Fraunhofer

Foresight Process – On behalf of the German Federal Ministry of Education and Research (BMBF)

Report

New future fields

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Karlsruhe/ Stuttgart 2009

Imprint

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Karlsruhe, August 2009

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1.1 Initial situation

Which areas of research will be important in the long term? Which topics can be thoroughly dealt with in Germany because they fit in with German science and business skills? Which research and technology areas have enough synergies and influential impact to enable them to provide an impetus in other areas? Which future fields cover a range of disciplines, promise outstanding, pioneering science and technology knowledge gains, and will therefore contribute significantly to people's quality of life and to sustainable resources use? These were the questions posed at the outset of the BMBF's Foresight Process, which started in the autumn of 2007.

1.2 Overview of results

Future topics in established fields

The starting point for this foresight process was the 17 thematic fields of the German High-tech Strategy and ongoing foresight activities in the departments, i.e. the BMBF's portfolio. By mid-2009, a set of advanced methods of future research had been developed to identify new research and technology focuses in 14 selected **established future fields**. This resulted in the so-called **future topics** in the areas of health research, mobility, energy, environment and sustainable development, industrial production systems, information and communications technology, life sciences and biotechnology, nanotechnology, materials, substances and their manufacturing processes, neurosciences and learning research, optical technologies, services science, systems and complexity research, and water infrastructures.

The future topics were analysed in several steps, discussed with national and international experts, then evaluated and sorted. In the course of this evaluation, the extent to which the research prospects and structure of the future topics are stable or still in flux was asked about. The topics were then selected, after being measured against the questions formulated at the outset.

The results on the future topics in the established future fields are documented in the report »Foresight-Prozess – Im Auftrag des BMBF – Etablierte Zukunftsfelder und ihre Zukunftsthemen (Foresight Process – On behalf of the German Federal Ministry of Education and Research – Established future fields and their future topics)« and can be read at http://www.isi.fraunhofer.de/bmbf-foresight.php and http://www.iao.fraunhofer.de/foresight.

With this report, the BMBF Foresight Process is providing differentiated, confirming or modifying indications on the programmatic in Germany's established research and technology fields.

New future fields

Investigations into the established future fields were also a necessary precondition in pursuing the central objectives of the BMBF Foresight Process. The identification of cross-sectoral aspects and research in the established fields provided initial starting points for interdisciplinary activities and for indicating areas outside current specialist logic and programme structures that are at the interfaces between individual disciplines over the further course of the process. Structures in fields that were identified in many specialist programmes as important for R&D, but whose connecting structures were often not discernible to experts, were derived from the overall survey of the various methods such as bibliometrics, monitoring, inventor scouting and the online survey. These areas, covering various research and innovation fields, were repeatedly separately evaluated and validated and continuously modified. Over the course of the process, the following **new future fields** developed out of this overall survey of the established fields and their future topics:

a. Human-technology cooperation

b. Deciphering Ageing

c. Sustainable living spaces

d. ProductionConsumption2.0

e. Trans-disciplinary models and multi-scale simulation

f. Time research

g. Sustainable energy solutions

Here the BMBF Foresight Process provides starting points for potential new research fields.

Actors in the areas of the new future fields

If policy supporting the future development of potential new future fields is to be consistent, familiarity with the respective innovation-policy environment will be required, so investigations into the new future fields were supplemented by a further aspect. A separate analysis of the actors in each future field shows how the actors' landscape currently »looks«. This involved first measuring the extent to which research prospects and structures were already established, and finding out whether sustainable starting points for »strategic partnerships« already existed and who the relevant actors were and could be. Information on these issues offered a possible starting point for a deeper examination of new future fields in Germany's research and innovation system.

1.3 The methodological approach

The BMBF Foresight Process looked into the future of research and technology with an outlook of more than 10 years so as to draw potential conclusions for current research policy activities based on the information obtained.

The BMBF Foresight Process pursued the following objectives[1]:

1. Identifying new research and technology focuses,

2. Identifying (and deriving) areas of activity covering a range of research and innovation fields,

3. Analysing potential fields of technology and innovation in which strategic partnerships[2] might be possible,

4. Deducing priority areas of research and development activity.

The **long-term** future perspective taken in the Process also took into account those specific foresight activities already begun by the BMBF and in the public and private sectors.

One particular focus of this investigation was identifying interdisciplinary research and technology topics. The concluding look »back from the future into the present« is designed to determine which research policy course must now

1 The symbols corresponding with the lines on the lower right hand side of the page indicate which of the objectives of the respective sub-processes is being primarily addressed. The coloured lines on the upper right hand side of the page are designed solely to improve the readability of texts on the future thematic areas and make them easier to find. They have no significance in terms of content.

2 Here: leverage for creating appropriate (funding) structures.

be set so that German research and innovation can occupy a leading position in international competition in the medium and long term.

The starting point of investigations in the BMBF Foresight Process was an analysis of the dynamics of change in research and technology (»Technology Push« perspective). It was also specifically designed to be more than just a survey. Current expectations were critically checked for their sustainability and attention focused on signals indicating factors beyond established structures. Only those future topics that could cover a presumed need were considered for further development. Figure1 provides an overview of the course of these investigations.

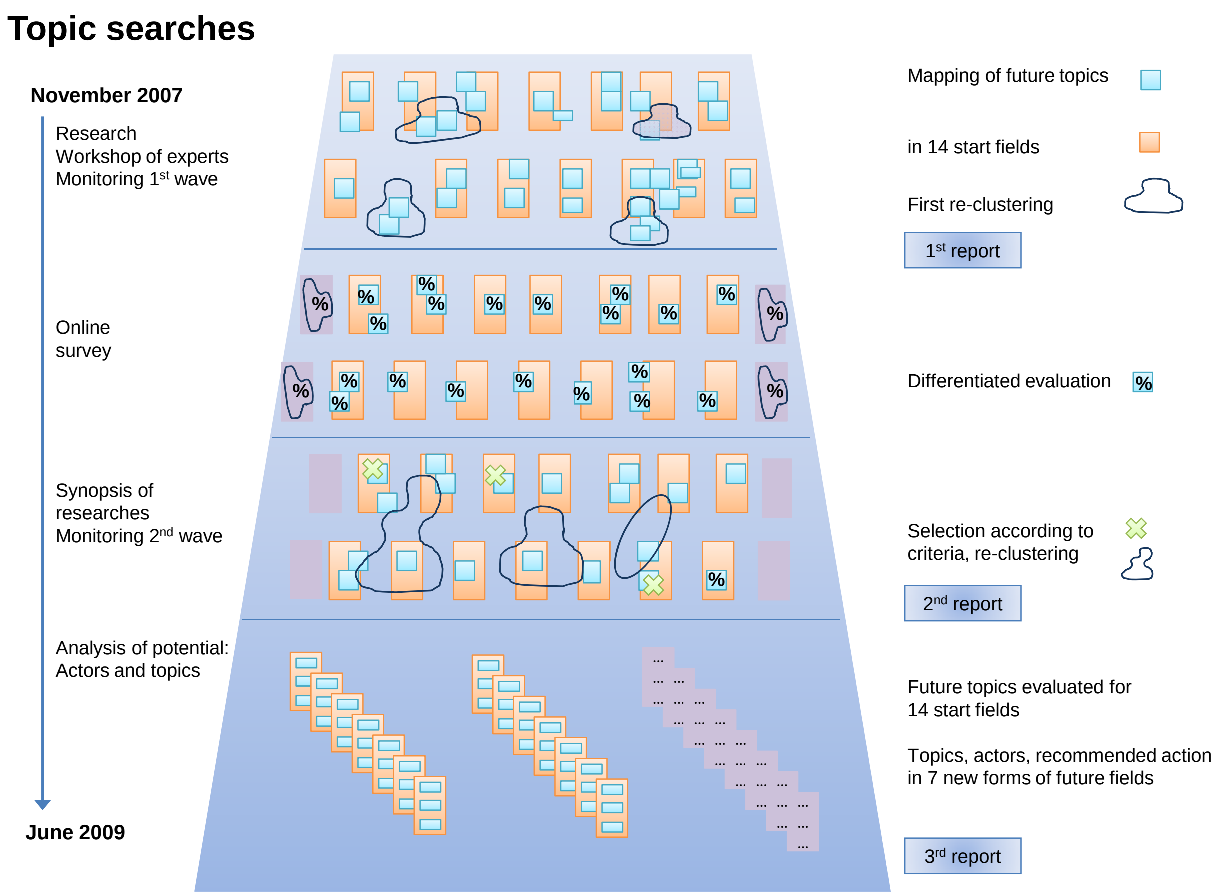


Figure1: Topic selection procedure

Structures established in the German innovation system were used to identify research and technology focuses (Objective 1). Specially nominated topic coordinators made detailed maps of the developments expected over the next 10 to 20 years in 14 of the research fields drawn from the German High-tech Strategy. A combination of very different methodical elements was used to do this:

- Structured, focused interaction with experts (workshops and interviews)
- An analysis of the innovation system, including a review of current strategic processes in the BMBF
- Environmental scanning (literature research, conference analysis, scanning of relevant results)
- Secondary analysis of current international foresight studies on research and technology
- Analysis of the dynamic in scientific publications (bibliometrics)
- A broad online survey of experts to provide a differentiated evaluation of relevance and the need for action (2,659 valid responses)
- Two-stage personal survey of top international experts (Monitoring Panel)
- Inventor-scouting (targeted surveying of young researchers)

The results of all the methods were continuously adjusted. These scanning activities and research resulted in a structured and evaluated set of wide-ranging future fields and future topics in research and technology with long-term relevance (Goal 1).

The BMBF and consortium jointly defined a stringent set of criteria for selecting the future topics, defining a **future topic** as one that would still be on the research and technology agenda ten years hence and largely fulfils the following **criteria**:

- promises outstanding, pioneering knowledge gains in science and technology.
- provides an impetus for other research areas (synergies, influential impact, transfers of findings)
- supports Germany's economic development and contributes to the country's international competitiveness
- contributes considerably to improving people's quality of life
- ties in with Germany's science and business skills.
- contributes sustainably to conserving resources and to climate and environmental protection.

A future field is a cross-sectoral thematic field and is only defined as sustainable if it completely meets the BMBF's criteria. In this context, there are established future fields, and so-called **»new future fields«**: Findings from the analysis were subjected to a continuous synopsis in order to identify areas for interdisciplinary activities (Objective 2). This means that there was a regular review of whether the dynamics of research and technology on the one hand and socio-economic conditions on the other hand, might suggest consolidating the identified future topics to form entirely new future fields. Two criteria were decisive in creating a »new future field«:

Research dynamics: The new field bundles a range of very dynamic research aspects with a similar outlook in a way that promises to enable better exploitation of their innovation potential.

Needs dynamic: The new field promises to address central future challenges in a new quality.

The results of the cross-sectoral analysis were repeatedly scrutinised using the methods describe above and re-evaluated until the developed structure was established at the end of the process. By the end of the Foresight Process, this research had produced the following results (cf. Figure 2):

- an evaluated set of future topics in the 14 established future fields. These 14 fields were partly reformulated so that they too correspond with the specified criteria and »future fields« defined in the BMBF Foresight Process.
- identification of research questions and actors for seven new future fields.

2 New future fields – introduction

The following chapters describe seven **new future fields**, which were developed in addition to the 14 future fields in the BMBF Foresight Process. These future fields are interdisciplinary future fields in accordance with Objective 2 of the BMBF Foresight Process and arise out of the other future fields and their associated future topics. These new future fields demonstrate a new dynamic that will be relevant for research in the long term. For this reason, only these future fields were dealt with in detail in the analysis of actors to identify potential sustainable actors' groups and recommendations (Objectives 3 and 4).

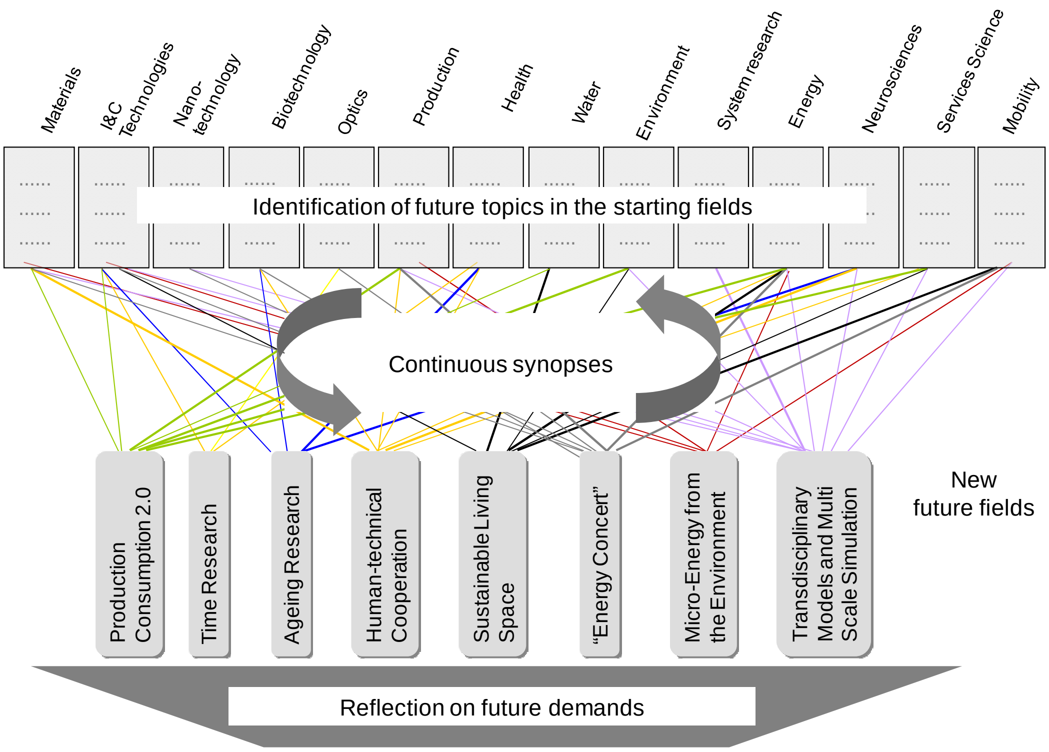


Figure 2: All the future fields of the BMBF Foresight Process[3]

Some of the future fields address very »big« topics; others are more »cross-sectoral technologies« that could have an influential impact. The future fields are ordered accordingly in the report.

