into practice commercially until their economic viability is demonstrated. For this reason, the development and optimisation of pilot and demonstration plants should be included in future funding programmes.

In principle, algae can also be used for the production of biomass. In the long term, they could be employed in association with CCU projects. A particular emphasis here should be placed on the improvement of CO_2 conversion. A substantial amount of basic research needs to be carried out in this area, however, before algae can be used on an industrial scale. This ranges from the optimisation of suitable production organisms (strain development, cultivation), process techniques in production and preparation (downstream processing), to their use as sources of energy or raw materials (DECHEMA, 2009).

Active substances can also be produced in the pharmaceutical industry by using biotechnology. Unlike health research, which investigates the effectiveness of medicines, bio-economic research focuses on the processes used to manufacture active and valuable medicinal substances. The biotechnological use of plants, animals and microorganisms for the targeted synthesis of medicines (antibiotics, vaccines) and pesticides is another possible way of creating value from biomass by producing high-value products. More studies on the range of potential organisms and how to extend this are necessary. Processes must also be developed and refined which will improve the quality of the desired substances, and produce them in greater quantities and quality.

b) Develop new bio-based energy sources and processes

One of the major challenges of the future will be to meet the rising demand for energy across the globe. The use of biomass in the energy sector opens up a wide spectrum of applications. Energy sources derived from biomass can be used to power vehicles, generate heat, refrigerate, or to produce electricity. A substantial proportion of renewable energy sources (solid, liquid and gaseous) is bio-based (Bley, 2009). Compared with other renewable energy sources, such as wind power and solar energy, bio-based ones have the significant advantage that they can be stored in solid, liquid and gaseous forms, and can thus be regulated.

The Council assumes that, with an increasing dependence on renewable energies, biomass will be an important pillar of the energy sector at least until efficient storage technologies have been developed and are ready for use, especially for electricity.

In principle, both agricultural and forestry raw materials are suitable for energy generation. Around 20 % of agricultural raw materials are currently used to produce energy in Germany (cf. Chapter 2.2), mainly in the form of biofuel and biogas. To reduce the competition for land for the cultivation of energy crops to produce biofuel and biogas and, on the other hand, food and feed crops, increased efforts are currently being made to investigate methods of deriving biofuels from lignocellulose (straw, wood). Unfortunately, the economics of these processes and their suitability for commercial use in Germany are still very unclear.

At present, around 43 % of the raw materials from the German forestry sector are used for energy generation (Mantau, 2009). Here the use of cultivation methods such as short rotational plantations or agro-forestry systems are very important, especially in places where there are low yields. Research projects need to be broader-based. Furthermore, pilot projects must be set up to investigate region-specific economic potential.

There also needs to be a closer examination of how, where and which biomass can be produced and made usable for material and energy provision most efficiently. The task here is first to compare the efficiency of various types of bio-energy, to analyse the potential for improving efficiency within these, and then to consider how they can be linked with material use. A combination of technological and socio-economic research is essential to this research area.

To help support regional economies there should be greater focus on schemes which allow the initial value creation of biomass for energy use to be undertaken on-site (cf. Chapter 2). It is conceivable that Germany might in future import the energy sources derived from raw materials rather than the raw materials themselves. Substantial environmental benefit would accrue from using the nutrients from the organic remnants in the soils where crops are grown, and also from a considerable reduction in transport volumes.

In comparison with that of today's highly efficient coal-fired power stations, the level of efficiency of biomass power stations is far lower (around 10–15 %). The co-firing of biomass in conventional power stations is undoubtedly an interesting option for sites that are adapted for this. Much research still needs to be done in this area, however, especially where the proportion of biomass is high (>25 %). Aspects of the value chain that need further investigation are technological (e.g. torrefaction) and economic and environmental (e.g. the impact of various cultivation techniques on the combustion characteristics of substances; return of waste ashes to the areas used for farming and forestry).

In addition to the processes cited above, there is also the long term possibility that biobatteries that employ an artificial photosynthesis technique will be able to help meet the increasing global energy demand. If we are to achieve this visionary goal, we need greater understanding of electrochemistry and energy conversion processes, closer cooperation between the disciplines of materials science, apparatus engineering and plant engineering, and the development and application of various physical, chemical and biological processes. With the help of systems biology, we can come closer to understanding the entire photosynthesis process.

At present, however, it is impossible to gauge to what extent the global energy sector may one day be supplied by algae production or by biobatteries. Basic research will help improve the potential in these future sectors while reinforcing over the long term the outstanding research profile of Germany's research in these areas.

c) Develop new food production processes

Plant and animal breeding will play a key role in meeting the future challenges of increasing the yields and efficiency, and changing the dietary and sensory characteristics of plant-based foods and feeds, as well as of foods from animals. With our increasing insight into the genomes of crop plants and livestock, of how the expression of genetic information is regulated – the result of a better understanding of metabolic processes, and of biomathematical, system-biological modelling of phenotype expression – new, more efficient breeding methods can be developed, and yield, efficiency and health deficiencies identified, all of which hold the key to targeting genetic measures for increasing yields or efficiency. By exploiting genetic diversity with the assistance of modern marker or sequence-based breeding processes in plants and animals, and by using genetic engineering to optimise the key genes, it will be possible for the first time to exert a significant influence over yield or efficiency by means of targeted physiological measures.

The ever-expanding range of specific and highly sensitive biotechnological techniques will enable us to identify those plant substances that are most important for human and animal nutrition or for potential industrial applications, and select suitable varieties for specific purposes (e. g. flavours, baking quality, vitamin content, antioxidants and content of unsaturated fatty acids).

What is more, technological innovations such as next generation sequencing techniques, the use of non-invasive techniques in phenotyping platforms, and processes to allow the creation of complex expression, protein and metabolite profiles, will lead to a paradigm shift in plant and animal sciences. They will make possible the molecular and phenotype analysis of individual specimens on a scale never previously seen. The knowledge gained from data on the origin of complex characteristics will be fundamental to the ongoing development of crops (yield productivity, resource efficiency) and livestock (efficiency, humane animal husbandry, animal health and welfare, reduction in greenhouse gas emissions).

d) Greater and more efficient production and use of exploitable biomass

The vast majority of biomass produced is used for making food (cf. Chapter 2). Around half of plant biomass is used to produce food derived from animals (FAO, 2006b). With this starting position, and given current global growth rates, it is absolutely essential to promote research into the improvement of plant breeding and feed conversion ratios. The aims here should be to raise yields overall, as well as to increase the content of specific substances which are of particular importance to humans and animals.

The full potential of crops and livestock can only be achieved if we make use of all breeding possibilities. Under practical conditions, successes in breeding can only be translated to higher yields or efficiency if the other production conditions keep pace. For this reason it is essential that the potential for progress in the soil-crop-animal system is exploited across the board. As well as plant and animal nutrition, this also relates to pesticide, animal health and agricultural technology.

It is the Council's recommendation that research programmes should ensure that studies into improving individual aspects of production systems (e. g. pesticide, plant breeding, feed cultivation, feed conservation, animal nutrition) tie in (where appropriate) with studies looking to improve the entire production system.

The traditional, broad-ranging disciplines of crop cultivation, animal husbandry and farm management have a key role to play here. Research should aim to place the methodological advances made in these three fields in the context of the system that obtains under practical conditions.

To increase the potential of the bio-economy in Germany, research programmes must take account of the heterogeneous natural conditions. Less favourable sites should also be considered in order to raise productivity when improved production techniques and innovative combinations of diverse production processes become available. The boundaries that have hitherto existed between aquacultures and agriculture need to be examined accordingly. A better integration of the two subsectors in a form appropriate to the site would unlock new potential for the bio-economy.

The same is also true of the integration of biotechnological processes. The need for research into the identification of suitable microorganisms and enzymes, and their optimisation for the targeted production of the necessary intermediate and end products remains undiminished. A large number of new processes and products are also expected to be derived from developments in, and applications of, synthetic biology. Where there is no possible direct use of by-products (cf. Recommendation 1a on biorefinery), the aim should be to find an alternative use, so long as this makes economic sense. This will lead to a substantial increase in the proportion of biomass employed as raw material and for energy generation.

e) Record, analyse and improve sustainability of different production techniques

There is great diversity in terms of the agricultural techniques employed throughout the world. This diversity reflects local and regional differences with regard to natural conditions, market conditions, and the knowledge and preferences of actors in the bio-economy.

These various production techniques should be assessed in different ways with regard to their economic, social and environmental consequences. But in the public debate on the future direction of the bio-economy, opinions as to which production techniques can be seen as particularly sustainable in specific locations vary widely. Currently ongoing in Germany and Europe is a polarised debate on the relative advantages of three cultivation techniques: organic farming, conventional farming, and farming using genetically modified crops. Although a more detailed analysis shows that often this crude categorisation does not accurately reflect the actual differentiated relationships along the value chain, in practice political administrations are continually obliged to come up with special arrangements for organic farming or the use of genetically modified organisms.

If the bio-economy is to be effective in the future, two things are important here:

– The scientific-analytical basis for evaluating and comparing agricultural production systems must be improved. All relevant parameters, e. g. land use, water and energy consumption, soil erosion, emissions that affect the climate, or biodiversity, must be recorded and assessed. The corresponding research projects must ensure that the actual conditions of production in various locations both in Ger-

many and abroad are recorded, and that a thorough analysis takes place which covers all aspects of sustainability, including indirect effects.
– There is a need for research which concentrates on the specific weaknesses of individual production systems and seeks to improve the economic, social and ecological impact of the production systems. For organic farming to be sustainable, for example, it is vital that there is a further reduction in the use of copper as almost the sole fungicide (Wilbois et al., 2009). Green or white biotechnology, in particular, may be able to create alternative solutions. Biotechnology and organic farming should not be fundamentally seen as being in opposition to each other. Rather they should complement each other, for example in the reduction of environmental problems by using plants that can reduce ecological 'footprints' through greater resistance to stress or higher yields.

f) Research topics

The research topics below are summarised from the preceding sections in Recommendation 1. The Bio-economy Council will prioritise these in subsequent stages of its work and define corresponding milestones for the related research projects.

– Expansion of the material uses of biomass using a combination of biotechnological and chemical conversion processes; new and improved enzyme systems to convert biomass (including the use of waste)
– New and improved processing techniques to produce the desired products in greater volumes and purity, but also alternative processes, such as the integration of separation processes at the reaction stage, to reduce production costs (process-integrated processing)
– Breeding of crops and livestock for greater yields or output and specific characteristics (including plant ingredients for healthy diet) and adapting production systems to exploit the genetic potential
– Further development of energy conversion processes (inc. co-firing)
– Methods and techniques of multiple use and coupled use, development and establishment of biorefinery plants; greater emphasis on pilot and demonstration plants from the perspective of sustainability
– Synthetic biology: expanding the application range of synthetic genes and genomes, genome engineering (genetic modification of many genes at the same time); design of new metabolic pathways; design of adapted minimal cells for industrial uses
– Research into the basis of alternative energy sources such as algae (optimisation of organisms, process techniques and use) and artificial photosynthesis systems (biobatteries)
– Development and production of new high-value products (e.g. pharmaceuticals, cosmetics, food supplements, special chemicals)
– Integrated biological production systems (agro-forestry systems, combination of crop production and aquacultures)
– Sustainability of various production techniques (comparative analyses of socio-economic and environmental factors at different locations; improving sustainability of production systems)
– Strategy development (e.g. development of dynamic systems models) and research into institutional measures to increase the competitiveness of the bio-economy

Recommendation 2:

Ensure global food security, promote health and assume global responsibility

The most important value chains in the bio-economy are in the food sector. The sustenance of the world's population is dependent on the efficiency of these chains, while their product and process quality directly determine health and quality of life. German research also has a responsibility in this area to help emerging and developing countries secure sufficient food for their populations.

a) Increase productivity with regard to basic foods

The rise in the world's population and changes in living and dietary habits, especially in emerging nations, has led to an increasing and changed demand for foods of plant and animal origin. Cereal production, for example, will have to rise by 50 % by 2030, and by 70 % by 2050, just to meet the expected demand for food and feed (FAO, 2006b). With total areas of agricultural land largely remaining unchanged, there will have to be a substantial increase in the yields of food and feed crops (Sc, 2009). There must also be a particular focus on minimising post-harvest losses.

It is essential to improve the yield capacity of the most important crops. This is now possible using modern methods and knowledge from genome research, biotechnology and gene technology as tools in the science of breeding.

Establishing the most advanced production techniques will also make a contribution here. The objective is to develop varieties which provide particularly high yields. As the most important cereal economically in Germany and Europe, wheat should be prioritised in research. There is also a need for studies on crop varieties apart from wheat that are important in other regions of the world. Crop varieties that are adapted to specific regions are a guarantee for the effective production of food and biomass at a regional level.

In addition to the optimisation of crop metabolism, a higher resistance towards external factors is also essential for increasing yields and ensuring that they remain at regular high levels. This includes resistance to pathogens and pests, lower water and nutrient requirements, as well as improved tolerance of heat, cold and salinity. The physiological and morphological mechanisms responsible for these must be identified and adapted. Findings gained here can be applied to other globally important crops such as rice, maize and soya, and integrated into international breeding programmes. This will lay the foundations for developing new efficient and regionally adapted crop varieties. Consideration must also be given to socio-economic and agropolitical innovations made by small farmers with regard to increasing productivity in developing countries.

In addition, there must be research into new sustainable processes for improving soil characteristics (see also Recommendation 3a). In this regard it is essential to increase the supply of water and nutrients to ensure adequate sustenance for the higher yielding crops. Finally, the external production factors such as fertilisation, watering and plant protection also need to be adapted appropriately. Agricultural engineering should support these developments by making further advances in the structures and technologies of cultivation, harvesting and transport. Better data is needed relating to the methods for determining correct timings for growing, crop care, or harvesting, so as to take maximum advantage of the potential output of crops, and to minimise post-harvest losses (e. g. by means of innovations in mechanical and plant engineering, agricultural technology, information technology, storage technology and the logistics chain).

Legumes,

such as lentils, beans and peas, are historically among the most important sources of plant protein for humans and animals. In many regions of the world, pulses also represent some of the most important basic foods. They have also long been used as animal feed. Before soya meal was introduced to Europe in large quantities, field beans and feed peas made up significant proportions of the feed produced in Germany and Europe. Grain legumes are especially rich in proteins. In Germany feed peas, field beans, as well as white, yellow and blue lupins are chiefly grown as feed crops. Legumes are not only of interest to farming because they are protein crops, but because they are able to fix nitrogen and enrich the soil. This occurs by means of a process by which the plant roots enter into a symbiosis with nitrogen-fixing nodule bacteria. When the legumes are harvested, the majority of the stems and all the roots are left in the field. The nitrogen reserves they contain are then available to the crops that follow. As a result, less nitrogen needs to be introduced by means of fertilisation.

Source: UFOP, 2010

In view of the rising demand for feed and the considerable shortage of protein that already exists (in Asia, for example), research into increasing the productivity of legumes as a source of protein ought also to be given priority in Germany. Legume cultivation is stagnating at a low level (Specht, 2009). The arable competitiveness of legumes must, therefore, be immediately improved by means of increased research activity. These studies should also look at how the use of energy-intensive nitrogen fertilisers can be reduced (see box).

The demand for foodstuffs of animal origin will almost double by 2050 (FAO, 2009a). Key factors in this area are an increase in output and resource efficiency, and a reduction in livestock-related emissions (WWI, 2009). Ensuring high standards of animal health and welfare is vital for future public acceptance.

Plans for improving global food security must address the particular farming structures that exist in many developing countries. Firstly, the development of policy approaches that look likely to succeed where small farm structures dominate must be identified. Important aspects here are the adaptation of education and training programmes, access to agricultural finance, and the development of efficient marketing systems. Secondly, development projects must make allowance for the tension that can arise when there is a clash between traditional and agro-industrial methods of production.

With regard to improving the food situation, studies must also examine the options for increasing the availability of acceptable-quality food for low-income population groups. In view of high price volatility, and the negative effects this has, an analysis of the solutions that private and public food storage might offer, and of the responsibilities in this area that could be assumed by the international community.

There must also be further investigations into widely differing dietary habits across the globe, the impact these have on health, and the associated consequences for food provision.

b) Improve product quality, promote health

Besides producing it in sufficient quantities, the quality of biomass is a crucial factor in subsequent value creation. Taking the requirements of the end products as a starting point, biogenic raw materials must be adapted through breeding or other suitable measures to meet the desired product and production standards. Plant-based or animal-based foods can be produced, for example, with added health-boosting benefits which may counteract nutrition-related health deficiencies throughout the world. Targeted breeding and modification of the appropriate genes can influence flavour, nutritional characteristics, and the content of desired ingredients.

It is certain that animal health will be an essential requirement in the future production of animal-based foodstuffs. Animal health and welfare will be the cornerstone of the essential link between animal protection and health-related consumer protection.

Research into the identification of the immunological causes of animal diseases is a fundamental requirement for the improvement of the quality of animal-based foods if higher levels of productivity are to be achieved at the same time. Here it must be noted that the likelihood of infection with pathogens which have hitherto been considered exotic will rise substantially in the German livestock population due to the globalisation of markets and climate change (WHO, 2002). Efficient strategies must be drawn up for combating animal epidemics by improvements in epidemiology and diagnostics, as well as in biotechnological vaccine development and production. This not only applies to animal diseases in the narrower sense, but also those infections that can be transmitted to humans by animals (zoonoses).

Animal health is also directly related to the conditions in which livestock are kept. The quality of animal husbandry, including the transport of live animals, must therefore be improved. Scientifically based, objective and consistently measurable parameters of welfare are the basis for improving existing animal husbandry techniques to achieve better animal welfare.

c) Support partnerships with developing and emerging countries

With regard to ensuring food security, there is need for agricultural and food research adapted specifically to the conditions of less productive regions in the world. The development of partnership structures, in which long term cooperation between institutions from developing countries and those from industrialised nations is possible, is especially important here (Evans, 2009). Research programmes must address in particular the specific local requirements in the target countries.