3 The two future fields involving energy developed in different ways, so they are presented separately in the graphic.

The new future fields were clustered together in a continuous survey after being identified in a »bird's eye view« of all the future topics. The fields in their entirety fulfil the criteria imposed on the selection of future fields and future topics. In Figure 3, crosses are placed against two of the criteria that especially respond to the new future fields. The field of Ageing Deciphering, for example, will be particularly important because of the scientific knowledge gained and improvements to people's quality of life resulting from this area, which is however not to say that it won't also make a significant contribution to future economic development.

New forms of future topics respond to criteria

Future fields	Knowledge gains	Providing impetus	Economy	Quality of life	Environment
Ageing Deciphering	X			X	
Energy Concert			X		X
Human-Technology Cooperation			X	X	
Micro-Energy		X	X		
ProductionConsumption2.0			X		X
Transdisciplinary Models and Multi-Scale Simulation	X	X			
Time Research		X		X	
Sustainable Living Spaces				X	X

Figure 3: New future fields respond to criteria

These new future fields are not of course the only result of the BMBF Foresight Process. There are also many future topics in the future fields that initiated the process.

3 Human-Technology Cooperation

Preliminary remarks on the technical term used

Technical change is viewed here against a background of social-scientific research into technological development as a dimension of social change. »Technology and society do not develop in isolation from each other, but are connected with each other diverse ways. The relationship of technology and society is characterised not by unilateral influence, but by »co-evolution« (Grundwald 2003, p. 10). The technical artefacts that emerge in this process then structure individual perception and ability to act. The individual and relationships between individuals and society thus change over the course of the adoption of technology. The »dense« technologies dealt with here demonstrate a specific characteristic of this interaction, in that they seem to question very fundamental, established assumptions about people's interaction with technology. Our analysis shows that a reflective technological development is required in order to shape this process in a desirable way. This would include an intense social discourse about desirable developmental paths and a new type of research that integrates knowledge from the humanities and social sciences on the one hand and from the technical sciences on the other to make desired developments possible and provide a basis for the necessary discourse. What we regard as the central aspects of such research is outlined below. **Nowhere here however, are technical artefacts given the status of subjects acting in accordance with their own consciousness.** It is merely stated that artefacts are increasingly taking on functions that were previously only available to people and therefore **seem** to be becoming increasingly human. New conceptual systems must be developed in discourse and research to enable us to adequately characterise the boundaries, differences and new types of interaction between people and technology. Currently established ways of speaking cannot appropriately describe these new forms. The terms »human–technology team« and »Human-Technologyl Cooperation« used here should be regarded as taking the place of terms yet to be developed.

Innovations that make a new quality of smooth technical support for people possible require not only technical developments, but also solid knowledge of human thinking, feeling, communication and behaviour. This new future field provides the necessary integrated research perspectives to deliver this knowledge, laying the foundations for developing **Human-Technology Cooperation (HTC) on a human scale** and for sustainable breakthroughs in central fields of innovation, such as ambient intelligence, robotics, context-sensitive services and neuroprosthetics.

Concrete development goals include:

- Modelling human behaviour and codes of behaviour to programme adaptive assistive environments
- Concepts for socially embedding personalised interaction with the »Internet of Things«.

3.1 The future field

Current technologies are demonstrating a new proximity to people, their bodies, brains and daily lives. The following developments have in particular created a new innovation dynamic:

- the availability of large amounts of information through digitalising and fast Internet connections,
- the ability of machines to interpret information using semantic technologies[4],
- profound knowledge of the human brain and the development of neuroprosthetics (see also the report on the established future fields),
- real-time processing of large masses of information in a range of technological systems due to considerable increases in computing power and the miniaturisation of switching networks,
- a broader range of potential applications, thanks to the greater integration of different components in the smallest space due to micro-systems technology,
- wireless networking and ubiquitous embedding of systems[5],
- greatly improved pattern recognition algorithms,
- broader access to satellite-supported positioning.

The potential for new innovations results especially from the interaction of these breakthroughs in research and technology. Areas typically currently showing a resulting great dynamism include »intelligent objects« (see acatech

4 Bibliometrics shows here a rapid increase.
5 Development of pervasive computing (rapid increase in bibliometrics).

2009a and b), prosthetics[6], telepresence/teleaction technologies[7] and cognitive assistance and cooperation systems[8].

Complex technical systems have now permeated almost every area of life. The expansion of the »technosphere« and humanity's »self-technicalisation« represent new challenges for science, politics and society. Humanity is increasingly surrounding itself with a growing number of multifunctional, miniaturised, networked and context-sensitive devices. The functional interaction of these technical systems, which are fragmented but organised to work in close communication, is forming it into a technical »shell«*, »which flows around people, rather than surrounding them like something rigid «* (Acatech2009a, p. 24). This means that a comprehensive, integrated knowledge of humanity and technology and their relations is vital. Areas of knowledge about people and technology must be integrated with each other in their entire individual disciplinary breadth and diversity if the great dynamism of development is to be successfully brought into a desirable framework. The complexity, extent of penetration, potency, and scope of effectiveness of the current and especially of the emerging technical continuum cannot be adequately comprehended by any of the single disciplines in the current research landscape, much less actively, reasonably, sustainably and desirably shaped by them in the long-term. Founding a discourse on socially-desirable forms of this »technosphere« is, in addition to maintaining freedom to act and to design, one of the main tasks of the proposed research field.

Against this background, »Human-Technology cooperation« research prospects are now leaving established disciplinary boundaries behind and **looking at new combinations of humanity and technology in all their complexity**, investigating the technical and social aspects of human-technical cooperation in their overall context from the outset. Changes to social relationships and humanity's image of itself are regarded not as consequences of technical innovation alone but are, like legal and ethical aspects, dimensions of more complex change. Social change and changing values are as much cause as effect in this process. **The interplay of human and technical change becomes the focus of observation**. This means that not only various research areas and scientific actors, but also various forms of knowledge and knowledge space will have to

6 Here too, there has been a rapid increase in the bibliometrics.

7 Telepresence means that a human operator with his subjective perceptions is present in another, remote or inaccessible environment through technical means. Teleaction means that the human operator is not only passively present, but can also actively intervene at the remote site. These impressions are realistic when the human operator can no longer easily determine whether his sensory impressions and feedback from his activities are occurring in direct interaction with reality or through technical means. See SFB 453, Wirklichkeitsnahe Telepräsenz und Teleaktion (Realistic telepresence and teleaction), http://www.sfb453.de/. Emphasised in the interview by Prof. Kirchner (DFKI, Robotics)

8 cf. in this area alone, three current special research areas SFB 453, 550 and 588.

be further developed, because knowledge of people and their relationship to technology is often only implicit[9]. This would also enable human-machine systems to be developed in which technology and humanity would »seamlessly « complement each other in a way that would allow people to extend their scope for action according to need.

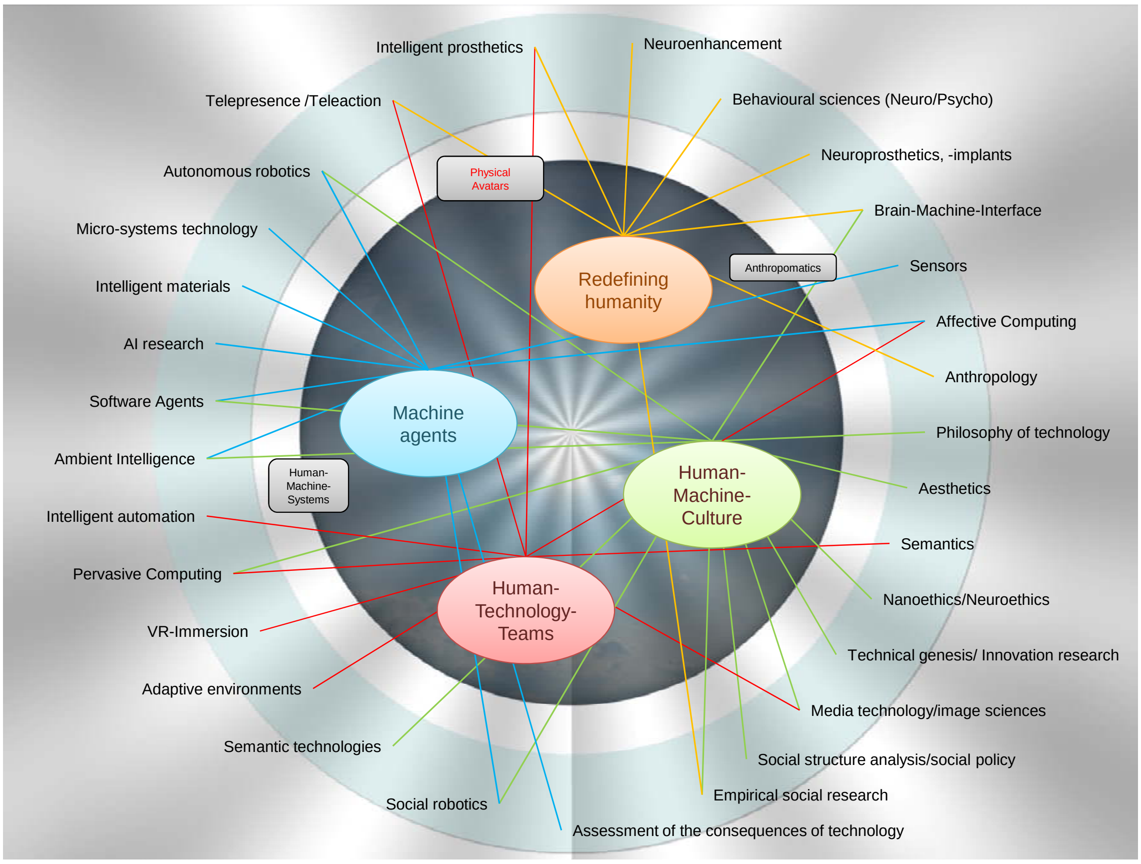


Figure 4: Future participating research areas

Thanks to its strong position in many of the relevant research areas, such as the engineering sciences, the humanities and social sciences, Germany is in an excellent position to develop these prospects as a pioneer and open up future leading markets.

Figure 4 shows a schematic representation of the research field. The outer ring in the diagram shows the current directions identified in research that should

9 Such as the knowledge of care and nursing staff as a basis for »Ambient Assisted Living« (see Initiative »Ambient Assisted Living for the Aging Population« (AAL), *BMBF* High-tech Strategy, www.bmbf.de/pub/bmbf_hts_lang.pdf, p. 90).

feed into the research field of HTC. These include technical, scientific and social-scientific and cultural science aspects. The inner circle shows the new future field with four central research areas. Connections between them show which research institutions will have to consolidate in order to achieve innovative further developments and progressive implementation of the new field. Some of the relevant technological lines of development will be outlined below (»Initial situation in the future field now«). The future field with its central research areas (inner circle) will then be described (»The long term outlook for the future field«).

3.2 The initial situation in the future field now (2009)

A range of current research prospects in different areas are oriented towards innovations involving closer interactions between people and technology. Many of these technologies are especially important for the German innovation landscape, on the one hand because they are connected with the existing strengths of the German innovation system, such as automation technology, information technology and medical technology, and on the other hand because a high level of potential for addressing central future challenges is ascribed to them[10].

Progress in the areas of telepresence and teleaction[11] is fundamentally changing people's relationship to space and distance, expanding their direct sphere of influence beyond the range of their reach and vision. This development is also contributing to the rapid networking of the world into a »global village«. ICT technologies have transformed the worlds of work and research, making it possible to establish intercontinental cooperation and global »scientific communities« via telephone and video conferencing and web-based work platforms.[12] Developments in the area of teleaction and the remote operation of machines around the world and beyond – whether it's unmanned aircraft, mine clearance devices, scientific deep-sea robots or Mars explorers – are also resulting in new possibilities and risks, to a new image of ourselves and our world. Teleaction and telepresence are developing great future potential beyond the area of ICT through combinations with progress in the areas of virtual immersion, robotics and mechatronics, and in psychology and medical technology. Teleoperation[13]

10 »Ambient Assisted Living« for managing the challenges of demographic change, for example.

11 See SFB 453, Wirklichkeitsnahe Telepräsenz und Teleaktion, http://www.sfb453.de/.

12 One example of research by a global »scientific community« is the large particle acceleration project of the European Organisation for Nuclear Research (CERN) near Geneva.

13 »Using a remote-controlled robot, doctors in New York have removed the gall bladder of a 68 year-old woman in Strasbourg. The world's first transatlantic operation on a person took about an hour and was carried out without complications.« (heise-online, ‚Erste Tele-Operation über den Atlantik' (19.09.2001 19:07); http://www.heise.de/newsticker/Erste-Tele-Operation-ueber-den-Atlantik-/meldung/21182, 09.07.09, 12:38).
See also the DFG Graduiertenkolleg »Intelligente Chirurgie« (http://www.intelligente-chirurgie.de).

technologies, which surgeons can use to operate on patients thousands of kilometres away, are now in use. »Remote manufacturing« concepts are expanding the possibilities of local infrastructure, because it no longer matters how far apart planning, control and production sites are. Most current developments in the area of telepresence are focused on solving these technical challenges. To achieve the desired Human-Technology Cooperation on a human scale, the integration of knowledge of the »human« aspects of this form of human-technological team, such as an understanding of the processes of cognition and perception and suitable organisational frameworks, is now essential.

Interfaces between people and technology play a special role in research into Human-Technology Cooperation. A Brain-Computer Interface (BCI) is currently being used to free quadriplegics from their »locked-in« situation through a »mental typewriter«[14], which they can use to communicate with their environment via »typed text«. To do this, brain waves are measured using electroencephalography (EEG) and the »thoughts« behind them are interpreted as control signals for various functions. This interface is non-invasive and so has potential for non-therapeutic applications, as long as it can be made suitable for daily use. To achieve this end, the equipment, currently a sort of »bathing cap« filled with gel, must become more comfortable and easier to use, through integration into a helmet, for example. A patent for the necessary contactless electrodes has already been applied for. Electroencephalographic monitoring of the attention spans and error rates of controllers and monitoring staff in their everyday work also promises more safety, fewer errors and more brain-compatible working conditions. Breakthroughs are emerging in terms of the brain ergonomics of working, living, learning and play environments. These however also pose essential questions of identity and the role of people in a broader context, answers to which are beginning to be approached in some humanities and social sciences. The possibility of controlling such interfaces remotely also raises legal and ethical issues. Continuing this research and cooperation between the humanities and social sciences and the areas of interface research and medicine will be indispensable in these questions.