For example, efforts to support ongoing developments in the breeding of food crops to achieve higher yields and nutritional value, including enhancement with vital vitamins and trace elements such as iron and zinc, must be specifically tailored to different regions. Soils must be conditioned to ensure that the essential trace elements which are vital for nutrition can be taken up in sufficient quantities by plants. In addition, selecting specific crop varieties for a particular location can reduce the uptake of health-damaging heavy metals (such as cadmium) and their introduction into the human food chain.

When devising schemes for productive livestock farming, too, consideration should be paid to the particular environmental conditions of an individual site, as well as the conditions in which livestock is kept.

There is great diversity in the traditional arable farming techniques used in developing countries. In general, these differ from the conventional agricultural methods employed in highly industrialised countries. It is thus difficult to compare organic farming with traditional arable farming in these regions. But given that some individual experiments with organic farming in these developing countries have also achieved stable and high yields, there should be a systematic analysis of how these experiences could be put into practice more widely under different localised conditions. Comparisons should then be made with results from conventional farming techniques (cf. Recommendation 1e).

d) Research topics

The research topics below are summarised from the preceding sections in Recommendation 2. The Bio-economy Council will prioritise these in subsequent stages of its work and define corresponding milestones for the related research projects.

- Localised analyses of production systems in their international context (with particular focus on small farmers), evaluation of their sustainability and strategies for improvement, including the reduction of losses in the marketing and consumption system
- Analyses of options for ensuring global food security and limiting the volatility of food prices, including regional and global storage
- Increase in the health benefits of foods (e.g. processed foods); promotion of healthy diets
- Development of higher-yielding crops that are more resistant to stress (with particular focus on wheat and legumes); use and further development of marker-assisted selection (MAS) and automated high-throughput techniques
- Optimisation of plant ingredients and animal products for health purposes (e.g. improvement of micronutrient contents and reduction of heavy metal uptake, mycotoxins, predictive breeding)
- Selection and propagation of productive, robust and disease-resistant livestock
- Improvement in animal health and development of efficient strategies for combating animal epidemics (zoonoses); humane animal husbandry and feeding methods
- Modern techniques for developing high-output organisms (systems biotechnology: genomics, proteomics, metabolomics, metabolic pathway engineering, fluxomics), i.e. the targeted modification of entire metabolic pathways

Recommendation 3:

Use natural resources sustainably

The geo-resources of soil and water, nutrients, and the biological diversity of plants, animals and microorganisms form the basis of bio-economic value creation. As the availability of these resources is limited, it is vital that they are used sustainably and managed responsibly. Regional changes caused by climate change also need to be examined here.

a) Improve land use, raise soil quality, protect ecosystem services

The amount of land that is presently used for agricultural purposes cannot be substantially increased, as either cultivation would make no economic sense due to low potential yields, or expansion would negatively impact the environment and climate. The preferred way of increasing productivity is, therefore, to intensify farming sustainably on the land that is already used for agriculture. There must also be further advances in crop varieties by breeding techniques (cf. Recommendation 2).

Research should also focus on maintaining or improving the quantity and quality of productive soils (see also Recommendations 1d and 2a). To achieve this, new national and international land use schemes need to be devised. Using innovative research approaches to locally adapted crop cultivation, which include economic analyses, alternative farming scenarios must be developed which allow priorities to be set for land use. This also includes the use of appropriate techniques and locations which have not previously been exploited for biomass, as well as new soil improvement techniques for marginal land, an approach that has also been advocated by the WGBU (WGBU, 2008). Advances in agricultural technology are also essential. To optimise the timings of farming activity and thus act in a way which is less detrimental to the soil and reduces harvest losses, there must be better use of meteorological know-how. The experiences of organic farming with regard to measures designed to permanently improve soil quality should also be considered and, if appropriate, be given greater attention in the future.

Soils produce a variety of closely related benefits. These benefits are also known as ecosystem services (EA, 2005). Besides the production of food and feed, energy sources and usable materials, these include the provision of clean water, climate regulation, flood protection and carbon storage. To date, the interrelationships between the individual services have been insufficiently understood. This very point was made by the WGBU in 2008 (WGBU, 2008). Research should help provide a better overview of the limitations of the various benefits and the potential of soils in their regional context, and thereby provide the basis for a systematic scientific analysis. Particular attention should also be paid to the efficient use of farmland, focusing on the aims of nature conservation and the essential preservation of biodiversity. Useful tools here include satellite and other remote sensing and information systems.

From a global perspective, the soil is the most important terrestrial resource for carbon storage (Scheffer & Schachtschabel, 2010). The soil is a potential depot for the increasing volumes of carbon dioxide in the atmosphere. In the context of emissions trading, there are distinct opportunities for assigning a monetary value to carbon storage in the soil. For this reason, the scientific bases for a quantitative analysis of the interaction between the soil-plants-land use system (inc. tillage, root depth, cultivation systems) and carbon storage (inc. forms of storage such as bio-coal, and storage volumes and depths) must be identified, as must also be the related legal and economic issues.

b) Use water efficiently, improve water quality

Another effect of climate change will be alternations to the availability of water. Soils represent very important water reservoirs. Research should aim, therefore, to improve the water-storage capacity of soils by developing the appropriate means and processes.

Before this can happen, there must first be a better understanding of the impact of changing rainfall volumes and distribution on the water-storage capacity of soils, not only in Germany and Europe, but particularly in developing and emerging nations. The relevant soil analysis and associated information systems must thus be developed, as well as real-time management methods for the optimal use of water in agriculture. Greater efforts are also needed to develop the appropriate soil tillage technologies, soil enrichment techniques and new soil adjuvants, while their positive and negative environmental and economic impacts must also be identified.

It is also possible to adapt to changes in water availability by breeding more efficient crops (see also Recommendation 2). In addition to enhancing the drought tolerance of crops, breeding techniques must also take into account a higher frequency of extreme meteorological events and species compatibility.

Technical solutions for water-saving irrigation systems must also be refined, and there needs to be greater research into methods of water harvesting (rainwater use) or grey water usage. This is especially important in urban areas. The hygiene aspects of irrigation water in relation to human health also need to be examined here.

To protect ground and surface water and the soil microflora when manure is applied directly to the soil, animal production systems should be optimised so that improved animal husbandry systems mean that there is a further reduction in the use of antibiotics or other medicines, and substances can decompose during interim storage. The use of nutrients in manure must also be optimised (see also c).

In addition, international commodity flows need to be examined for possible excess use of water resources that are locally limited and any negative impacts on water quality, and to ensure there is adequate water provision for the local population. Concepts of virtual water consumption need further development here.

c) Targeted application and use of nutrients

Fertilisers account for a considerable proportion of the factor costs in crop production. At the high end of biomass production they are indispensable, and must be applied externally in most cases (FAO, 2008). If fertilisers are not used properly, such nutrients impact on other environmental media. What is more, the production of nitrogen fertilisers, in particular, requires a large amount of energy.

To use nutrients more efficiently than in the past, new techniques must be developed for fertiliser formulation, improving cultivation techniques (such as soil tillage), and optimising fertiliser production and dosages. On the breeding side, meanwhile, efforts must be made to help plants make better use of nutrients. Modern plant-breeding techniques can, for example, alter the structure of plants to improve their take-up or exploitation of nutrients.

The industrial production of a kilogram of mineral nitrogen requires energy corresponding to about one litre of crude oil. For this reason, a primary objective is to improve the way in which crops exploit nitrogen by using traditional and genetic engineering breeding techniques. It is also essential to optimise the nitrogen-fixing potential of legumes, especially in view of their importance for human nutrition (see also Recommendation 2a). This includes the improvement through breeding of the legume varieties that are currently grown. Moreover, developing ideas to improve the exploitation of nitrogen and phosphorus from manure is an important area of research for making the use of nutrients in agriculture more sustainable.

Over the medium term, it is expected that there will be a supply shortfall of phosphorus (Cordell et al., 2009). Research should focus, therefore, on how existing secondary raw materials in Germany can be efficiently retrieved and recycled. The excellent interdisciplinary funding programme for phosphorus recycling should be expanded to include other secondary raw materials (manure, subhydric sediments). In order to protect soil and water, care must be taken to ensure that materials are as free from hazardous substances as possible. The existing grades of soil nutrient content that are used to establish recommended dosages of phosphorus fertiliser need to be scientifically checked in relation to modern crop varieties.

More research is needed into the breeding of phosphate-efficient crop varieties which can unlock and use more efficiently the existing nutrients in the soil that plants find difficult to exploit, and can deliver greater yields with less phosphorus input. The potential of adapted microorganisms should also be exploited. Working in cooperation with animal science, this research should aim to improve the digestion of forms of phosphorus storage in feeds. This is possible with the right feed enzymes. These are produced by biotechnological processes and either added to the feed or, as Chinese scientists recently demonstrated with regard to maize (Origin-Agritech, 2008), produced in the feed plant itself. With the targeted introduction of a gene which induces the creation of phytase, pigs and poultry can make better use of the phosphorous content of maize feed.

Animals differ in their capacity to exploit phosphorus and other limited nutrients. This has an influence on the demand for resources and also, through the animals' excrement, the level of fertilisation available to crops and to transformation in the soil. There is thus an urgent need for research clusters in animal science to promote an increase in resource efficiency through means of the development of suitable breeding and feeding methods, and which are tied in to wider research programmes on the recycling of nutrients.

d) Safeguard genetic resources of plants, animals and microorganisms, and use these efficiently

The genetic diversity of livestock breeds and crop varieties, as well as the diversity of the organisms found in the natural world, are an important resource for the bio-economy (RNE, 2008). In particular, the huge biodiversity of the close relatives of livestock breeds and crop varieties represents a potential that has scarcely been tapped until now. This gene pool can firstly be used in a targeted fashion to create breeds or varieties with new characteristics. Secondly, the gene pool represents a substrate for synthetic biology, especially for the construction of artificial cell factory systems or new proto-organisms.

Enzymes and metabolic pathways, as they exist in nature (e. g. in archaebacteria), are now playing an ever greater role. A comprehensive inventory of genetic resources is thus needed, e. g. by systematically recording genomic data from various habitats in metagenome banks, in which the genomes of entire populations can be analysed.

Besides genetic databases, there is also a need for a greater expansion of physical gene banks which collect, test and preserve material or seeds from the various species. The collection and preservation of as many species as possible is essential if we are to make use of the vast biodiversity in the future. These materials must be classified both genetically and in terms of their phenotypes to make them available as starting materials, e. g. for plant and animal breeding or synthetic biology (see also Recommendation 1d).

Phenotype analysis provides quantitative data on the structural and functional characteristics of animals and plants relative to environmental factors. New, non-invasive processes must be developed and implemented to select predictive characteristics in breeding, and guide agricultural production towards higher yields, improved plant and animal health, and more efficient use of resources. This key technology will have considerable spin-off effects and will integrate developments in other technological spheres of the bio-economy.

e) Aid and support agriculture and forestry in their adaptation to climate change

Climate change will have a significant impact on agriculture, forestry and horticulture. These sectors are, at one and the same time, contributing to the emission of and the capture and storage of greenhouse gases. Beef cattle farming and wet rice cultivation, in particular, are major emitters of methane, while nitrous oxide is chiefly produced by microbial conversion of nitrogen compounds used in fertilisers and legume cultivation.

These emissions can be reduced by the further optimisation of production conditions. Increases in the nitrogen efficiency of crops, e. g. through advances in plant breeding, can lower the output of nitrous oxide per production unit. There also needs to be greater research into the use of nutrients from organic manures (see also c).

Although direct carbon dioxide emissions from agriculture are fairly low, across the globe large amounts of carbon dioxide are released when there are changes in land use (expansion of farmland at the expense of woodland etc.) and this results in a loss of biomass and humus (IAASTD, 2009). Technological and institutional measures in addition to economic tools that can adapt and prevent the release of gases that affect climate must be developed in close cooperation with the countries concerned. Projects for woodland use are also very important for the preservation of species diversity in these ecosystems (see also d).

Production techniques in agriculture and forestry also contribute to climate protection. When agricultural crops are grown, the plants remove carbon dioxide from the air and at the same time release oxygen. The soil on agricultural and forestry land, as well as the biomass above ground, contain large volumes of carbon compounds. There are still many gaps in our knowledge with regard to the technological, spatial, temporal and quantitative sequestration of carbon when it comes to climate protection (see also a).

In view of the predicted temperature increases and the fact that day and night temperature variations are likely to be less pronounced, we need a new analysis of the physiological requirements and the physiological output potential of livestock. This research should take into account the new biotic (e. g. pathogens) and abiotic stress factors that are appearing in different regions, as well as the changes in plant-based feeds.

The breeding of healthy, productive animals and higher-yielding crops can help promote increasing food production without the need for extra farmland, or even with the use of less land. Enhancement of resource efficiency and reduction of the level of environment- and climate-relevant excretion per kilogram of edible protein will lead to a reduction in greenhouse gas emissions. All sub-systems along the process chain must be optimised accordingly.

f) Research topics

The research topics below are summarised from the preceding sections in Recommendation 3. The Bio-economy Council will prioritise these in subsequent stages of its work and define corresponding milestones for the related research projects.

- Soil quality, land use, ecosystem services (prioritising land use; national and international regulations on land and water rights; progress in agricultural technology; improving monitoring and data; soil aspects of organic farming)
- Water use, water efficiency, water quality (locally adapted schemes for water storage and irrigation; agronomic adaptation measures; soil measurement systems and information systems; plant breeding), biological approaches to water purification on the ground
- Targeted use and recovery of nutrients (interaction between plant roots, soil and microorganisms; optimisation of cultivation techniques and fertilisation; closing material cycles; recovery of phosphorus,

in particular; development of plant systems that reduce ecological 'footprints', e.g. phytase maize as an animal feed)
- Safeguarding the genetic resources of plants, animals and microorganisms, and efficient use of these (biodiversity; cell factory systems; systems biology; synthetic biology); metagenome banks.
- Adaptation to climate change (plant and animal breeding; climate-friendly animal husbandry and crop cultivation; weather forecasting; agronomic measures, e.g. mixed cropping, agro-forestry systems); adaptation of forestry (REDD); carbon storage in soils and incentive mechanisms
- Economics of resource use (competition between uses for land and water, 'virtual water', ecobalancing); institutional arrangements for supporting innovations (including collective action for water use and ecosystem services); and adaptation through action
- Quantitative analysis of genotype-environment interaction at the mechanical level, in the high throughput situation and its application in the field (breeding nursery); instrument and concept development; expansion of the German network of plant phenotyping network

Recommendation 4:

Ensure appropriate integration of the bio-economic approach in the system

In order to be able to work effectively on the three research areas cited above and act on the findings, existing structures and external framework conditions must be adapted to meet new requirements. This point was already outlined in the Council's 'First Recommendations' (Bio-economy Council, 2009). In particular, there needs to be more research funding, further development of the research infrastructure, a more strategic orientation of the way German research interconnects with the international research environment, and better training of young academics. There must also be more communication of the findings of bio-economic research to the public.

a) Develop the public and private research infrastructure for the bio-economy, create networks, coordinate research funding and organise it jointly

Although parts of the existing research environment rank as excellent, many areas of it are frequently fragmented into university and non-university research institutes, as well as federal and regional research institutions. Research into the bio-economy takes place across a large number of academic subjects, research institutions and programmes, as well as in the private sector. Relevant academic disciplines include the agricultural, food, horticultural and forestry sciences, veterinary medicine, biology, as well as aspects of pharmaceutics, geo-sciences, chemistry, other engineering sciences, law, economic and social sciences, psychology, mathematics and information technology. This large number of subjects is matched by a similar breadth of existing research institutions.

Around 100 universities and colleges research and teach aspects of the production, processing and use of biological resources. The huge importance of colleges for innovation in the bio-economy is also demonstrated by the large number of doctorates being awarded in subjects related to the bio-economy. The number of PhDs in bio-economy-related disciplines compared to other countries underlines Germany's high international standing in this sector (see Figure 8).

Around 50 institutions belonging to the four non-university research associations – the Hermann von Helmholtz Association of German Research Centres (HGF), the Leibniz Association (WGL), the Max Planck Society (MPG) and the Fraunhofer Society (FhG) – in addition to government research institutes are involved. It should also be emphasised that joint appointments are often made to positions in colleges and non-university research institutions. The HGF research centres that are focused on this field are those in Jülich, Potsdam, Karlsruhe, Munich and Leipzig. They specialise in areas relating to biology, climate and geo-sciences, health, energy and the environment, information, key technologies, biodiversity, environmental and biotechnologies. Amongst other things, the WGL institutes, predominantly concerned with life and environmental sciences, provide research infrastructures and offer research-based services.

Application-orientated research and cross-disciplinary investigation are mainly carried out by FhG institutions, whereas institutes that are part of the MPG undertake essential basic research, particularly in the biological sciences. Some government departments also have institutes that carry out bio-economy-related research. These include the Johann Heinrich von Thünen Institute, the Friedrich Löffler Institute, the Julius Kühn Institute and the Max Rubner Institute, which all operate under the aegis of the BMELV.

In addition to this publicly funded research, a substantial volume of bio-economic research is also being carried out in the private sector. In Germany, industrial research is being undertaken in areas such as agricultural engineering, plant breeding, plant protection and biotechnology. Two of the world's leading pesticide producers, BASF and Bayer, have their headquarters in Germany, and each spends more than one billion Euros per year on research (BASF, 2009; Bayer, 2009). The seed industry, which includes corporations with worldwide interests as well as a large number of medium-sized, regionally important businesses, traditionally spends a large proportion of its turnover (16 %) on research (BDP, 2010). In view of the importance of private bio-economic research for the economy, we must ask whether and how efficiency and effectiveness in this sector can be increased, especially in the areas where it interfaces with publicly funded research. So-called 'unusual' alliances and innovative partnerships can play a role here. The creation of innovation alliances (cf. the High-Tech Strategy; BMBF, 2006) for exploiting synergies in private and public R&D is very important.