The field of neuroprosthetics initially emerged out of therapeutic pressure. Deep brain stimulation (DBS) for example, uses weak electrical impulses to help suppress the tremors in Parkinson's patients, which can enormously improve their quality of life but can at the same time cause significant side-effects, including personality changes (Clausen 2009). The complex spectrum of the effects of direct brain stimulation can also include negative effects that are not

14 See also the Berlin Brain Computer Interface Project (BBCI) of Prof. Curio at Berlin's Charité hospital (funded by the BMBF), at www.bbci.de

foreseeable and not completely controllable and may therefore not be ethically justifiable. The mere possibility of remotely controlling our »free will« makes it essential to develop appropriate ethical and legal frameworks at an early stage. Being able to switch emotions on and off would touch the nerve of humanity's image of itself, especially because EEG and DBS are integrated as neuroprosthetics[15] into the body and cannot simply be taken off like glasses if they are annoying. More than any other current technology, neuroprosthetics will fundamentally challenge current concepts of human identity and sovereignty.

Space for expectations, expectations of expectations[16], background analyses and scope for interpretation must be made in technologies such as autonomous robotics[17], intelligent software agents[18] and intelligent environment systems so that they can function in the context of activity with people. To this end, algorithms that they can use to interpret their environment, including human behaviour, are programmed into these artefacts. [19] Today's environmental models are at best rudimentary however, and fail to comprehend complex human beings, causing dissonances in the interaction of people and technology. **Technology »knows« too little about people**. The more people operate a specific technology and the more central the functions that are carried out based on these interpretations are, the greater the problem becomes. Interdisciplinary research on suitable interaction models is just as necessary as a social dialogue on desirable levels of technological proximity.

A central role is played by the development of semantic technologies as an interface between people and technical knowledge spaces and the semantic use of human communication, especially nonverbal communication and human behaviour as an instrument in human-technology teams. The »semantic web« is currently still limited to a few restricted areas and is far from being able to make human forms of expression and knowledge comprehensible to machines. The implementation of programmes that interpret meaning and of technical context-sensitive exegesis and information evaluation will increasingly lead to machines **being perceived** less as mere instruments and more as independently operating entities. »Semantics« enable cooperation between classic and virtual activity and knowledge spaces (Hubig 2008), shifting the locus of infor-

15 e. g. Fraunhofer-Institut für Biomedizinische Technik IBMT (Fraunhofer Institute for Biomedical Engineering IBMT), http://www.ibmt.fraunhofer.de

16 While expectations anticipate certain actions as possible or probable in order to orient the observer's reaction towards them, the expectation of expectations provokes this response this in respect of anticipated expectations (and not activities). »pre-emptory obedience« would be an extreme example of the expectation of expectations.

17 See also the Robotics Innovation Center (RIC) of the Deutsches Forschungszentrum für Künstliche Intelligenz (German Research Center for Artificial Intelligence) in Bremen (http://robotik.dfki-bremen.de).

18 See also the 'Agents and Simulated Reality' research department at the Deutsches Forschungszentrum für künstliche Intelligenz (German Research Center for Artificial Intelligence) in Saarbrucken (http://www.dfki.de/ga/index_de.html).

19 Driver assistance systems for example, interpret driver behaviour and intervene to control vehicles where necessary.

mation away from the person and making evaluation skills and access rights more important than the possession of information. The human being is currently the only functioning semantic system. If this situation apparently changes, and machines succeed in emulating intelligent behaviour in a way that is perceived as real, this will have consequences for humanity's image of itself. The use of learning programmes can offer advantages in learning, mediation and consultancy. If however, technical tutors could carry out comprehensive interpretation with the help of semantic technologies, and be presented and perceived as »teachers« with advanced knowledge and skills, and if machines can learn from human »colleagues«[20] by simulating and »understanding« work processes, then the human being and the machine are, in a learning and cooperative context at least, **apparently** on the same level. Should such »human-technology teams« become established, in which the fixed distribution of tasks between people and technology becomes indistinct, new learning and work structures would be necessary. Discourse on and research into possible formations and their desirability are still however at a rudimentary stage.

These approaches to this diverse research field with great future potential reveal a difficult situation of complex interactions and cover implications that cannot be described with the previously existing set of terms and research concepts. No single discipline, in their highly-specialised and productive but limited domains, will be able to master their formulation. A new quality of integrated social scientific, humanities and technical scientific research will be necessary in order to exploit these technologies on a human scale.

Progress in this direction is currently being made in many disciplinary directions, ranging from neuro-ethics, emerging from philosophy, up to »human centred design« in engineering. Research into Human-Technology Cooperation is however currently still largely isolated. Some research organisations are unable to completely develop the full scope of their activities within their own fields. At all levels of the innovation system, from universities through to industrial development, there is a lack of joint research platforms among different forms of knowledge and disciplines. At the same time, interdisciplinary Human-Technology Cooperation research issues across a range of technological fields are still barely developed. This field is like a mosaic with many facets, but without any clearly-recognisable shared outlook.

20 Bionic manipulators creating new automation technology applications, such as the 'BioRob' bionic robot arm (funded by the BMBF), (http://www.biorob.de).

3.3 The long-term outlook for this future field

New research prospects in the field of Human-Technology Cooperation begin precisely where previous single-disciplinary research seems likely to fail because of the new complexity of this research.

The future field is divided into four central research areas, although a strict separation between these areas is neither possible nor desirable. This division rather serves the purpose of explaining the complex scope of this field.

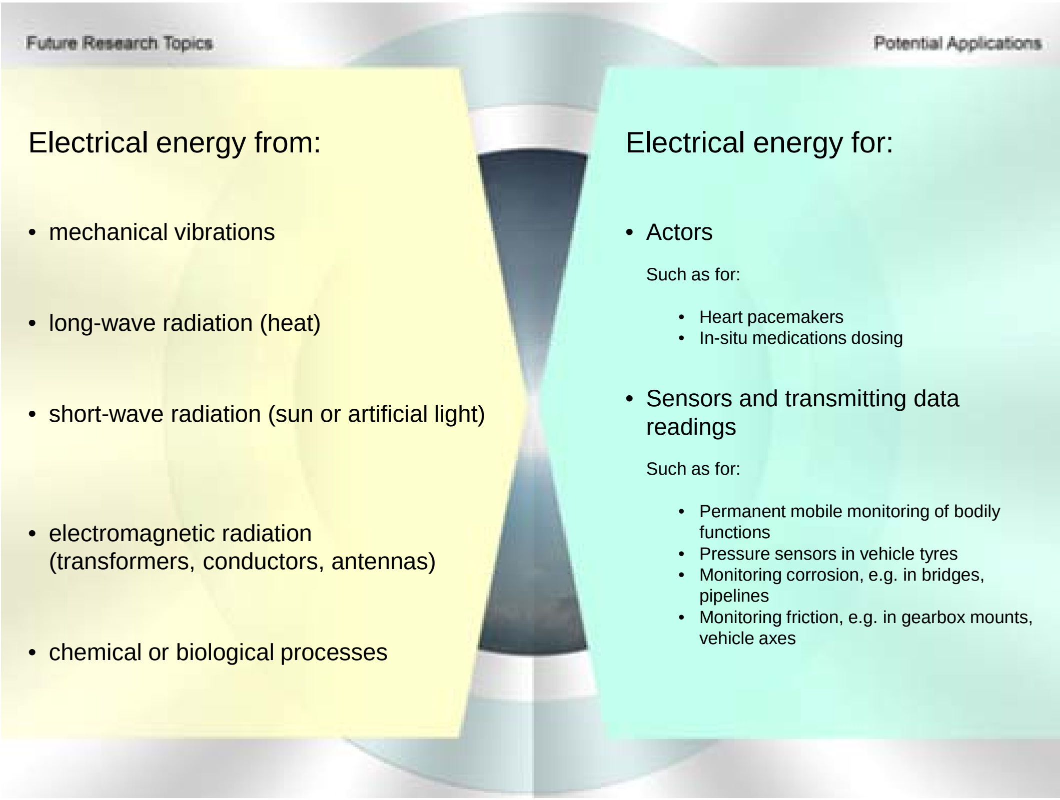


Figure5: Future research topics and potential applications in the future field of »Human-Technology Cooperation«

Redefining humanity

In our increasingly dense technical »shell«, and given machines that seem to demonstrate human qualities, the definition of humanity in the face of the technical environment it has created must be reflected on in new ways. Only thus will these »dense« technologies be able to be used to expand human potential and avoid exposing people to unwanted technological »coercion« of any kind in the course of future developments. New technologies result in complex effects and transformation processes in humanity's image of itself and the world. The concept of **identity** becomes problematic when deep brain stimulation and »cognitive enhancement« medications infiltrate the intimacy of thoughts and emotions. Potential fields of activity in the area of HTC could therefore include researching identity-sensitive neuroprosthetics, therapeutic assistance and linking a desirable improvement of quality of life with protection of the overall concept of the human and the individual person. Knowledge of terms and topics[21] such as »identity«, »the person« or »humanity« already developed in philosophy or psychology must be used by technology developers and further developed in a constant process of exchange.

Other potential applications could include an anthropocentric cooperation design for Human-Technology Teams, in which research is carried out not into how the person as an operator should act, so how the person should behave in conformity with technology, but which human expectations and inherent knowledge should be projected onto technology in the course of its development and what the result is for the shaping and design of technology. These anthropocentric assistance concepts should be people-friendly and focus on human-adaptive aspects of technology. The goal is to provide the basics for designing technical assistance systems whose parameters are adapted to the individual person.

Machine agents

The area of machine agents covers research issues around the evolution of machines (in the broad sense, so in all their forms and functions) from the old »cog and crank« forms up to today's complexity. This means that the role of machines needs to be viewed in new ways. Machine agents include for example robots, software agents, »intelligent« objects[22] and machines and virtual avatars.

Concepts such as **autonomy** and **intelligence**, qualities hitherto ascribed only to people, will increasingly frequently be unquestioningly transferred to machines. At the same time, machine agents are acquiring greater freedom of movement and operational ranges. If interactions between people and tech-

21 A common interdisciplinary understanding of terms used was emphasised in the workshop »Mensch-Technik-Grenzverschiebungen« (Crossing human-technical boundaries), (held in Karlsruhe on 27.05.2009) as fundamental and of top priority for the entire area. The consensus of humanities, social sciences and science representatives present was to use established philosophical traditions, especially the term »human«, so as not to repeat obsolete debates on basic principles and to be able to start from a shared understanding.

22 See acatech (2009a)

nology are increasingly seamlessly shared[23], issues of responsibility and codes of behaviour will also have to be considered. Possible potential applications of research areas around **machine agents** include the development of behavioural models for freely-moving robots[24], a kind of **»robot etiquette«,** and concepts for organising interaction with machine agents, such as issues of responsibility and trust e.g. in dealing with virtual brokers or auctioneers.[25] There is also an urgent need for research into improving machines' ability to perceive, especially their ability to interpret and use the components of complex human communication (language, gestures/facial expressions, context and behaviour).

The example of distributed action clearly shows the need for integrated research between the humanities and social sciences and the technical and natural sciences, which extends beyond mere accompanying research. Only if this is achieved will the technically feasible range of interactions with machine agents be able to be productively exploited.

Human-Technology Teams

One major core area of research into human-technology cooperation is the investigation of the dynamic of human-technology teams. How can people and machines interact better, given the expanded possibilities of current technologies? What forms of interaction are possible and desirable? How can individual developments be modulated to focus on a productive form that will make people's lives easier?

Interaction can be divided into three main forms. On the one hand there are human (remote) controlled machines of all kinds, on the other hand there are systems and environments that adaptively adjust to people, and finally there are »independently operating«, cooperating machines, such as »cobots«[26]. Mixed forms are also possible. The point at which an assistance system is regarded as an adaptive environment or cooperating agent depends on the system's specific range of functions and the abilities granted to it.

Research into **semantic technologies** will play a central role here, because these technologies act as »hinges« between human knowledge spaces and

23 »It is not easy to say who at a specific time and in a specific place is »really« acting and in control: the shift worker or the emergency cooling system, the plane's captain, the air traffic controller or the autopilot, a car's driver, the anti-skid system or the driver fatigue detection system – the activity is »distributed «.« (Acatech 2009a, p. 11)

24 See SFB 588 Humanoid robots – learning and cooperating multi-modal robots (http://www.sfb588.uni-karlsruhe.de/).

25 cf. European Robotics Research Network, http://www.euron.org/

26 So-called 'cobots' (cooperative robots) have been developed by the Fraunhofer Institute for Production Systems and Design Technology (FhG IPK), among others. These 'cobots' are however restricted to the area of work and manufacturing; they have yet to be »released« into daily life.

formal, technically-coded algorithms. The success of efforts to »teach« technological devices an interpretive, context-sensitive understanding of information will depend largely on achieving an understanding of human communication behaviour and of the transmission of linguistic and extra-linguistic meaning and then a merging of these spheres of knowledge with those of the technical disciplines. All cooperation and interaction between people and technology relies on technology learning to correctly interpret human communication.

Robots are already established in production, although factory robots in some areas are carefully shielded by people and vice versa, because without corresponding perceptual sensors they cannot interact with their environment. Here there is space for future **cooperation concepts for machines and people**.

In order to build functioning human-technology teams for daily life, machines' sensors must be sensitised to the proximity of the vulnerable human physique and a model of the behaviour and nature of people must be stored in the machine. The complex tasks of machine »colleagues« will no longer be a priori programmable, but will only be learnt in direct cooperation. Research into technology's ability to learn is also in its infancy. Successful human-technology teams also need an understanding of the reasonable distribution of tasks and appropriate organisational and cooperative structures. What sense of which tasks do »humanoid« robots have? Which tasks is it proper to leave in human hands, which can be delegated to machines, and which structures can optimally support typical human abilities?[27]

A further form of Human-Technology Cooperation with a high level of future potential is that of **physical avatars**. Physical avatars are machines that are controlled remotely via virtual immersion. Some examples of the use of physical avatars have been mentioned above. These mean that HTC research is faced with the task of expanding the possibilities of telepresence and teleaction while maintaining safety and profitability. Further developing successful human-avatar teams to carry out tasks where rescuers could be endangered, for example, will be one central challenge here.

Both the human brain's ability to make combinations and the physiques of machines are of great importance in this context.[28] The sensory density of remote-controlled avatars must be greatly increased. At the moment there are more sensors in a single human fingertip than in all the robots in Europe. Data

27 This issue can be illustrated by taking hospital or nursing care as an example. The imposing and relieving of burdens on staff are in proportion to various other factors, such as a need for closeness to other people and economic efficiency.

28 This is also the assessment of Prof. Kirchner, head of the Robotics Innovation Center (DFKI Bremen). He regards the robots of the 21st century as mainly taking the form of physical avatars.

transmission between the »pilot« and the avatar will also have to cope with a huge and growing flood of data from a higher density of sensors, while at the same time providing greater security. Further research is also needed in the area of interface design. The joystick, screen, mouse and keyboard will no longer be adequate for the complex controlling of physical avatars. Force-feedback joysticks, data suits and further multi-modal virtual immersion interfaces are initial approaches here, while effective voice control is still waiting for breakthroughs in the area of semantics. These aspects highlight the great potential of the games industry, which can run very large »field tests« with new interfaces and whose »test subjects«, who work indefatigably and in constantly increasing numbers, ensure a fruitful empirical basis that should be used by researchers working on interfaces and in psychology and other areas.

A further HTC research topic in this area is **adaptive, assistive environments**. Many technologies in the area of »ambient intelligence« are in development and some are already in use. Here too, knowledge about people must be integrated with knowledge of the respective technology. The central challenge of assistance systems, such as those for walking[29] or those in vehicles and houses, is always the relationship between people and technology. Successful solutions cannot be unilaterally created from one of these two poles. Only a comprehensive understanding of what and how much assistance people need and when - and more especially what they don't need – can result in progress in this area.

The critical point of »ambient intelligence« applications is an interpretive understanding of human behaviour by the »components« involved. Safer and more comfortable vehicles, houses and communications and information paths using adaptive assistance systems rely largely on semantic technologies development. Should the »intelligent« environments identify needs and react before a user says anything (or can say anything) or even consciously think[30], it will need to be able to use concepts beyond language and meaning. HTC research is therefore attempting to create a holistic interaction with other research areas with existing humanities and social sciences knowledge.

29 See for example Honda's »Bodyweight Support Assist« (http://world.honda.com/news/2008/c081107Walking-Assist-Device).
30 Some driver assistance systems for example, monitor the driver's eyelid movements and pulse and warn of fatigue and stress before the driver is aware of it. The challenge for adaptive environments is to »surmise« much more than fatigue. The Institut für Anthropomatik (Institute for Anthropomatics) in Karlsruhe is carrying out research into intention recognition (as well as synchronising the movements of robot-controlled operation instruments, multi-modal, long-range telepresence, recording the movement of people, and miniaturised mobile robots). See also the research project currently funded by the BMBF, ' Der Fahrer als Sensor' (driver as sensor) (http://www.fasor.info).

Research into an **ergonomics of the mind**[31] becomes an important focus in the context of issues such as intuitive operation and in developing technology that must quickly adapt to a large number of heterogeneous users (such as »intelligent« ticket machines). Taking findings from the cognitive and neurosciences into account, the formal models of humanity that machines should work with must be reflected on. Machines that people interact with must be provided with an »idea« of what people are, how they can differ, what they have in common and what logic underlies their actions and statements. The term »ergonomics of the mind« describes a reversal of the situation in which a person, in order to use technology, has to adjust to it and adapt to its »language«. Ways in which technology could really serve humanity in future need to be researched. Technical implementation of this aspect is in turn closely linked with the process of redefining »human«.

Human-machine culture

Human-Technology Cooperation has great potential for explaining human spheres of activity in many areas of life, as long as they are adequately embedded in society. If technology ***seems*** to take over functions that were previously reserved for people, such as tutor, colleague, teacher, service provider, or communication partner, if distributions of tasks that have become established between people and technology are questioned, then a social discourse on people's relationship to technology must be held (Hubig 2008; Levy 2007). This discourse could be promoted by politics, held in society, research and science, and taken up by business. Technology hype and euphoria must be critically examined against a background of justified reservations about technological developments. Fear of security technologies, alienation or even displacement by machines, as popularised in science fiction dystopias, must also be alleviated.

Trans-disciplinary research into the actual and possible socio-cultural embedding of »Human-Technology Cooperation« could make a considerable contribution to founding this discourse.

One current example of such a topic is cognitive »enhancement« technologies. The technologies discussed under this term raise a series of ethical and legal issues that have long been subjects in the areas of ethics and technological impact assessments (Clausen 2009). These affect not only specific technologies or applications. Rather cultural change is emerging, for which appropriate institutional frameworks must first be developed. Research into the socio-cultural

31 The concept of the »ergonomics of the mind« resulted out of the »Mensch-Technik-Grenzverschiebungen« workshop (Karlsruhe, 27.05.2009), where it was introduced by Prof. Martin Gessmann. Prof. Gessmann worked on the establishment of the Interdisciplinary Centre for Phenomenology and Neurosciences in Heidelberg in 2009.

embedding of these technologies could provide the necessary basis for a critical discussion culture. The transformation of words such as »performance«, »standard«, »normal«, »healthy« and »natural« that will accompany »enhancement« technologies must be researched and incorporated into a social discussion. In a similar way, other technologies discussed here raise questions impacting the whole of society.

A further research topic examining new forms of Human-Technology Cooperation at the macro level emerges in the context of the »Internet of Things« (BMBF 006). Here the critical points of the coexistence of a society of private data spheres and a system of networked objects, control over your individual availability, privacy and data, and the legal consequences of the use of avatars, agents who conclude contracts for us on the Internet, for example, must be investigated. Concepts like **digital territory** (Daskala and Maghiros 2006) could mediate interaction with the »Internet of Things« here.

The distribution of the effects of new human-technical relationships in society must also be researched, posing the field of social structural analysis and social policy with the task of proposing perspectives for equal distribution, social participation, equality of access and opportunities for use and an appropriate distribution of risk.

3.4 Why is this future field relevant?

Successfully functioning human-technology teams would have great potential. Promises of expanding areas of human activity, simplifying orientation in information spaces and relieving people from compulsion and excessive demands are all on the horizon. The various possible human-technical cooperative projects have attractive solutions for many of the urgent challenges of the future in sight, but also bring their own new challenges.

Who or what mediates between the two spheres and how? Where is more, where less, and where is no technology appropriate? These and similar questions outlined here require new, integrated approaches to research, in which knowledge of technical processes and knowledge of human thinking and acting is jointly developed. The more hybrid, complex and multi-disciplinary the issue is, the more a potential solution structure must adapt to this situation. The current research landscape is however fragmented in this respect and therefore only barely able to cope with new challenges (cf. 1.5). The future field of Human-Technology Cooperation covers such a structure of solutions, offering the necessary integration of knowledge about people with knowledge about technology end enabling entry into a new quality of Human-Technology Cooperation.

3.5 Current actors in the innovation system

Germany's research landscape is densely populated with relevant actors and groups able to decisively advance developments in the area of Human-Technology Cooperation. Many of the areas of research central to this future field are also German strengths, such as robotics, neurology and psychology, automation technology and mechanical engineering.

The following table lists actors who currently researching in areas that are important in various ways to HTC research. The type numbers are explained in chapter 3.6.

Actors in the field of Human-Technology Cooperation

- Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. (Federal Association for Information Technology and New Media) (BITKOM), Berlin (Type 1)
- Charité Universitätsmedizin Berlin, Klinik für Neurologie (Charité Medical School, Neurology Department) (Prof. Dr. G. Curio) (Type 1)
- Deutsches Forschungszentrum für Künstliche Intelligenz (German Research Centre for Artificial Intelligence) (DFKI), Forschungsbereich Sprachtechnologie (Research Department of Language Technology) (Prof. Dr. H. Uszkoreit), Saarbrücken (Type 1)
- Deutsches Zentrum für Luft- und Raumfahrt e. V. (German Aerospace Center) (DLR), Institut für Kommunikation und Navigation (Institute of Communication and Navigation), Weßling (Type 1)
- Deutsches Zentrum für Luft- und Raumfahrt e. V. (German Aerospace Center) (DLR), Institut für Luft- und Raumfahrtmedizin ME (Insitute of Aerospace Medicine), Cologne (Type 1)
- Deutsches Zentrum für Luft- und Raumfahrt e. V. (German Aerospace Center) (DLR), Simulations- und Softwaretechnik (Institute of Simulation and Software Technology) (SISTEC), Cologne (Type 1)
- Empolis GmbH, Kaiserslautern (Semantic Technologies) (Type 1)
- Forschungszentrum Informatik (FZI) (Research Center for Information Technology), Karlsruhe (Type 1)
- Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (Fraunhofer Institute for Production Systems and Design Technology), (IPK) Berlin (Type 1)
- Fraunhofer-Institut für Rechnerarchitektur und Softwaretechnik Fraunhofer Institute for Computer Architecture and SoftwareTtechnology) (FIRST), Berlin (Type 1)
- Fraunhofer-Institut für Software- und Systemtechnik (Fraunhofer Institute for Software and Systems Engineering) (ISST), Berlin, Dortmund (Type 1)
- Gesellschaft für Informatik e. V. (GI), Bonn (Type 1)
- Gesellschaft für Technische Kommunikation e. V. (German Professional association for technical communiation and information development) (tekom), Stuttgart (Type 1)
- Hertie-Institut für klinische Hirnforschung (Hertie Institute for Clinical Brain Research) (HIH), Cognitive Neurology, Tübingen (Type 1)
- Intelligent Views GmbH, Darmstadt (Semantic Technologies)
- Forschungszentrum Karlsruhe, Institut für Angewandte Informatik (Institute for Applied Computer Science) (IAI) (Type 3)
- Fraunhofer-Institut für Informations- und Datenverarbeitung (IITB), Fraunhofer Institute of Optronics, System Technologies and Image Exploitation) Karlsruhe (Type 3)
- Fraunhofer-Institut für Integrierte Publikations- und Informationssysteme (Fraunhofer Institute for Integrated Publication and Information systems (IPSI), Darmstadt (Type 3)
- Hasso-Plattner-Institut für Softwaresystemtechnik GmbH, Fachbereiche Human Computer Interaction (Hasso Plattner Institute - Human Computer Interaction Group) (Prof. Dr. P. Baudisch) (Type 3)
- Humboldt Universität Berlin, Institut für Informationssysteme, Kognitive Robotik (Type 3)
- Institut für Wissenschaft und Ethik (Institute of Science and Ethics) (IWE), Bonn (Type 3)
- Max-Planck-Institut für biologische Kybernetik, Abt. Wahrnehmung, Kognition und Handlung (Max Planck Institute for biological cybernetics, Department of Human Perception, Cognition and Action) (Prof. Dr. H. H. Bülthoff), Tübingen (Typ 3)
- Max-Planck-Institut für biologische Kybernetik, Selbstständige Nachwuchsgruppe: Multisensorische Wahrnehmung und Handlung (Max Planck Institute for biological cybernetics, Multi-sensory Perception and Action Research Group) (Dr. M. Ernst) (Type 3)
- Max-Planck-Institut für Informatik, Exzellenzcluster Multimodal Computing and Interaction, (Max Planck Institute for Informatics, Multimodal Computing and Interaction Excellence Cluster) Saarbrücken (Type 3)
- SFB 550, Erkennen, Lokalisieren, Handeln: Neurokognitive Mechanismen und ihre Flexibilität (Collaborative Research Center 550, Recognising, Localising, Acting, Neurocognitive Mechanisms and their Flexibility) , Tübingen (Type 3)
- Technische Universität Berlin, AG Maschinelles Lernen/ Intelligente Datenanalyse (Technical University Berlin, Machine Learning and Intelligent Data Anlaysis Research Group) (Typ 3)
- Technische Universität München (Technical University Munich), Institute of Automatic Control Engineering (LSR, Prof. Buss) (Type 3)
- Technische Universität München, Lehrstuhl für Angewandte Mechanik (Institute of Applied Mechanics) (Type 3)