In conformity with the promotion of the concept of interdisciplinarity and the interlinking of private and public research, several research projects and programmes have been launched in the last few years which are very positive examples of scientific and economic integration and the development of clusters of excellence. These include GABI[6] (Genome Analysis in the Biological System of Plants), FUGATO (Functional Genome Analysis in the Animal Organism), GenoMik (Genome Research into Microorganisms) and the National Genome Research Network (NGFN).

Here we should also mention the funding of networks of excellence in agricultural and food research such as CROPSENSe, FOCUS, PHÄNOMICS and SYNBREED within the BMBF's framework programme: 'Biotechnology – exploiting and shaping opportunities'. In addition, Germany's BioRegio programme gives it a leading position in Europe with regard the funding of whole regions. Under this programme, companies developing marketable products as a result of intensive knowledge exchange have become established in 25 regions of Germany.

The competitiveness of German bio-economic research must, however, be measured against the corresponding research activities

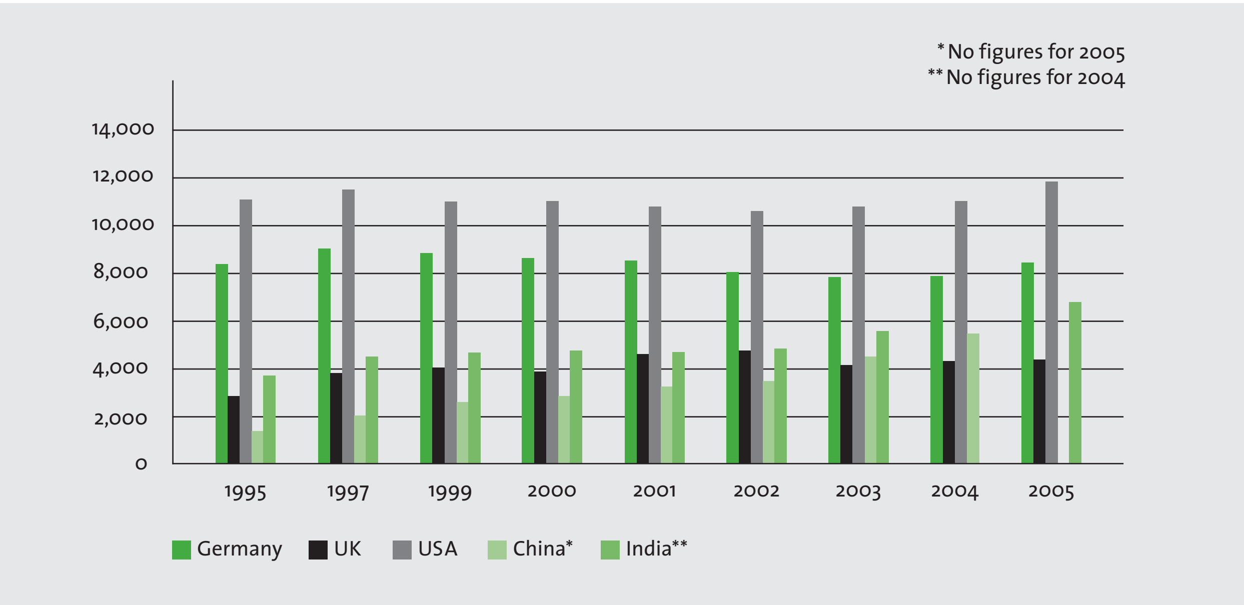

Figure 8: PhDs in bio-economy-related subjects 1995 to 2005 (NSF, 2008) 5)

5) These include the agricultural sciences, natural, biological and geo-sciences, as well as atmosphere and maritime sciences (NSF, 2008).

6) Known as 'Plant Biotechnology' since October 2010

Research systems in the bio-economic sector – many countries are expanding and repositioning themselves

Systematic research into the bio-economy is still in its infancy. An indicator for the status of bio-economic research is research into biotechnology and agricultural engineering, which is receiving greater funding volumes.
In China, for example, public expenditure on R&D in the agricultural sciences has risen progressively from 2.2 billion $ in 2000 to 3.5 billion $ in 2006 (figures are in PPP prices for 2005). In addition, the number of academics working in the agricultural sciences in China increased by about 6,000 to more than 58,000 between 2000 and 2006.
In Brazil, the number of scientists in agricultural research rose from around 4,700 to almost 5,300 over the same period. Between 2003 and 2006 the number of Brazilian biotechnology experts increased from 204 to 462.
Substantially more funds are available to the Indian Council of Agricultural Research (ICAR), the most important research institute in the agricultural sciences in India. There, more than half of the scientists have a PhD. At EMBRAPA, the largest Brazilian research institute in the agricultural sciences, as many as 64 % of the employees have a doctorate.
In 2009 the European Union set up a 'Joint Programming Initiative' on Agriculture, Food Security and Climate Change, to strengthen coordination beyond European borders. There are currently around 60 programmes across the USA that have as their focus research and support of sustainable food production, bio-energy and climate change, while at the same time, research into the agricultural sciences is being revived at universities. With the establishment of the National Institute of Food and Agriculture (NIFA) at the Department of Agriculture (USDA), the USA has pooled its research into the agricultural sciences. The NIFA alone had around 1 billion US $ for funding projects in 2008. The aim of an increasing number of international partnerships and research centres is to tackle global challenges, especially food security, sustainable forestry and climate change. The CGIAR, for example, is planning to double annual expenditure from half a billion to 1 billion US $ on research into improving the food situation and the sustainable use of natural resources, particularly in developing countries.

Sources: CGIAR, 2009; CR, 2009; OECD, 2006; USDA, 2010

of other countries. The trend in international agricultural research can act as an indicator for this. The figures in this area exhibit an upward trend in many countries (see box).

The agricultural sector can also serve as an indicator of research activity in the private sector on the global stage. In 2007, the eleven largest multinational firms invested some 5.6 billion US $ in research and development in the areas of chemistry, seeds, animal health and agricultural machinery (Evenson & Pingali, 2007).

Structural adaptation and development are needed to be able to make better use of the existing research environment in Germany. This is especially true of research funding. The German ministries BMBF, BMELV, BMWi and BMU are all funding from their own budgets individual research projects which are associated with the bio-economy's scientific areas of activity. In wider terms, the BMZ has for a long time been funding the centres of international agricultural research (CGIAR) as well as the joint projects with these undertaken by German research institutions, thereby making an important contribution to the provision of global benefits, particularly in the form of ensuring food security.

Only a research funding strategy that is better aligned to common objectives and directed at existing challenges will help promote economic success as well as the accretion of scientific knowledge. To achieve this, these objectives need to be analysed in order to provide the basis for the modification of existing research structures.

In view of this, the Bio-economy Council's recommends the setting up of an interdepartmental national bio-economy research programme to facilitate a joint research funding strategy at federal level. This research initiative should be aimed at both business and science, and have as its subjects natural, engineering and social sciences.

This will lay the necessary foundations for pooling the Federal Government's research funding and gearing it towards a common objective. The research programme should be embedded in an overriding bio-economy strategy and tied into the Federal Government's other strategies, such as those related to maintaining sustainability or biodiversity. This will allow the various interconnected areas to be brought closer together, thereby creating enhanced synergies.

Existing expertise, strengths and experience of the various government departments must be given consideration and appropriately integrated into the research strategy. In the past, the research department has focused mainly on basic research, while the governmental organisations have looked at practical applications. Efforts must be made to integrate this with current ongoing federal research programmes that are related to the bio-economy.

But this should merely represent the first step. Following the establishment of a national research programme, the aim must be to achieve greater cooperation at lower levels as well, e. g. in the issue of joint topic-related calls for tenders. Increased coordination and a joint interdepartmental tender process will make possible the more efficient use of budget resources (avoiding the funding of overlapping research and the inefficient use of labour resources by project managers), and raise Germany's profile at the European and international level.

We have not yet examined initiatives for the closer interlinking of private research with Federal Government project funding, or the integration of projects undertaken by the individual German Länder. This subject will be addressed in the Bio-economy Council's next report.

Mention must be made, however, of the German AgrarForschungsAllianz (German Research Alliance) which is seeking to bring together a number of Federal Government and Länder authorities in a bottom-up process for the purpose of agricultural research. The aim of the alliance is to strengthen German agricultural research so as to raise its profile nationally, throughout Europe, and at a wider international level.

Tasks that cross boundaries between areas should only be tackled by means of cooperation between different disciplines and structures, and implemented in close collaboration with enterprises. More theme-specific research networks should thus be created, and the participation of business should be encouraged. One possibility here would be the formation of so-called unusual alliances (see box).