- Clinic at the Technischen Universität München, Deutsches Herzzentrum München (German Heart Centre Munich) (DHM) (Type 1)
- SAP Research Centers (SRC) and Campus-based Engineering Center (CEC); SRC Walldorf, CEC Darmstadt, CEC Dresden, CEC Karlsruhe (Type 1)
- Technische Universität Braunschweig, Institut für Betriebssysteme und Rechnerverbund (Prof. Dr.-Ing. M. Beigl) (Type 1)
- Technische Universität München, Institut für Werkzeugmaschinen und Betriebswissenschaften (Institute for Machine Tools and Industrial Management) (Type 1)
- Technische Universität München, Lehrstuhl für Informatikanwendungen in der Medizin & Augmented Reality(Chair for Computer-Aided Medical Procedures and Augmented Reality) (Prof. Dr. N. Navab) (Type 1)
- Technische Universität München, Lehrstuhl für Medientechnik (Institute for Media Technology (Type 1)
- Technischen Universität München, Lehrstuhl für Raumfahrttechnik (Institute of Aeronautics) (Type 1)
- Universität Berlin, Berlin School of Mind and Brain (Geistes-, Verhaltens-, Neurowissenschaften) (Type 1)
- Universität Bielefeld, Centrum für Biotechnologie (Bielefield University, Center for Biotechnology) (CeBiTec) (Type 1)
- Universität Karlsruhe, Institut für Sport und Sportwissenschaft (Karlsruhe Institute of Technology, Institute for Sport and Sport Sciences) (Type 1)
- Universität Leipzig Biotechnologisch-Biomedizinisches Zentrum (Leipzig University, Centre for Biotechnology and Biomedicine), (BBZ) (Type 1)
- Universität Leipzig, DFG-Forschergruppe 742, Grammatik und Verarbeitung verbaler Argumente (Type 1)
- Universität Leipzig, Innovation Center Computer Assisted Surgery (ICCAS) (Type 1)
- Universität Leipzig, Translational Centre for Regenerative Medicine (TRM) (Type 1)
- Universität Marburg, Fachbereich Mathematik und Informatik (University of Marburg, Department of Mathematics and Informatics) (Prof. Dr. B. Freisleben) (Type 1)
- Universität München, Allgemeine Psychologie I (Institute of General Psychology) (Type 1)
- Universität Stuttgart, Institut für Steuerungstechnik der Werkzeugmaschinen und Fertigungseinrichtungen (University of Stuttgart, Institute for Control Engineering of Machine Tools and Manufacturing Units) (ISW, Prof. Dr.-Ing. A. Verl) (Type 1)
- Berlin-Brandenburgische Akademie der Wissenschaften, (Berlin-Brandenburg Academy of Sciences and Humanities) Berlin (Type 2)
- Biotechnologisches Zentrum Dresden, Exzellenzcluster Regenerative Therapien Dresden (Biotechnology Center Dresden, Regenerative Therapies Excellence Initiative Dresden), (CRTD) (Type 2)
- Deutsche Akademie der Naturforscher Leopoldina, (German National Academy of Sciences, Leopoldina) Halle/ Saale (Type 2)
- Deutsche Akademie der Technikwissenschaften (German Academy of Science and Engineering) (acatech), Munich (Type 2)
- Deutsches Zentrum für Neurodegenerative Erkrankungen e. V. (German Centre for Neurodegenerative Diseases) (DZNE), Bonn (Type 2)
- Technische Universität München, Lehrstuhl für Datenverarbeitung (Institute of Data Processing) (Type 3)
- Technische Universität München, Lehrstuhl für Realzeit-Computersysteme (Institute for Real-Time Computer Systems) (Type 3)
- Technische Universität München, Robotics and Embedded Systems (Type 3)
- Transregional Collaborative Research Center 28, Cognitive Automobiles (Type 3)
- Universität Augsburg, Institut für Informatik, Lehrstuhl für Multimedia-Konzepte und Anwendungen (University of Augsburg, Department of Computer Science, Chair of Multimedia Concepts and Applications) (Prof. Dr. E. André) (Type 3)
- Universität Bielefeld, Technische Fakultät, AG Angewandte Informatik (Bielefeld University, Faculty of Technology) (Type 3)
- Universität Bonn, Institut für Informatik (University of Bonn, Institute of Computer Science), Department of Computer Science III and IV (Type 3)
- Universität Bremen (University of Bremen), Technologie-Zentrum Informatik und Informationstechnik (Prof. Dr. R. Malaka) (Type 3)
- Universität der Bundeswehr München, Institut für Arbeitswissenschaft (IfA), Neubiberg (Type 3)
- Universität Karlsruhe (Karlsruhe Institute of Technology), Institut für Betriebs- und Dialogsysteme, Dialogsysteme und grafische Datenverarbeitung (Type 3)
- Universität Karlsruhe (Karlsruhe Institute of Technology), Institut für Produktentwicklung (IPEK, Prof. Dr.-Ing. Dr. h.c. A. Albers) (Type 3)
- Universität Karlsruhe (Karlsruhe Institute of Technology), Institut für Prozessrechentechnik, Automation und Robotik (Type 3)
- Universität Karlsruhe (Karlsruhe Institute of Technology), Institut für Technische Informatik (ITEC), Industrielle Anwendungen der Informatik und Mikrosystemtechnik (IAIM), (Prof. Dr.-Ing. R. Dillmann) (Type 3)
- Universität Paderborn, Institut für Humanwissenschaften (University of Paderborn, Department of Human Sciences) (Type 3)
- Universität Siegen, Lehrstuhl für Wirtschaftsinformatik und neue Medien (University of Siegen, Information Systems and New Media Research Group) (Prof. Dr. V. Wulf) (Type 3)
- Universität Stuttgart, Institut für Philosophie (University of Stuttgart, Institute for Philosophy) (Prof. Dr. Ch. Hubig) (Type 3)
- Universität Tübingen, Fakultät für Biologie, Lehrstuhl für Kognitive Neurowissenschaft (University of Tübingen, Faculty of Biology, Cognitive Neurosciences Unit) (Prof. Dr. H. A. Mallot) (Type 3)
- Universität Würzburg, Institut für Informatik, Lehrstuhl für Informatik 6, Künstliche Intelligenz und Angewandte Informatik (University of Wuerzburg, Institute for Informatics, Chair of Informatics 6, Artificial Intelligence and Applied Informatics (Prof. Dr. F. Puppe) (Type 3)
- Universitätsklinikum Bonn, Medizinische Fakultät, Zentrum für Nervenheilkunde, Abteilung für Medizinische Psychologie (University Clinic Bonn, Faculty of Medicine, Department of Psychiatry, Division of Medical Psychology (Prof. Dr. med. Dr. phil. H. Walter) (Type 3)
- Deutsche Servicerobotik Initiative (German Service Robotics Initiative) (DESIRE) (Type 4)
- Fraunhofer-Institut für Biomedizinische Technik (Fraunhofer Institute for Biomedical Engineering), (IBMT), St. Ingbert (Type 4)

- Forschungszentrum Jülich (FZJ) (Type 2)
- Forschungszentrum Karlsruhe GmbH, Institut für Technikfolgenabschätzung und Systemanalyse (Institute for Technology Assessment and Systems Analysis) (ITAS) (Type 2)
- Georg-Simmel-Zentrum für Metropolenforschung, (Georg Simmel Center for Metropolitan Studies), Berlin (Type 2)
- Hasso-Plattner-Institut für Softwaresystemtechnik GmbH (Hasso Plattner Institute), School of Design Thinking (Prof. U. Weinberg) (Type 2)
- Helmholtz Zentrum München – Deutsches Forschungszentrum für Gesundheit und Umwelt (German Research Center for Environmental Health), Neuherberg (Type 2)
- Institute of Electrical and Electronics Engineers Inc. (IEEE), German Section (Type 2)
- Internationales Institut für Sozio-Informatik (International Institute for Socio-Informatics) (IISI), Bonn (Type 2)
- Max-Planck-Institut für Wissenschaftsgeschichte (Max Planck Institute fort he History of Science), Berlin (Type 2)
- Universität Berlin, Hermann von Helmholtz Zentrum für Kulturtechnik (Typ 2)
- Universität Frankfurt am Main, Exzellenzcluster »Die Herausbildung normativer Ordnungen« (Frankfurt University, Cluster of Excellence »The formation of normative orders« (Type 2)
- Universität Leipzig, Institut für Biologie II, Forschungsbereich Gehirn, Kognition und Sprache (Type 2)
- Universität Osnabrück, Institut für Kognitionswissenschaft,) (University of Osnabrück, Institute for Cognitive Sciences (Prof. Dr. P. König) (Type 2)
- Universität Stuttgart, Internationales Zentrum für Kultur und Technikforschung (IZKT, Prof. Maag) (Type 2)
- Zentrum für Bioinformatik Saar (ZBI), Saarbrücken (Typ 2)
- Deutsches Forschungszentrum für Künstliche Intelligenz (German Research Center for Artificial Intelligence) (DFKI), Bremen, Robotics Innovation Center (Prof. Dr. F. Kirchner) (Type 3)
- Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI), Saarbrücken, Agenten und Simulierte Realität German Research Center for Artificial Intelligence, Agents and Simulated Reality) (Prof. Dr. P. Slussalek) (Type 3)
- Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Robotik und Mechatronik, (German Aerospace Center, Institute for Robotics and Mechatronics) Weßling (Type 3)
- European Media Laboratory GmbH, Heidelberg (Intuitive multimodal user interfaces etc) (Type 3)
- Fraunhofer-Institut für Grafische Datenverarbeitung (Fraunhofer Institute for Computer Graphics Research) (IGD), Darmstadt (Type 4)
- ICT&S Center of Advanced Studies and Research in Information and Communication Technologies & Society, University of Salzburg (Type 4)
- Karlsruher Institut für Technologie (KIT), Institut für Philosophie, New Field Group »Autonome technische Systeme« (Karlsruhe Institute of Technology (KIT), Institute for Philosophy, New Field Group »Autonomous Technical Systems (Prof. Gutmann) (Type 4)
- Karlsruher Institut für Technologie (KIT), Karlsruhe, Institut für Anthropomatik (IFA), Intelligente Sensor-Aktor-Systeme (Karlsruhe Institute of Technology, Institute for Anthropomatics, Intelligent Sensors-Actor Systems) (ISAS) (Type 4)
- SFB 453, Wirklichkeitsnahe Telepräsenz und Teleaktion (Collaborative Research Center 453, High-fidelity telepresence and teleaction), Munich (Type 4)
- SFB 588, Humanoide Roboter: Lernende und kooperierende multimodale Roboter, (Collaborative Research Center 588, Humanoid Robots: Learning and cooperating multimodal robots) Karlsruhe (Type 4)
- Technische Universität Berlin, Graduiertenkolleg prometei (Prospektive Gestaltung von Mensch-Technik-Interaktion) (Technical University Berlin, research training group ‚prometei') (Type 4)
- Technische Universität Berlin, Institut für Psychologie und Arbeitswissenschaften, Zentrum für Mensch-Maschine-Systeme (Technical University Berlin, Institute for Psychology and Ergonomics, Chair for Machine-Human Systems) (ZMMS, Prof. Dr.-Ing. M. Rötting) (Type 4)
- Technische Universität München, Cluster of Excellence Cognition for Technical Systems (CoTeSys) (Type 4)
- University of Bielefeld, Center of Excellence Cognitive Interaction Technology (CITEC) (Type 4)
- University of Bielefeld, Research Institute for Cognition and Robotics (CoR-Lab) (Type 4)
- Universität Heidelberg, Zentrum für Phänomenologie und Neurowissenschaften, im Aufbau bis Anfang 2010 (University of Heidelberg, Center for Phenomenology and Neurosciences – to be established by early 2010) (Prof. Dr. M. Gessmann) (Type 4)
- Universität Mainz, Philosophisches Seminar, Interdisziplinärer Forschungsschwerpunkt Neurowissenschaften (IFSN) und Arbeitsbereich Neuroethik (University of Mainz, Philosophical Seminar, Interdisciplinary Research Centre for Neurosciences (IFSN) and Department of Neuroethics) (Prof. Dr. T. Metzinger) (Type 4)
- Universität Tübingen, Interfakultäres Zentrum für Ethik in den Wissenschaften (University of Tübingen, International Centre for Ethics in the Sciences and Humanitites (IZEW) (Type 4)

Table 1: Actors in the area of Human-Technology Cooperation in 2009

3.6 Sustainable actors' groups

Many of these research institutions are leaders in their area at an international level. In order to deal with the new complexity as it appears in prospects for research into Human-Technology Cooperation however, some structural changes will have to be made.

As part of our analysis of potential, those actors demonstrating a great potential for sustainable cooperation in the area of HTC are presented. These actors are to varying extents *sustainable* in the specific context of HTC research. In order to structure the actual heterogeneous results, they were typified using two parameters. This typology provides a guideline for establishing effective and sustainable actors' groups. Conclusions and recommendations will then follow from the combination and typology of actors.

Analysis of potential partnerships for HTC research in Germany reveals a very heterogeneous group of actors who are all relevant to this topic, although only those who already demonstrate a certain proximity to the new future field through their disciplinary diversity or thematic focus are listed. Many other areas of course influence the research and development of new prospects, but the analysis of potential could not possibly draw up a comprehensive list of every possible connection in the German research system. In order to arrive at expedient potential partnerships, it was important to include only the **smaller circle** of relevant actors. The research areas in which these actors are active are listed on the outer ring of Figure 4.

Autonomous robotics and **teleaction** are two research areas listed here, for example, mechatronics, mechanical engineering and physics are not. These vital but more general areas should be imagined on a ring outside this representation, so to speak. The actors are not generally irrelevant, but are irrelevant only for the purposes of presentation in this analysis of potential, so they are no longer included in this representation.

Clustering in types of actors

All the actors included were clustered according to two parameters: on the one hand their **disciplinary diversity** and on the other hand their thematic **proximity to the area of HTC research**.

The extent of interdisciplinarity and the integration of various areas of knowledge in a research context must correspond with the diversity of the research area. As has been made clear, human-technology research requires by definition the integration of very different disciplines, so the extent of **disciplinary diversity** is a decisive factor in qualifying actors for this new future field.

There are also many actors in the current research landscape whose areas of research play a key role in further developments on the way to new research prospects, without however recognising the specific prospects of the HTC field. Progress in the area of semantic technologies for example, is also paving the way for other areas of HTC research, but thematic **proximity to the prospective research area of HTC** depends on other aspects, such as effects on the relationship of people and technology and the potential to fundamentally influence humanity's self-image, for example.

→ Proximity to the research area of HTC →	Actors Type 3	Actors Type 4
	Actors Type 1	Actors Type 2
	→Disciplinary Diversity →	

Figure6: Four clusters of types of actors

Figure6 shows the four clusters that result when these two parameters are shown as axes.

Type 1 actors demonstrate low levels of disciplinary diversity and a relatively great distance to the prospective research area of HTC. This means that Type 1 actors are carrying out more research into the basics of the future field and working on either single or very closely-related disciplines. These are for example information technology or technical institutes, »semantic technology« developers or clinics.

Type 2 actors have a similar distance to the prospective research area of HTC, but cooperate more with other and more distant disciplines. These tend to be, due to their organisational structures, academies, centres, networks, excellence clusters and institutes that have recognised the potential of broader interdisciplinary cooperation and implemented it.

Type 3 actors address research areas close to HTC research and work specifically on potential core areas of the future field. These are however actors from single disciplines or those researching in weakly or slightly interdisciplinary areas, not with the necessary breadth of perspective or implementing a new quality of integrated research. They are typically actors in the areas of robotics, software agents, machine learning or »embedded systems«

Type 4 actors, like Type 2 actors, research a central research topic or topics of the future field with greater disciplinary diversity and address, as do Type 3 actors, a central research topic or topics in the future field.

The four types of actors can be identified in the diagram above (Figure6). They are shown in Figure7 with the corresponding numbers 1 to 4, with »1« identifying Type 1 actors, who can be assigned to a single research area, »2« being those involved in interdisciplinary cooperation among several research areas (Type 2 actors), »3« those with a concrete connection of one single discipline with one of the core topics at the centre (Type 3 actors) and »4« standing for interdisciplinary research projects with high levels of future potential in the prospective research area of HTC (Type 4 actors).

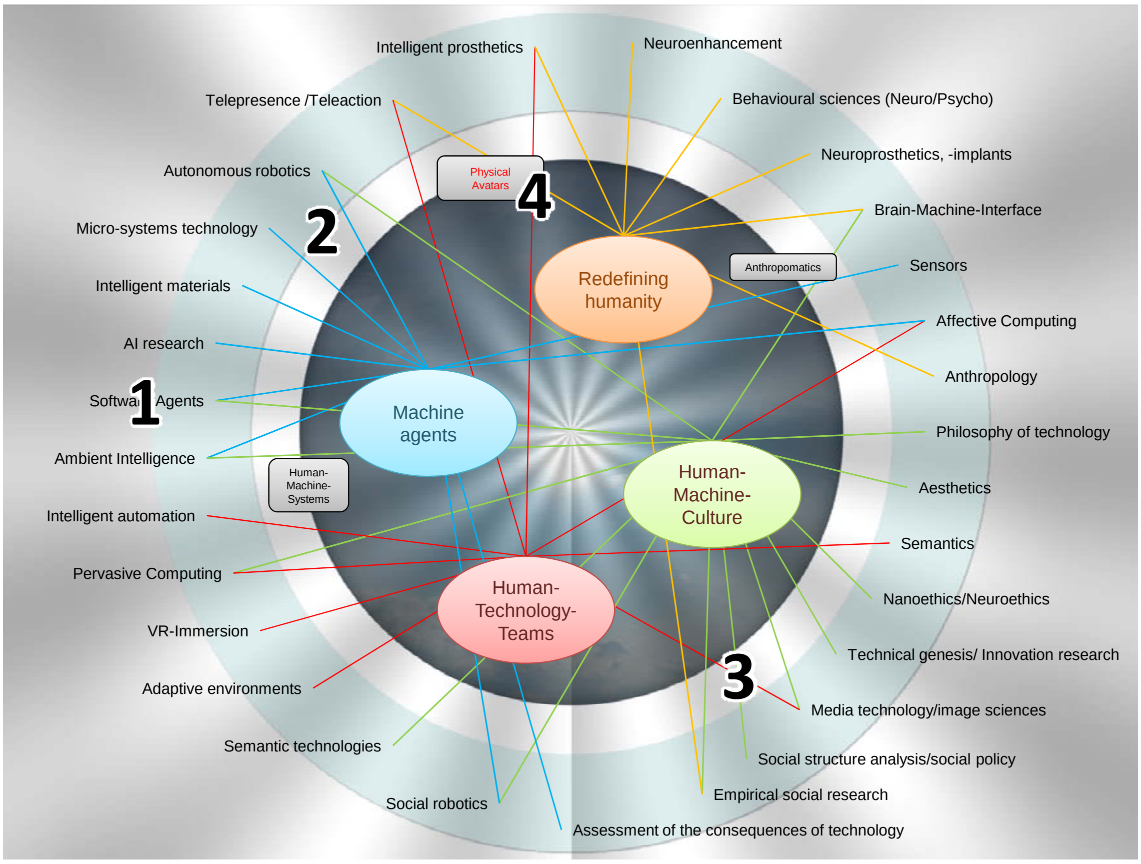


Figure7: Actor types, assigned to the future research directions

Conclusions

The varying numbers of actors of the individual types allow certain statements to be made on the research landscape in Germany with reference to the future field.

The group with less disciplinary diversity (Types 1 and 3) is almost three times as large as the group carrying out interdisciplinary research. These are all the actors outside the narrower circle of actors selected in accordance with thematic criteria. Support for the integration of knowledge as a condition of top-level research in new complex areas is not yet anchored on a broad basis in research structures, although an awareness of the necessity of interdisciplinary research seems at least to be established. It is however, in the opinion of all the actors surveyed over the course of the Foresight Process, still extremely difficult to work against boundaries that have become fixed and to invest the initially high additional time and effort involved in integration and communication.[32] The two great knowledge areas of the technical sciences and the social sciences and humanities must especially move more closely together in practice.

Classification based on proximity to the prospective research area of HTC also reveals how remote the new future field described still is. It shows that even among those actors close enough to the topic to be included on the list of identified actors, the greater number, compared with the few pioneers, are still very remote from the central issues of the HTC field.

The few Type 4 actors demonstrate the greatest potential for penetrating into the core of the field of Human-Technology Cooperation with its central research areas (Figure7, circle in the middle). But this group is relatively small and still some distance from being able to be active and creative for the purposes of a new quality of integrated research in the complex future field.

In order to implement the HTC research required, something more fundamental than the mere increase of disciplinary diversity is needed. Some possible steps, upcoming tasks and further recommendations follow in chapter 3.7.

3.7 Recommendations

Following the structuring of the complex field of actors undertaken here, the topic coordinators are of the view that the tasks listed below emerge as a result:

32 The most recent publication of the German Academy of Science and Engineering acatech (2009) on »Intelligent Objects« (a sub-area of HTC research) should be mentioned as an example here. It recommended **increased interdisciplinarity** (p. 34). The following statements about intelligent objects also apply to the whole area of HTC:
»Intelligent objects are typically not developed by a single specialist discipline. The knowledge and skills of a wide range of fields must be combined. Many development projects however, involve only technical disciplines, which are also often related or contiguous.
> acatech recommends: The particular social relevance of developments in the area of intelligent objects requires more accompaniment and monitoring by the social sciences and humanities. Direct involvement of non-technical disciplines in product development to create user-oriented designs would also be desirable. The social sciences and humanities should work together with the technical sciences on developing and trialing products. The effort involved in such cooperation and projects is well-known. Interdisciplinary integration is however still the best way of avoiding an unreflected technical developments that bypass people’s wishes, needs and cultural values and can ultimately lead to economic loss.« (Acatech 2009a, p. 34)
In the discussion at the acatech forum on 28.05.2009, all the speakers (see sources) spoke of the need for and problems in engaging with interdisciplinarity.

- Systematic support for Type 1, 2 and 3 actors in developing along the lines of Type 4,
- Enable Type 4 actors to advance to the core areas of the future field,
- Prepare actors of all Types for the direct leap to a new level of research,
- Founding of new actors and integration of those actors still outside the framework outlined here, who participate even less than the Types 1 and 2 groups in HTC research, but are urgently needed here.

In order to open the boundaries to the future field's inner circle to all actors, it was the view of the topic coordinators that transmission processes must be coordinated, integration promoted, institutions, structures and organisations reorganised and – where necessary – newly founded. The following points are, in the opinion of the experts, the preconditions for a new quality of research:

- wider and broader networking over a range of disciplines (technical and non-technical),
- complete abolition of some disciplinary boundaries to induce a fusion of new, adequate disciplines,
- institutional and structural course-setting, to enable the integration of knowledge from previously separate and incompatible spheres of knowledge,
- diffusion of the special prospects that bring the interaction of human and technical change into focus, so that individual developments can be viewed in terms of the overall human and technological context.

The topic coordinators think that strategic dialogues could provide important communication processes. Fundamental debates on terminology, which were generally regarded as indispensable and involve the successful integration of knowledge, could be held in this context.

4 Ageing Deciphering

Ageing continues over our entire life span and is a multifactorial process. Some ageing processes cause disorders or disease. The biological processes of ageing and brain development (e.g. changes to neuroplasticity) that occur over the course of a lifetime have so far only been basically explained. Future findings in the areas of cellular and molecular developmental biology will provide new insights into cognitive, emotional and psychomotoric processes.

New institutions are currently being established, so it is expected that in 15 years time, research will yield results that will be implemented in new products and services, such as innovative pharmaceutical products (simulation of calorie reduction etc.), protection from the risks of longevity or learning products adapted to specific phases of life. Repair mechanisms at the DNA-level could also be discovered and used therapeutically (e.g. in cancer treatment).

4.1 The future field

Ageing research has a long scientific tradition, especially in the disciplines of psychology and sociology (Lehr 2007) but rapid developments in the life sciences have given new impetus (Gruss 2007). Here the focus is less on demographic change as on biological ageing processes, the effects of ageing processes in all phases of life and the potential for innovation that could be derived from developments in this area. Investigations into the scientific foundations of these developments have shown however, that many fundamental questions have not yet been answered, in particular the question of how ageing processes actually occur - which is the focus of biogerontology research.

Biogerontology is a sub-field of developmental biology dealing with research into the causes and mechanisms of biological ageing and its consequences (Ahlert 1999). It is a major basic discipline of **gerontology**, so is sometimes also referred to as »biological gerontology«. There are three main research areas of gerontology: geronto-psychology, geronto-sociology and geriatrics (Rieber 2005). The latter is the study of the illnesses of ageing people and is also referred to as geriatric medicine.

The **difference between ageing and age** is vitally important in ageing research (Kruse 2007). **Ageing** describes a lifelong process that is defined by the continuous changing of an organism and progressive transformation. **Age** is a specific phase of life. The age at which this phase of life is reached depends not only on the changes occurring in the ageing process, but is also the result of social conventions.

Analysis of this future field has shown that reducing and concentrating the phenomena of ageing to focus exclusively on advanced age will not further the achievement of goals in this area. Science and politics have both recognised demographic change and its consequences as a social megatrend, so in recent years research activities have increasingly been dedicated to the phase of life known as »age«. In the discussions with experts it was suggested that the entire process of life and ageing should be researched in the future field of »Ageing Deciphering«, taking a multi-perspective and trans-disciplinary approach. The focus should be on **processes of development from young to old,** not exclusively on »older people«.

The future field of deciphering ageing, »ageing research« or »Ageing Deciphering« has been aptly and briefly described in remarks made by the President of the Max Planck Society, Prof. Gruss. **Ageing research employs a systemic and interdisciplinary approach to investigate the causes and mechanisms of ageing** (Gruss 2007). The focus of this research should be as broad as possible, involving molecular and cellular biological disciplines and taking areas of science and research fields such as epigenetics, life course research and the cognitive sciences into account.

Within ageing research, the **development of the brain** and its plasticity in different phases of life, its molecular and biological fundamentals (**developmental neurobiology**) and the resulting consequences for teaching and learning, are topics of particular importance. This is because of the special importance of cognition and human consciousness for people's »everyday competence«, with the maintenance of function from prenatal development through to old age of particular significance.

4.2 The initial situation in the future field now (2009)

Despite the increase in knowledge of **biological ageing processes,** mainly in model organisms, the exact causes of ageing remain unclear. Explaining the fundamental mechanisms of ageing has **implications** for the understanding of **early childhood development** (e.g. supporting maturing processes), for **gerontological research** (e.g. active ageing and preventative medicine) and for **society** (e.g. the social implications of longevity and the acceleration of demographic change).

There are hundreds of theories on ageing, most of which postulate genetic, cellular-biological or evolutionary explanatory models and wear and tear as the cause (Bengtson et al. 2009; Medvedev 1990). According to the current state of knowledge, ageing cannot be explained by one theory alone, rather it seems to be a multi-factorial, complex process, in which individual factors also play a role (Wickens 2001).

The individuality of ageing is based on genetic configurations, environmental conditions and variations in intrinsic stochastic damage, in which damage accumulates within the cell (Brosche, Sieber 2003). Experimental biogerontology deals with the molecular mechanisms of ageing and includes the search for longevity genes, the identification of repair mechanisms within cells and the potential of pluripotent stem cells. Intervention in the biological ageing process is now recognised as a real possibility and is being discussed in scientific circles (Baltes 2002; Gruss 2007; Knell, Weber 2009; Lucke, Hall 2005; The President's Council on Bioethics, Kass L. R. 2003). The term **biogerontechnology** has been proposed to describe the development of biological techniques for influencing the ageing process (Juengst et al. 2003; SRI Consulting Business Intelligence 2008). This should not be confused with gerontechnology, which deals with products and services specially designed for the needs of older people (Gassmann, Reepmeyer 2004). At the moment, the project to use a future high-tech medicine to significantly lengthen human life remains a largely speculative one (Knell, Weber 2009). Its chances of being realised are controversial among life scientists and regarded with scepticism by many researchers (Olshansky et al. 2002). The debate on its possible implications is being held mainly in Anglo-Saxon countries (Knell, Weber 2009; The President's Council on Bioethics, Kass L. R. 2003). It is however already clear that it raises many ethical, religious, and economic issues.

The **prevalence of many illnesses** is often linked with advanced age (»Age and illness are two sides of the same coin«). There is therefore a justified hope that a better understanding of ageing processes in the human organism could also yield new findings on the pathological mechanisms of different diseases.

Illnesses for which old age is a risk factor and symptoms of old age include:

- Arthritis
- Metabolic disorders, e.g. Diabetes mellitus Type II
- Hearing loss
- Cataracts, macular degeneration
- Skin ageing, impaired wound healing
- Cardiovascular diseases (heart attacks, strokes)
- Cancer
- Neurodegenerative disease, e.g. Alzheimer’s and Parkinson’s disease

In the context of chronic diseases, incidence of which is increasing in all industrialised countries, morbidity and mortality only become noticeable over a long period. For this reason, prevention strategies that begin as early as possible seem most promising (Sachverständigenrat zur Begutachtung der Entwicklung im Gesundheitswesen 2009). What is crucial in this context, is that the course can be set for specific diseases in certain phases of life, including in prenatal and perinatal phases, in combination with genetic configurations and external influences.

Since these are mainly illnesses that can powerfully impact quality of life and have immense epidemiological significance, it is to be expected that findings from ageing research would also be quickly translated into therapeutic products and services.

The developmental neurobiology of the human brain shows that it can retain its »plasticity«, the term neuroscientists use to describe the human brain's ability to adapt to changing environmental demands by re-structuring itself, throughout the human lifespan. Researchers previously assumed that the brain's ability to change as a result of new tasks was barely present in old age and previously regarded plastic adaptation processes as being mainly possible in the brain's critical developmental phase. Recent research results show however, that a blanket statement is untenable in this context (Dinse, Eysel 2003). There is a partial reduction in cognitive performance with increasing age. Process-oriented abilities, also called »fluid intelligence«, are acquired mainly in the first three to four decades of life. The more the cognitive resources are used in this period, the easier it is to integrate new content (crystalline intelligence) and the easier it is to counteract a possible decrease in brain function, as long as no neurodegenerative illness, such as Alzheimer's, occurs (Anderton 2002). Developmental neurobiology generally deals with the formation and maturing of nerve systems (neurogenesis). The main findings of developmental neurobiology relate to the production and function of messenger substances in the brain.

4.3 The long-term outlook for the future field

The span of life and health[33] can be prolonged in three ways (Knell, Weber 2009; The President's Council on Bioethics, Kass L. R. 2003):

1. Through measures to combat causes of death among the young and middle-aged (e.g. reducing infant mortality, increasing immunization

33 The period of time a person can live largely free of illness.

rates). Over the past century such measures have led to a significant increase in life expectancy, especially in industrialised countries.

2. By reducing the incidence and seriousness of disease and impairment in older people, possibly replacing tissue and organs or substituting substances (e.g. replacing joints, dialysis treatment, and insulin substitution for diabetes mellitus). This is currently being done in the field of medicine and is increasing average life expectancy.

3. Through procedures that attenuate or delay the effects of senescence in their general form by **intervening in the general process or in ageing processes,** thus potentially prolonging not only the average, but also the maximum span of life and health. The discipline used to do this, **biogerontechnology,** was identified at a National Intelligence Council conference held in the USA in 2008 as one of six disruptive technologies for 2025 (SRI Consulting Business Intelligence 2008).