Such partnerships between different sized firms from non-related sectors, with product portfolios that do not overlap, that use differing variety of business models, and are positioned at different locations in the value chain, are characterised by the fact that the businesses have access to considerable private sector funds.

Research funding can intervene in this process and exert considerable leverage if the entire value chain – from basic research, product development, process technology and production, including the external framework conditions, to market approval – is supported in a way that is technology-neutral and stimulates competition.

Combining technological and economic expertise at an early stage is essential if research findings are to be put successfully into practice. Successful structures that already exist should be expanded and neighbouring fields should be integrated more closely than before. It must be noted that project-related funding based on the GABI or FUGATO models, for example, is not ap-

Unusual alliances

Alliances of this type can assume a model pioneering role with regard to actual product development, i. e. in the form of cross-sector innovation initiatives or innovation alliances. An archetypal unusual alliance of enterprises which had been previously been unable to exploit the synergies of their research was created when the Industrial Association of White Biotechnology (IWBio) was formed. A producer of feed additives, a detergent and cosmetics concern, and an array of biotechnology firms specialising in bioinformatics, biocatalysis and production strain development combined forces to develop and produce biosurfactants. Another example is the partnership between one of the largest European sugar manufacturers, a leading agrochemical concern, the pharmaceutical industry and more than ten biotechnology companies. Together, these businesses are developing cosmetic ingredients, probiotics and biocatalysts.

Source: IWBio, 2010

propriate to the on-going tasks that are required in these projects (e.g. data management). Combined solutions – project-related funding in tandem with institutional funding – offer a suitable way forward here. Refinancing through economically successful research projects is also an option that should be examined.

The creation of further networks can be modelled on European technology platforms. Besides the areas already mentioned, existing capacities in soil research and biotechnology should be combined, and linked across disciplines. As far as biotechnology is concerned, projects such as the Leuna chemical-biotechnological processing centre (biorefinery project) or the planned establishment of a bio-economy centre in North-Rhine Westphalia are the right way forward.

Another way of achieving a high degree of interlinking is the creation of centres of excellence. These can ensure that technical expertise and scientific infrastructures from the various research and development disciplines are combined locally, and that business is brought in at an early stage. This dovetails research and product development.

For the successful implementation of theme-specific R&D programmes, technology platforms are suitable instruments for making the scientific and technological bases available to the institutions involved. Priority areas in this respect are genome research, proteomics and metabolomics, phenotyping, and bioinformatics. The last of these must be developed to make available tools for evaluating, interconnecting and using the diverse data that are obtained.

b) Strategically realign international partnerships, improve international networks

The establishment of the bio-economy and its associated research cannot be implemented at the national level alone. Particularly where the need is to achieve international, overriding goals, Germany needs to play her part.

To allow us to gear our focus to the future, the first step is to realign the national strategy and increase support for the established partnership with the leading international network of the Consultative Group on International Agricultural Research (CGIAR). This encompasses the European research area with its joint research funding instruments. The setting of priorities relating to the direction of research at the European level can be effected within the Joint Programming Initiative. The second step requires concrete policy measures, such as the establishment of international regulations, e.g. on soil tillage and measures to prevent the depletion of biological resources.

Because trade is a global activity and land use is increasingly becoming internationalised, purely national regulations are no longer adequate to guarantee that soil productivity remains at roughly the same level worldwide. For this reason, an international initiative is needed to devise a universally binding set of rules to ensure that the international community manages the soil in line with its responsibility to future generations.

There is also a need for investment in research and development to establish specific measures, tailored to the conditions prevailing in the less productive regions of the world, for increasing agricultural yields. This will not only require knowledge transfer, but also the integration and support of local expertise in bi-national and multinational research networks.

The implementation of measures thus developed will help establish new economic ties with emerging and developing countries. The expansion of strategic international partnerships, exchange in research and development, and the targeted export of technology will also be of service to international markets. Essential here is the development of a national strategy on international research funding.

c) Adapt legal parameters to the needs of the future, eliminate obstacles to innovation

The bio-economy in Germany, an important centre of commerce, will only be able to develop further if it is supported by an appropriate legal framework and if the existing obstacles to innovation are eliminated.

Clearly defined legal parameters are thus essential if on-going development, marketing and the use of new biotechnological processes and products are to continue. Also required is adequate protection of intellectual property.

A happy medium needs to be achieved in the field of plant breeding between protecting patents and plant varieties while, at the same time, the requirements of Article 53 of the European Patent Convention (the exemption of plant varieties from patentability) need to be followed. This means guaranteeing the protection of technological inventions on the one hand and, on the other, protecting plant varieties by plant variety rights.

It has been claimed that the existing regulations governing the co-existence of the various cultivation techniques of conventional agriculture, from farming with the use of genetically improved varieties to organic farming, are problematic (SRU, 2004). As, after years of deliberation, there is still no decision on seed thresholds, legal uncertainty prevails, resulting in considerable economic losses for farmers and breeders alike.

As far as the licensing of genetically modified crops for import and cultivation is concerned, the risks of using and not using these should be analysed, and the subsequent decision – based on scientific principles – should be implemented by the EFSA throughout Europe. Appropriate economic and institutional parameters are also essential for the successful introduction of new techniques and products onto the market. These must be included for consideration at an early stage in research and development projects.

Investment in R&D requires a competitive environment. This includes tax and financial incentives. Unlike many OECD countries, Germany lacks tax-related funding of R&D by means of tax credits; for example, no support is provided to new companies by measures such as a reduction in social contributions (Young Innovation Company Status) or through start-up financing at reduced rates of interest with private or public capital.

New models of cooperation between research and business, such as the creation of value chains via known markets and areas of application, can accelerate the development and use of new products or services in the field of industrial biotechnology. The setting-up of technology parks with pilot and demonstration plants is also necessary for the introduction of new products or processes onto the market, particularly in an international context. For this, however, it is both necessary and unavoidable to impose effective, success-oriented controlling measures.
As a further aid to the development of investment structures, it would be advisable to conduct a trial of a Lead Market Initiative for Germany to support research and innovation. Bio-based products could be seen as a lead market of the future, and should be supported correspondingly. This involves identifying obstacles barring the introduction of such products onto the market, as well as searching for ways to eliminate these, thereby stimulating innovation, job-creation and new, sustainable products and processes. This would include changing existing obstructive regulations. A model here could be the equivalent European initiative.

Propagation or ‘second generation’ regulation

The so-called ‘farmer’s privilege’ in Germany allows the harvest of certain crop varieties – such as cereals or potatoes – to be resown. This farmer’s privilege is only legal under certain conditions, and requires the payment of a so-called ‘propagation fee’ to the breeder of the particular variety. By paying this propagation fee, farmers play their part in ensuring progress in breeding.
In practice, both farmers and breeders feel there is a need for improvement to the propagation fee system. For a large number of farmers, the process of levying the payment is too detailed and complicated, which means that a significant proportion of them ultimately evade paying the fee. For the breeders, meanwhile, there are too many loopholes in the regulations that apply to the propagation fee. Often their claims to the fee fail because many of the legal provisions cater insufficiently for the situation in practice. The dissatisfaction of both parties has resulted in the need, in the interest of long-term progress in breeding, to simplify the propagation fee system and ensure that it is applied comprehensively.

A further challenge is to overcome the separation between agricultural and forestry production, which for the most part is still very rigid. Particularly conspicuous evidence of this separation is provided by the so-called 'NaWaRo-Bonus' – renewable raw material energy incentive – by which biomass produced in agriculture receives a considerable competitive advantage, even though this preference is not justified from an economic perspective. The inequality of treatment must be eliminated by a corresponding change in the law on renewable energies.

In an international context it is important to create a uniform international legal framework for access to genetic resources and, within the scope of the United Nations Convention on Biodiversity, to promote an equitable sharing of benefit which includes harmonised regulations on the preparation, acquisition and use of genetic resources, thereby providing legal security and guidance worldwide.

It must also be borne in mind that there are already regulations that must be complied with, yet in normal everyday cases these generally do not involve an increase in administrative costs, not even for small and medium-sized businesses.

d) Adapt systems and criteria for assessing scientific research, set up structures to evaluate the competitiveness of research funding in the bio-economy

At present, the systems used to assess scientific investigation put most emphasis on published articles in high impact factor journals that focus predominantly on basic research. The consequence of this is that there are insufficient incentives for interdisciplinary and transdisciplinary research or practical knowledge transfer. Key elements of the bio-economy thus receive inadequate consideration. Criteria for assessing research in the field of the bio-economy must be adapted to address these features and developed correspondingly. The principles for such methods of assessment already exist in a number of non-university research institutions.

To ensure that research funding in future-oriented areas is better targeted, the foundations must be laid for the development of future scenarios and evaluation of the success of research work and research structures for the bio-economy. Essential here is the further development of data and information bases beyond subject-specific borders. Bio-economic research must focus on the market systems which are created when value chains are linked together. For a better understanding of interlinked structures, tools must be devised to develop and control these systems productively.

e) Attract young academics to the field of the bio-economy

The bio-economy, as a very broad field, needs well-educated young academics that are willing and able to think and act systemically. These young academics must be made aware of the areas of activity of the bio-economy at as early a stage of their education as possible so that suitable students can be won over. In addition, the education and training on offer must be of high quality.