- Although further progress and consequences are to be expected in the areas covered by the first two points, it is primarily the third point that will have far-reaching consequences once researchers succeed in making substantial breakthroughs in this area. It will however give rise to other questions at an individual and collective level (e.g. who will be able to undergo such treatments, who will be able to afford them, how demographic change as a whole will »look« etc.). The research issues in the future field of »ageing research« to be investigated in the next years and decades will include the following:
- How does the individual ageing process progress and how can it be influenced?
- What is the connection between age and disease? Can findings in one area stimulate other research fields (e.g. in neurodegenerative diseases)? What are the results of findings in this context for prevention?
- What are the causes – apart from environmental factors and others such as smoking – of significant differences in the ageing process between the sexes?
- Can repair mechanisms at a DNA level be explained and used for preventative or therapeutic purposes (e.g. in cancer treatment)?
- Will it only be lifespan that is prolonged or can the span of healthy life also be significantly extended?
- What innovative products and services will be derived from research results (e.g. drugs that simulate calorie restriction; protection from the risks of longevity)?

- What will the economic and social effects of longevity be, especially if the span of life and health is extended?[34] What other social issues arise in the context of understanding ageing?
- How will work processes and the image of ageing change as a result of a longer span of life and health (individually, in companies, socially)?
- In what ways is the brain able to react to changing conditions in different phases of life? What developmental physiological correlates is this ability based on?
- What mechanisms of learning can the neurosciences identify? How can life-long learning be stimulated and how should successful learning settings »look« (e.g. early childhood learning products; geragogics, to support learning in old age)?
- How can learning be promoted in conditions of increasing pressure (»compression« of work processes, information overload)?
- What can politics do to sustainably improve the transfer of new knowledge on (healthy) ageing in practice, ranging from child-care through to geriatric care?

In addition to these research issues, new ethical debates and political discourses and research questions on the economic, legal, and social effects of longevity also arise and there are overlaps with the new future fields of Human-Technical Cooperation and Time Research (see Figure 1).

[34] A particularly high relevance was ascribed to this topic (also for the economy) in the online survey.

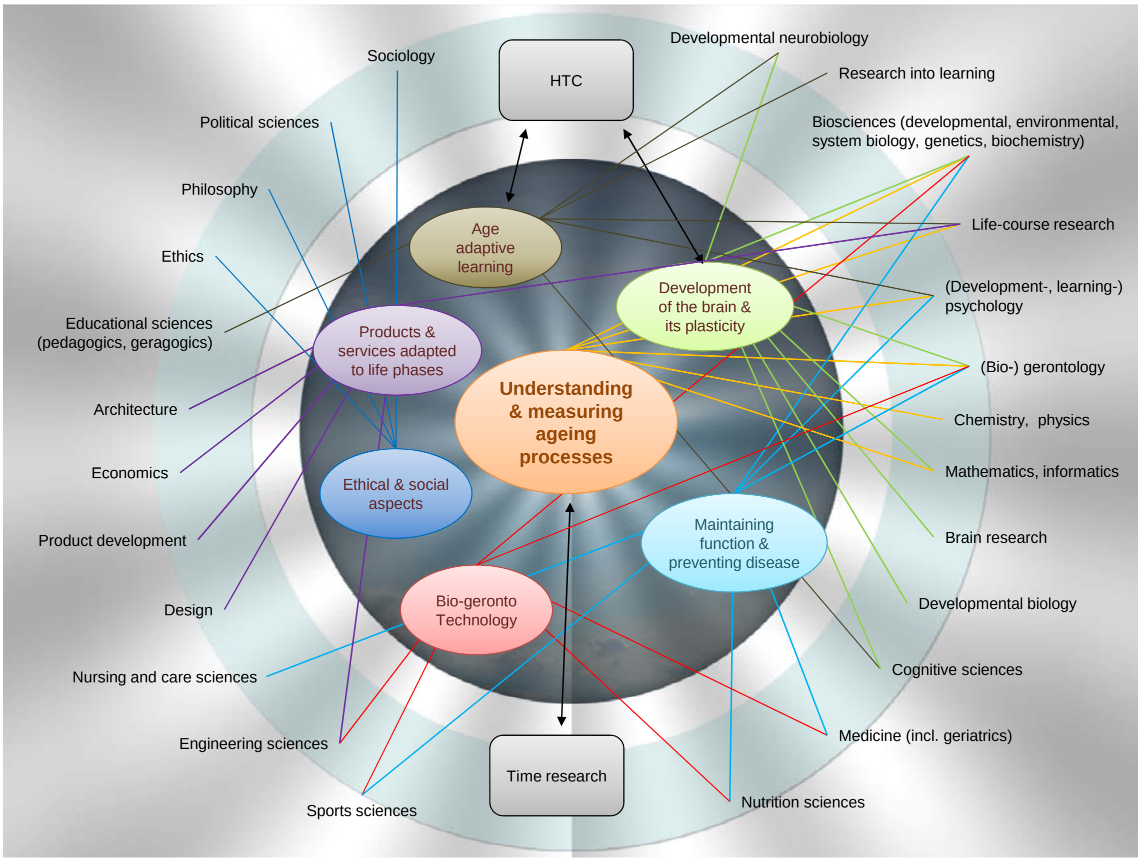


Figure 1: Future participating research areas

Figure 2 shows future the research fields and potential applications of ageing research. Ageing research will also have effects on the detection and treatment of cancer and neurodegenerative diseases and biological age will become a vital indicator in individualised medicine, in addition to gender aspects and specific genetic configurations. Many social-scientific, political and ethical issues will arise on the way to an understanding of ageing.

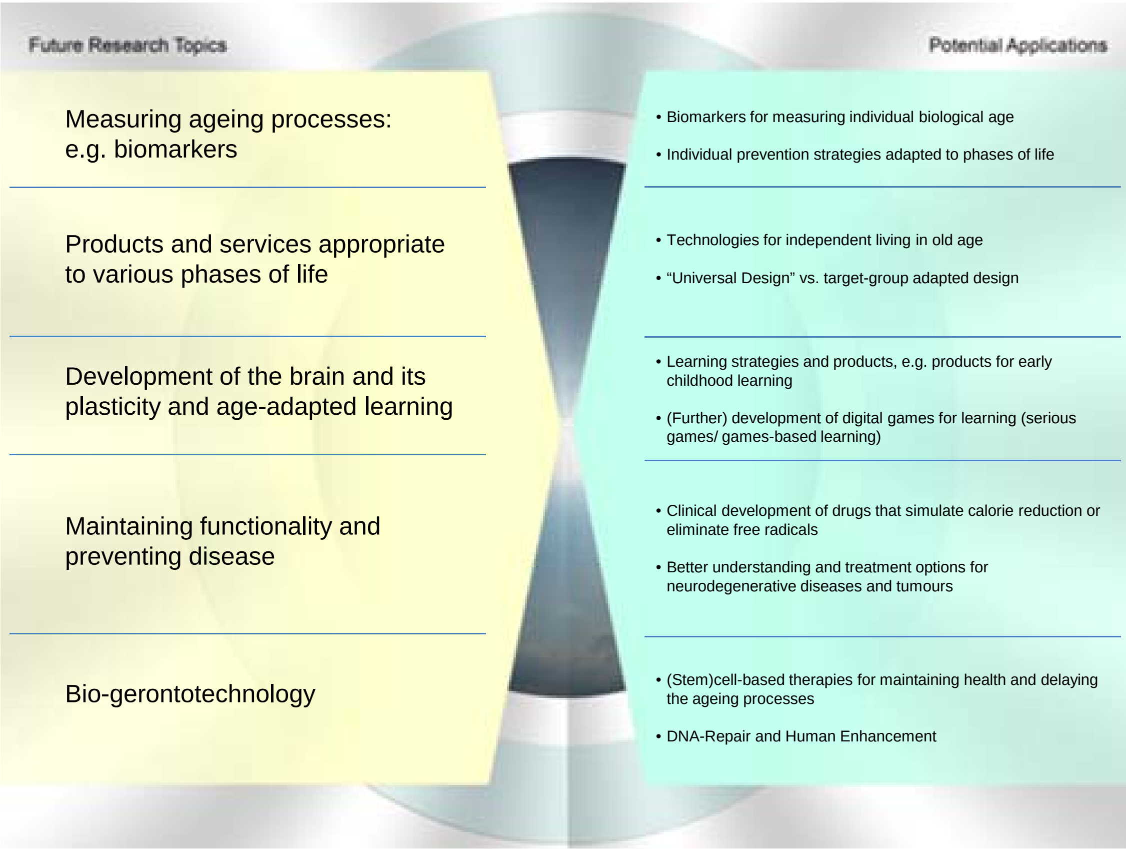


Figure 2: Future research topics and potential applications in the future field of »ageing research«

4.4 Why is this future field relevant?

The future field of »ageing research«, with its broad orientation as outlined here, will remain an economically and socially relevant research topic in coming decades. Its dynamism should also increase due to the results expected from basic research.

A better understanding of ageing processes and the development of biogerontology techniques to influence them could lead to the prolonging of the individual span of life and health (SRI Consulting Business Intelligence 2008) or to explaining the causes of diseases (e.g. cancer development). Healthier ageing, and not just extending the lifespan, will probably result in lower or similar health and nursing care insurance costs, while economic productivity will increase.

»Anti-ageing measures« are already a growth area in the health-care industry, although there is no proof of the effectiveness of most applications (Oswald et al. 2006; Juengst et al. 2003; Kruse 2007). If their effectiveness were given a more solid scientific foundation, this market could be expanded and positive public health effects achieved.

Findings from cellular and molecular developmental neurobiology could also help to improve our understanding of cognitive, emotional and psychomotoric processes and to enhance learning processes.

The interdisciplinary findings combined in »ageing research« could make a vital contribution to establishing and expanding society's adaptation to ageing, with appropriate products, services, supply concepts and infrastructures etc.

Demographic developments in industrialised countries mean that research findings affecting ageing are increasingly important. Research is currently focused on the pathological effects of ageing. Since ageing processes are partly reversible however, strategies for maintaining cognitive function are increasingly important. The overall goal is to maintain the physical health and cognitive potential of the increasingly large group of old people.

Merging discussions (learning in various phases of life) and actors into a strategic dialogue could have a great influential impact on the various groups of actors actively involved in the future topic of ageing and learning, this is the conclusion of the topic coordinators.

Synergy effects could also be expected from links among the fields of healthcare research, information and communication technologies, biosciences and life sciences and the future fields of human-technology cooperation and time research.

4.5 Current actors in the innovation system

The following selected institutions, societies, initiatives and networks are working on aspects of ageing research (in the broad sense) in Germany and would seem to be relevant from the point of view of the experts surveyed and the bibliometric analyses (it is not claimed that this list is complete). Some institutions – especially those in the area of the life sciences – were rated by the experts as particularly relevant. These include the Max Planck Institute for the Biology of Ageing, currently still in development, and the Helmholtz Centre for Neurodegenerative Diseases. One important issue will be the extent to which existing institutions and those still to be established can be networked and coordinated so that synergies can be exploited.

Actors in the field of ageing research	
German research institutions - Max-Planck-Forschungsgruppe für Stammzellalterung (Max Planck Research Group for Stem Cell Ageing) in Ulm - Max-Planck-Institut für demografische Forschung (Max Planck Institute for Demographic Research), Rostock - DFG Sonderforschungsbereich 728 »Umweltinduzierte Alterungsprozesse« (Collaborative Research Centre 728 for »Environmentally-Induced Ageing«) in Düsseldorf	- DFG Sonderforschungsbereich 488 »Molekulare und zelluläre Grundlagen neuraler Entwicklungsprozesse« (Collaborative Research Centre 488 »Molecular and cellular bases of neural development«, Heidelberg - Leibniz-Institut für Altersforschung (Leibniz Institute for Age Research) – Fritz-Lipmann-Institut e. V.(Fritz-Lipmann Institute) (FLI) in Jena - Max-Planck-Institut für die Biologie des Alterns (Max Planck Institute for the Biology of Ageing) in Cologne, in combination with the CECAD Excellence Cluster

Table 2: Actors in the field of ageing research in 2009

Analysis shows that some institutions are however still lacking, so the topic coordinators concluded that Helmholtz Association institutions, such as the German Cancer Research Center in Heidelberg or the newly-founded German Centre for Neurodegenerative Diseases in Bonn, which focus mainly on pathology, should become involved in this area, as should the Max Planck Institute for Human Development in Berlin, the Jacobs Center on Lifelong Learning and Institutional Development in Bremen and the Fraunhofer Ambient Assisted Living Alliance.

4.6 Sustainable actors' groups

The future actors in the area of ageing research emerge from those already in existence, but they will work in an increasingly interdisciplinary and long-term context and also involve industry. Ageing research will however rely on a scientific approach in the long term.