Because of the high degree of innovation potential offered by the bio-economy, which contributes to the ongoing advancement of various technologies, and because of the necessity for interdisciplinary research, the need for educational measures is also increasing. Consequently, the orientation of education and training must guarantee accessibility to the needs of the bio-economy as well as a high level of quality.

An interest in biological, technological and economic issues needs to be promoted in schools. Here there is an urgent need to adapt teacher education and training.

The education of excellent young academics requires the creation of structures which take into account the all-embracing nature of the bio-economy. This presents university teaching with a considerable challenge. The potential for innovation potential can be demonstrated by means of deficit analyses. Furthermore, the most promising young academics must be identified and supported at an early stage. Education should be more interdisciplinary and geared more closely to practice.

f) Put communication and participation for innovative research and technological development on a new footing

The bio-economy encompasses many new areas of research and technology which are extensively interconnected. The most effective way to promote the image of the bio-economy across wide sections of society is to make the public aware of these interdependencies, which are also becoming increasingly significant in the fields of energy provision, urban mobility and many other future-orientated areas.

There are also less prominent, hotly debated issues, where open public discussion must be encouraged. For example, innovative techniques in plant research for tackling the global challenges of increasing food and energy provision will be undoubtedly playing an important role. One of the key tasks in supporting research is to communicate this significance appropriately.

In contrast to the widespread scepticism in Europe, green gene technology is perceived positively in North and South America, and in the Far East (China, India). One consequence of this is that product development using green gene technology is being vigorously pursued in America and Asia, thus leading Europe into a state of ever greater dependency. This is true for both the import and product side. It is already the case that 30 million tonnes of feed produced by GM farming are imported by Europe (EC, 2007). And yet research in Germany in this area focuses predominantly on the safety aspects. Meanwhile, white and red biotechnology have entered into the public consciousness, and have received acceptance due to the large number of possibilities they offer, particularly with regard to improvement of health.

The reservations cited above have been the subject of intense discussion for years. The arguments, often presented very rationally, have not yet led to any fundamental change in wider public opinion. The reasons for this are complex.

It should be noted here that communication on this subject has not in the past succeeded in highlighting clearly the individual benefits of innovative plant research when it comes to solving global issues (food security, climate change, need for renewable energy).

Acceptance of these new technologies and of other areas of biotechnology, such as that existing in other parts of the world, has to date been very limited among the German population. This is chiefly due to the fact that it is scarcely possible, in the time frame necessary, to impose the climate change-related adaptation measures using conventional crop cultivation techniques, as well as communicating these to the public (WWI, 2010).

Given the rapidly changing external framework conditions and the likely future technological requirements that are not yet fully visible from today's perspective, it seems even more necessary to keep all technological options open, e. g. in the area of energy research. An important general premise of bio-economy research is thus to emphasise for Germany a basic openness to technology. This includes techniques of modern plant research, of which green gene technology is only one, albeit the most hotly debated.

In the field of communication, therefore, there needs to be further research – adapted to the changed global parameters – into biotechnology. New aspects which are predictably difficult to present to the public, such as synthetic biology, must be included here. Previous communication strategies must be examined and the complex reasons for the widespread rejection identified. In this regard, a tie-in to the scientific academies seems urgently needed.

To achieve greater acceptance of new technologies, consumers must be made aware of the need to protect our natural resources, and the opportunities that new technologies can offer in this regard. The necessary methodological-didactic framework must be created here, starting with concepts for pupils and teachers and ranging to more comprehensive strategies for public dialogues.

address in sufficient detail some key areas of bio-economic research. These include the sectors of biomass production (including fishing and aquaculture, forestry sciences and horticulture), as well as food, energy use and the production of pharmaceutical compounds.

In the food sector, especially, we need to investigate how value chains can be interlinked so that the necessary health factors can be integrated, while ensuring the future security of the food production industry. Food and health are directly related areas. Existing knowledge already allows us to take preventative measures against nutrition-related diseases, and in the next few years, health-boosting foods may become of increasing importance.

The structural recommendations of the report are in the first instance restricted to those areas which can be influenced by Federal Government measures. But the German Länder also have a large number of structures and institutions which belong to the field of the bio-economy and which should be included in concepts for developing this area. The same is true of private research undertaken by businesses. The links with Europe and the rest of the world must also be integrated into future thinking.

Of significance here is an extensive analysis of the advantages and disadvantages of the various management and structural models of research organisation. A multifaceted and future-oriented management model is needed which can lead to strategic action, and which can be used to guide and fine-tune the development of the bio-economy in Germany. Besides international aspects, the state instruments that exist in Germany must also be included here.

The predominant feature of the bio-economy is the close cooperation across academic disciplines and sectors of the economy. It is necessary, therefore, to bring together the various scientific communities and business to achieve the desired pooling of knowledge.

In the 2009 coalition agreement, it is stipulated that the Bio-economy Council will support the Federal Government in devising an internationally competitive strategy for a knowledge-based bio-economy. The Bio-economy Council believes that the first step is to produce a research strategy whose findings can evolve into a strategy for the bio-economy. The preparatory studies on how to develop a bio-economy strategy should, however, run in parallel and begin in the near future.

The production and use of biomass, with the corresponding biotechnological processes, should be equally at the core of such a strategy. There are many ideas in this field: for optimising the energy use of biomass – for innovations in, and extension of, the use of material – for improving food and feed quality so that people and animals eat more healthily and for adapting agricultural technology to changing climactic conditions. A greater use of bio-based products can help meet climate goals as well as the aim of 'combating hunger and poverty', one of the UN's Millennium Goals. It is clear that biotechnological processes, as key technologies, can make a vital contribution here. The various branches of industry involved, in addition to business finance in association with science, research and the political community, need to respond to the challenge. The Bio-economy Council believes it would be a good idea to establish a 'National Bio-economy Platform' to ensure the necessary coordination.

In this context, particular consideration must be afforded to international competition and partnerships. It is the Bio-economy Council's view that the German bio-economy and bio-economic research should be aligned more strategically than in the past, to link more closely with other global actors. This would both strengthen Germany's own interests, as well as protecting common global benefits in the bio-economic sphere. A number of G-20 states have already begun to position themselves in this area.

Orientating Germany to a bio-based economy can strengthen the national economy, generate economic stimuli, create jobs, and thus lead to a better world to live in for the whole of mankind. The objective is to create growth, while at the same time linking the consequences of all technological changes in the system to the principle of sustainability. The opportunities this offers must be communicated to society at large.

Glossary

A

Agricultural raw materials
Raw materials derived from agricultural production that are used for secondary purposes depending on their nature, e.g. in the food and feed sectors, in fibre processing, as building materials or energy sources.

Agro-forestry systems
Agro-forestry systems are forms of land use in which woody plants, e.g. trees and shrubs, are combined with crops on the same plot of land, either in strips or mixed together.

Aquaculture
The controlled breeding and rearing of aquatic organisms, i.e. those that live in water, especially fish, mussels, prawns and algae.

Archaebacteria
Simple bacteria that can exist under unusual conditions, such as high temperatures, low pH and high salinity which presumably prevailed early in the history of the Earth. They are used in biotechnology to help discover enzymes or secondary metabolites with interesting characteristics.

B

Bio-based products
'Bio-based' is a term used to describe all products derived from biomass (agricultural and forestry plants, algae, marine organisms and bio-waste from homes, animals and food production), with the exception of food and feed. These products include refined chemicals, pharmaceuticals, cosmetics, biopolymers, and basic chemicals, as well as high-value traditional bio-based products such as wood pulp, paper and wooden products.

Biobatteries
Energy generation by means of photosynthesis and transfer of this to technical systems.

Biocatalysis
The use of enzymes as biochemical catalysts to initiate and control a reaction.

Biodiversity
The variability of living organisms and of the ecological complexes to which they belong. It includes the diversity of ecosystems, communities, habitats and landscapes, as well as the diversity of species that exist within them and the genetic diversity within the various species.

Bio-economy
That part of the economy encompassing all industrial and business sectors and their associated services which produce or process biological resources or use them in various forms.

Bioinformatics
A computer-assisted research field on the boundary between biology and computer science in which biological data is analysed (e.g. sequence data, structural data, omics data).

Biological and life sciences
A collective term for the sciences which deal with processes or structures of living organisms and processes that involve living organisms. In addition to biology, these also include related fields such as medicine, biomedicine, biochemistry, molecular biology, biophysics, bioinformatics and biodiversity research.

Biomass
The total volume of organic material produced biochemically in a defined ecosystem. It comprises the sum of all living things, decaying organisms and the organic metabolic products.

Biorefinery
A factory plant which fractionates, refines and processes renewable raw materials.

Biotechnology
The application of science and engineering to living organisms, whose parts, products or models are used to produce goods, materials and products via the modification of living or non-living matter. Biotechnology also involves research and the provision of services. It comprises technologies such as genetic engineering, bioinformatics and bioprocess engineering.

C

Cell factory systems
The use of living cells or parts of cells to produce selected cellular substances.

Cross-disciplinary technology
Technology whose application is not limited to a certain research area, but which can be used across a number of research areas and fields of application, linking these together.

E

Ecosystem services
An ecosystem service is a service provided by nature that can be used by human beings, but one that does not normally have a direct monetary value. Examples of ecosystem services are the pollination of fruit flowers by insects, the provision of fresh and drinking water by precipitation and natural filtration, the availability of fish as food in aquatic ecosystems, and the provision of fresh air.

G

Gene
A unit carrying genetic information composed of specific nucleotide sequences of DNA.

Gene bank
A systematic collection of DNA molecules.

Genome
The entire genetic material of an organism.

Genome research
Research into genomes.

Global benefits
Benefits that can be enjoyed by everybody and which are characterised by the fact that nobody can or should be excluded from using them, and that they can be consumed by various individuals simultaneously.

Green gene technology
The use of genetic engineering techniques in which selected individual genes or gene sequences, even genes foreign to the species, are transferred to the genome of plants.

Green Growth strategy
The Green Growth strategy is based on the assumption that 'green' and 'growth' can go hand in hand. The strategy was brought into being by the OECD Ministerial Council in June 2009, to help economic recovery on the basis of sustainable and social development.

H

High throughput phenotyping
Phenotyping with a high rate of throughput.

I

Industrial biotechnology
The industrial and commercial use of enzymes and microorganisms to produce materials and products.

Innovation
The development and economic introduction onto the market of new products, methods, techniques or processes.

Innovation alliances
Strategic partnerships between science and business, geared towards a certain field of application or future market.

K

Knowledge-based
Knowledge-based means based on the most varied areas of knowledge and technologies, especially bio-, nano-, information and communications technology, and on the findings of modern engineering sciences and the so-called cognitive sciences.

L

Land / Länder
The political regions or states within the Federal Republic of Germany, each of which has its own government, parliament and ministries.

Lead Market Initiative
This initiative, launched by the European Commission in 2006, aims to facilitate the initial introduction of technological innovations onto various markets. The basic strategy is to eliminate or overcome obstacles, introduce new ideas to assist market entry, set norms and standards for R&D and public procurement. The production of bio-based goods is one of the five Lead Markets that have already been identified.

M

Marker assisted selection
A technique using molecular markers at the DNA level to help select a particular characteristic of a plant or animal, or of their offspring.

Metabolome
The complete set of metabolites of a cell or a tissue.

Metabolomics
Research into metabolomes.

Metagenome
The complete genomic information relating to microorganisms in a particular location (e. g. the soil, or seawater).

O

Omics technologies
Technologies that analyse the entire genome (genomics), protein pattern (proteomics) or complete metabolic complex (metabolomics).

P

Phenotyping
The quantitative analysis of key functions and structures of organisms and biological systems, and of the underlying physiological, molecular and genetic mechanisms.

Phytase
An enzyme which breaks down phytic acid by means of hydrolysis, thereby releasing previously bound phosphorus.

Plant phenotyping
The quantitative analysis of key functions and structures of plant systems in their interaction with the dynamically changing environment, and of the underlying physiological, molecular and genetic mechanisms.

Platform chemicals
Chemicals from which a line of important industrial chemicals can be derived.

Proteome
The entirety of all proteins present in a cell or a tissue, relative to the cellular environment.

Proteomics
Research into proteomes.

4. Future tasks of the Bio-economy Council

The bio-economy is a new sector of the economy which not only encompasses many established branches of industry, but also integrates those which have only become established over the past few years into the bio-based sector. Elements linking the old and new branches include the use of biological systems, the scientific disciplines associated with these fields, and cross-disciplinary technologies. Because of the frequently cited global challenges we currently face, however, new ideas are urgently needed for even closer cooperation in common areas. In this report the Bio-economy Council has outlined three research areas and offered suggestions relating to structural aspects.

All recommendations were initially based on the expert input of researchers in the various fields. The recommendations have not yet been validated by modelling, nor has the potential impact of the research measures on the business sector been investigated. This is accepted as standard practice in other areas of research management (as well as in individual segments of the bio-economy – cf. Chapter 2.1). This sort of modelling is used by the CGIAR (Consultative Group on International Agricultural Research), amongst other organisations. It already allows us to simulate potential global developments and evaluate their consequences and risks for consumers and business.

Transparent models must similarly be developed for the German bio-economy in order to construct relevant scenarios which can then be assessed independently. This will make it possible to steer the bio-economy in the direction of areas with future potential. The facts, figures and data needed for this are not yet currently available. For this reason, the first step must be to devise a scheme identifying the core areas that the bio-economy encompasses, and the parts of neighbouring areas that also belong to the bio-economy.

A second step must be to create the appropriate criteria for evaluation. This is only possible with an adequate database. Even today, most of the data and statistics that are available in the research and business environments tend to be non-homogeneous and fragmented – and thus largely unusable. Only by using comparable values can bio-economic output in a system be measured, research goals prioritised, and research projects defined. With this in view, the Bio-economy Council will, in its next report, prioritise the research topics cited in this report and define appropriate time frames for carrying out research. A uniform methodological language may also be necessary to create indicators for fine-tuning activity that has already commenced.

If the Federal Government takes up the suggestion in Recommendation 4 and turns it into a national programme for bio-economic research, it is the Council's view that an independent scientific body would be needed to monitor such a programme. This would be essential for independent validation using the instruments cited above. Only with such testing would the system remain verifiable and sufficiently dynamic to recognise international developments at an early stage, and identify the consequences for German bio-based research and business – whether this be achieved by shifting the focus of research, or investment in concrete, bio-based sectors of the economy.

Because of the broad scope represented by the field of 'bio-economy' and the timeframe available, it has not been possible to

R

Renewable raw materials
Products from agriculture and forestry that are not used for food. They can be used as materials or for energy generation.

Resource efficiency
Relationship (ratio) of products (output) to the resources used to manufacture these, e.g. raw materials or energy (input).

Resources
Solid, liquid and gaseous substances exploited economically by human beings.

S

Secondary raw material
Recycled material from used products and production waste for use as a raw material, with the exception of waste arising from the production of raw materials.

Systems biology
A biological science which seeks to understand the complex and dynamic biological processes occurring in cells and organisms in their entirety.

T

Technology platform
The term for a technology that makes possible the production of products or processes which support current or future developments.

Torrefaction
The pyrolytic degradation of biomass in anaerobic conditions and at relatively low temperatures (250 to 300° C).

V

Value chain
The path taken by a raw material until it reaches its end consumer (sourcing, production, processing and selling), taking into account the increase in value at each stage. Several stages of value creation make up the value chain.

Value creation
In terms of political economy, value creation includes all income factors (wages, salaries, interest, rent, leases, sales profits) generated in a particular period, and corresponds to the national income (gross domestic product). In the business economy, value creation refers to the production value per period, minus the input from other businesses in this period.

Z

Zoonoses
Diseases and infections which can be transferred naturally between humans and other vertebrates.

List of abbreviations

BMBF	Federal Ministry of Education and Research
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMWi	Federal Ministry of Economics and Technology
BMZ	Federal Ministry for Economic Cooperation and Development
BÖR	Bio-economy Council
c.	circa
cf.	compare
CCU	Carbon Capture Utilisation
CeBiTec	Centre for Biotechnology
CGIAR	Consultative Group on International Agricultural Research
CO_2	carbon dioxide
DIB	German Industrial Association of Biotechnology
DNA	deoxyribonucleic acid
ed.	editor
ECN	Energy Research Centre of the Netherlands
EFSA	European Food Safety Authority
EMBRAPA	Brazilian Agricultural Research Corporation
EPC	European Patent Convention
EU	European Union
EWG	Energy Watch Group
FhG	Fraunhofer Society
FUGATO	Functional Genome Analysis in the Animal Organism
GABI	Genome Analysis in the Biological System of Plants
GDP	gross domestic product
GenoMik	Genome Research into Microorganisms
GMO	genetically modified organism
HGF	Hermann von Helmholtz Association of German Research Centres
ICAR	Indian Council of Agricultural Research
ISI	Fraunhofer Institute for Systems and Innovation Research
IWBio	Industrial Association of White Biotechnology
IWBT	industrial white biotechnology
MPG	Max Planck Society
NaWaRo	renewable raw materials
NGFN	National Genome Research Network
NIFA	National Institute of Food and Agriculture
OECD	Organisation for Economic Co-operation and Development
PPP	purchasing power parity
R&D	research and development
REDD	Reducing Emissions from Deforestation and Degradation
UFOP	Union for the Promotion of Oil and Protein Crops
USDA	United States Department of Agriculture
VCI	Chemical Industry Association
WGBU	Scientific Advisory Board to the Federal Government on Environmental Changes
WGL	Leibniz Association
WWI	Worldwatch Institute

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