Actors in the field of ageing research	

- Max-Planck-Institut für Biologie des Alterns (Max Planck Institute for the Biology of Ageing), Cologne
- Max-Planck-Institut für demografische Forschung (Max Planck Institute for Demographic Research), Rostock
- Max-Planck-Institut für Entwicklungsbiologie (Max Planck Institute for Developmental Biology), Tübingen
- Max-Planck-Institut für molekulare Zellbiologie und Genetik (Max-Planck Institute for molecular cell biology and genetics), Dresden
- Max-Planck-Institut für Bildungsforschung (Max Planck Institute for Human Development), Berlin
- Max-Planck-Institut für biophysikalische Chemie (Max Planck Institu-
	- Universität Ulm (Ulm University)
	  - Max-Planck-Forschungsgruppe Stammzellalterung (Max Planck Research Group for Stem Cell Ageing), Ulm
	  - Transferzentrum für Neurowissenschaft und Lernen an der Universität Ulm
	- DFG Sonderforschungsbereich 728 »Umweltinduzierte Alterungsprozesse« (Collaborative Research Centre 728 for »Environmentally-Induced Ageing«), Heinrich-Heine-Universität Düsseldorf
	- Forschungsgruppe Gesundes Altern, Universitätsklinikum, (Research Group for Healthy Ageing),Schleswig-Holstein, Kiel
	- Jacobs Center on Lifelong Learning and Institutional Development, Jacobs University, Bremen

te for biophysical chemistry), Karl-Friedrich-Bonhoeffer-Institut, Göttingen

- Helmholtz-Gemeinschaft (Helmholtz Association): Max-Delbrück-Centrum für Molekulare Medizin (Max-Delbrück Center for Molecular Medicine), Berlin
- Helmholtz-Gemeinschaft (Helmholtz Association): Deutsches Krebsforschungszentrum (DKFZ) (German Cancer Research Center), Heidelberg
- Helmholtz-Gemeinschaft: Deutsches Zentrum für Neurodegenerative Erkrankungen (DZNE) (Helmholtz Association - German Center for Neurodegenerative Diseases), in Bonn, with six partner units (Göttingen, Greifswald/ Rostock, Magdeburg, Munich, Tübingen, Witten/ Herdecke; with Dresden planned to be the seventh partner)
- Leibniz-Institut für Altersforschung – Fritz-Lipmann-Institut e. V. (FLI) (Leibniz Institute for Age Research – Fritz Lipmann Institute) Jena
- Leibniz-Institut für Neurobiologie (Leibnitz Institute for Neurobiology), Magdeburg
- Fraunhofer-Institut für Zelltherapie und Immunologie (IZI) (Fraunhofer Institute for Cell Therapy and Immunology)I, Leipzig

University research institutions and groups

- Ludwig-Maximilians-Universität Munich
- Ruprecht-Karls-Universität Heidelberg
  - Netzwerk Alternsforschung (NAR) (Network Ageing Research), which regards itself as the successor to the Deutsches Zentrum für Alternsforschung (DZFA) (German Center for Research on Ageing)
  - DFG Sonderforschungsbereich 488 »Molekulare und zelluläre Grundlagen neuraler Entwicklungsprozesse« (Collaborative Research Center 488 »Molecular and Cellular Bases of Neural Development«, Heidelberg
- Technische Universität München
- Rheinische Friedrich-Wilhelms-Universität Bonn
- Leipzig University
- Eberhard Karls Universität Tübingen – Hertie-Institut für klinische Hirnforschung (Hertie Institute for Clinical Brain Research) at Universitätsklinikum Tübingen
- Georg-August-Universität Göttingen (Göttingen University)
- Johann Wolfgang Goethe-Universität Frankfurt am Main
- Interdisziplinäres Zentrum für Altern, Martin-Luther-Universität Halle- Wittenberg
- Entwicklungsneurobiologie am Institut für Biologie (Developmental neurobiology at the Faculty of Biology) at the Ruhr-Universität Bochum

Research networks

- Max-Planck International Research Network on Aging (MaxNetAging)
- Fraunhofer Ambient Assisted Living Alliance

Relevant expert organisations

- Deutsche Gesellschaft für Alternsforschung (DGfA) (German Association for Ageing Research)
- Deutsche Gesellschaft für Gerontologie und Geriatrie (DGGG) (German Society of Gerontology and Geriatrics)
- Deutsche Gesellschaft für Neurogenetik (DGNG) (German Society of Neurogenetics)
- Deutsche Gesellschaft Neuropathologie und Neuroanatomie (DGNN) (German Society of Neuropathology and Neuroanatomy)
- Deutsche Krebsgesellschaft (DKG) (German Cancer Research Center)
- Gesellschaft für Entwicklungsbiologie (GfE) (German Society for Developmental Biology)
- Gesellschaft für Biochemie und Molekularbiologie (GBM) (Society for Biochemistry and Molecular Biology)
- Gesellschaft für Neuropädiatrie (GNP)
- Deutsche Gesellschaft für Perinatale Medizin (DGPM) (German Society of Perinatal Medicine)
- Deutsche Gesellschaft für Zellbiologie (DGZ) (German Society for Cell Biology)
- Gesellschaft für Humangenetik (GfH) (German Society for Human Genetics)
- Neurowissenschaftliche Gesellschaft (NWG) (German Neuroscience Society)
- Deutsche Gesellschaft für Geriatrie (DGG)
- Deutsche Gesellschaft für Neurologie (DGN)
- Gesellschaft für Regenerative Medizin (GRM) (German Society for Regenerative Medicine)

- Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen-Nürnberg University)	- Deutsche Gesellschaft für Prävention und Anti-Aging-Medizin German Society of Anti-Ageing Medicine) (GSAAM)
- Universität Konstanz (University of Konstanz)	
- CECAD Cologne (Exzellenzcluster zur zellulären Stressantwort bei alters-assoziierten Erkrankungen, Universität zu Köln	

Table 3: Future actors in the field of ageing research in 2009

Several of the experts surveyed deplored the fact that there are two competing specialist organisations both claiming ageing research as their own (the DGfA and DGGG). On the one hand this makes interdisciplinary dialogue more difficult. On the other hand, the lack of an agreed position makes it almost impossible to get involved in research policy debates.

Other organisations

- Deutsche Akademie der Technikwissenschaften (acatech) (German Academy of Science and Engineering), Nationale Akademie der Naturforscher Leopoldina (German National Academy of Sciences Leopoldina), the Jacobs Foundation, Zurich and the »Akademiengruppe Altern in Deutschland« (2006-2009)
- Deutsches Zentrum für Altersfragen e. V. (DZA) (The German Centre of Gerontology), Berlin, funded by the German Federal Ministry for Family Affairs, Senior Citizens, Women and Youth (BMFSFJ)

Funding programmes

- **Volkswagen Foundation**
  The Volkswagen Foundation's research initiative on »Individual and Societal Perspectives on Ageing« has a total funding of approximately 3.6 mio. Euros for twelve projects, in which scientists from 17 universities and research institutions are participating. These research projects, which started in October 2008, will run for three years.
- **BMBF GerontoSys –Systembiologie des Alterns (A systems biology of ageing)**
  Three projects with a total funding amount of 12 million Euros, in which ageing processes are being investigated in interdisciplinary research, with further tendering round(s) planned.

Many existing funding programmes, especially the BMBF's, deal with sub-fields of ageing research (e.g. funding for neurosciences, research into demographic change or skills networks in medicine, including more funding for research into neurodegenerative diseases) (Roloff and Beckert 2006).

Projects and funding programmes at the European level

Again, this is just a brief selection: there are many other programmes funding research into ageing.

- **ERA-AGE**
  An ERA-NET was started in March 2004 with the goal of networking funding for ageing research. The ERA-AGE Network (»European Research Area in Ageing Research« (Walker 2009)). The ERA-AGE project follows a structural scheme within EU research funding. It is designed firstly as a research funding instrument help to further develop the area of ageing research. Secondly, by setting future priorities for research funding programmes, the network will intervene in and shape developments in this area. Thirdly, it seeks to emphasise the social benefits of ageing research through intensive contact with politicians and users and to concretely focus on the need for research in this area (Geyer 2008). A related funding programme headed by European scientists (»Future Leaders of Ageing Research«, FLARE) has also been initiated.
- **AGEACTION**
  As part of the 6th Framework Programme, a conference on the topic of »AGEACTION – Changing Expectations of Life« was held on the 23rd of April 2007 at Newcastle University (Denley, Bell 2007). The goal was to advance ageing research at a European level. A range of different topics were discussed in five panel sessions (biology, finances & industry, technology, medicine and social sciences) and corresponding recommendations formulated.
- **INNOGRIPS**
  The third »Innovation Policy Workshop« was held as part of the PRO INNO EUROPE initiative on the 18th-19th of December 2008, with the motto of »Innovation in an ageing society« (Basset 2009).
- **SHARE**
  The SHARE (»Survey of Health, Ageing and Retirement in Europe«) (Börsch-Supan, SHARE project team 2009) project was also initiated at a European level. This was a long-term collection of data on the health and social and economic situations of people aged over 50. The project is to be continued from 2009 by individual participating states.

4.7 Recommendations

A wide range of various actors are active in ageing research and should be better networked and coordinated in future. Multidisciplinary projects currently predominate in the area of gerontology: the various disciplines involved in ageing research work mainly in parallel. »Interdisciplinary« projects often do not mean however, that methods and theories are in fact integrated (Geyer 2008).

Further research on integrating the methods and theories of ageing research could make a major contribution to improving the possibilities of cooperation (Baltes 2002). A developed interdisciplinary and trans-disciplinary cooperation could yield a great potential for ageing research in terms of the meaning of targeted research results (Baltes 2002; Geyer 2008).

Consolidating discussions about learning and ageing (learning in different phases of life) in a strategic dialogue could also have an influential impact in the various actors' groups now.

As in the future field of Health, the experts also recommended strengthening translational research in the area of ageing. Only a prompt and scientifically monitored transfer of basic scientific findings to applications can result in tangible benefits for people. There is still a need to explain the mechanisms of ageing processes at a molecular, cellular, tissue and organ and organism level using model systems and animal models in fundamental research. A stronger focus on orienting fundamental research in terms of concepts and organisation is also required so that it can contribute directly to delivering a transfer of findings to people and to clinical and health-care research.

The topic coordinators also recognised that ageing research poses many ethical, religious and regulatory issues, which also need to be researched, preferably contemporaneously. This would go beyond classic »accompanying research«, because it addresses fundamental areas of life such as extending the life span and immortality (see also Human-Technology Cooperation).

The topics of ageing research were regarded as very important in the online survey and by the Monitoring Panel. Immortality and prolonging life were however viewed more critically and largely rejected as goals for research. The German population shares this ambivalent attitude. This same ambivalence expressed by the scientists surveyed in the BMBF Foresight Process is also reflected in the current survey, » Vision Deutschland – neue Wege in die Welt von morgen (Vision Germany – New Ways in the World of Tomorrow)« (Opaschowski 2009). In this survey, 96 percent of those surveyed said that they regarded treatments for diseases ranging from Alzheimer's to Aids as »the« No. 1 future innovation. Only 31 percent in contrast, viewed the use of genetic technology findings to simply increase life expectancy to a hundred years as relevant (drugs to increase intelligence did even worse, with only 20 percent approval) (Opaschowski 2009). Yet findings on the mechanisms of ageing will create a knowledge and technology base that would make such interventions to prolong life possible. Extending life is often objectively rejected, yet when it's your own life or that of a family member that is affected, such evaluations can change completely (Cuhls et al. 2007). A similar situation can also be observed in the future field of Human-Technology Cooperation. There too, the treatment of neurological diseases (e.g. »locked-in syndrome«) was approved of, but »brain doping« and implants to increase performance were rejected.

The topic coordinators were of the opinion that there is a general need for social-scientific monitoring and ethical, social and political reflections on research into the biology of ageing, to determine which forms of extending life are regarded as either socially desirable or unacceptable. This discussion is emerging slowly in Germany (von Bredow 2005). A broader ethical-social discourse, like the one being held in the USA, will however be necessary (Knell, Weber 2009; The President's Council on Bioethics, Kass L. R. 2003).

5 Sustainable Living Spaces

Living spaces will in future be different in terms of structure and organisation. Driven by the reorganisation of ways of life and technological possibilities, chronological and spatial residential and living patterns are changing. Together with demands for sustainable spatial development, these changes require innovation and adaption in various research areas.

In order to react to continuing social trends in the long term, settlement-structural concepts will have to be made more dynamic to better manage basic conditions, and flexible, environmentally-friendly spatial and settlement structures established, for example. Efforts to meet these demands, which are still in flux, are obstructed by current settlements and infrastructures, which can only be changed at a high cost and expenditure of resources in the short to medium term. All infrastructures, those for providing energy, transport, water and even information and communications must be made more flexible at a technical level and the possibility of reconstructing or dismantling them in the future must be taken into account in their implementation.

Sustainable settlement development also requires different planning and governance structures specifically aimed at integrated infrastructure management and cognisant of the wider significance of the built environment's life cycles. Actors' structures and new forms of cooperation play an important role in implementing and establishing sustainable settlement and service concepts, not just in technical infrastructure, but also in the area of social services.

Well-coordinated efforts by actors in various research areas will be necessary in future operations in this area of tension. Potential structural and technical innovations will emerge that cannot be foreseen today. Firstly however, a fundamental understanding of complex connections is necessary. The vital role of the state in developing and building up large new infrastructures must also not be neglected.

5.1 The future field

On the one hand, living space worldwide is subject to constant structural change. On the other hand, settlements and infrastructures that can only be changed in the short to medium term at a high cost and the significant expenditure of resources required stands in the way of this change (cf. Koziol/ Walter 2006; Siedentop et al. 2006, Schiller et al. 2009). Although active organisation and design of this space is of great social and practical relevance, many current technologies and research approaches are oriented towards existing forms of life and housing. Research is required that is oriented on the one hand towards the general principle of sustainable spatial development and which on the other hand accommodates the challenges of providing greater flexibility and dynamism in land use and infrastructure. There are already initial approaches being made in this area as part of the »Stadtumbau Ost« research programme (cf. Koziol et al. 2006). A further future focus of research will be the organisation and provision of public and private services and questions of the »governance« of living space (e.g. in connection with local sustainability strategies).

This requires interdisciplinary cooperation and networking across various fields of research and technology such as spatial development, mobility, materials, energy, water, information and communications technologies, production concepts, biotechnology, architecture and building research.

Among the central aspects of this research field are:

- Structures and concepts to allow for a greater **dynamism** in the expansion and conversion or renaturation of human living spaces
- Technologies and concepts for greater **flexibility of supply and disposal systems** (including energy, supply and disposal, information and communication, water, integrated transport and logistics systems, contemporary architecture and building research)
- **»Governance« concepts**[35] to enable sustainable settlement management and innovations for sustainable services in residential and living environments by re-defining the role of spatial planning and new groups of actors.

5.2 The initial situation in the future field now (2009)

Despite the countless spatial and urban planning approaches towards developing a compact, sustainable city, the trend towards high land-consumption housing development (external development) oriented more towards the margins of urban space continues unabated, despite stagnating or shrinking population developments. This spread of settlement structures is accompanied by an even greater expansion of the scope for action, which is continuing in the face of efforts to create compact settlement development (cf. BBR 2005).

35 »Governance« is defined here as the systems for controlling and regulating institutions and organisations, including the state in its hierarchical division into the federal, state and local levels. Other private and public organisations can however also be involved in »governance« concepts.

Spatial research (urban and regional research) has been dealing for some time with unsustainable spatial development processes such as suburbanisation and urban sprawl and their interaction with the development of traffic volumes, assuming population growth and immigration. There are many model projects and research programmes aimed at developing and providing application-oriented, scientific and practical findings for decision makers in the areas of land use and urban planning and transport.[36] The aspect of infrastructure, which accompanies spatial development and on which it relies, is increasingly important in this context. This is particularly important from the point of view of the state, because the public infrastructure that maintains public services, despite a continuing EU-wide tendency towards liberalisation, is often state-owned or strongly regulated by the state.

More recently however, research has focused on the effects of megatrends, in particular on demographic and social change (e.g. the ambivalent development of regions in terms of demographic developments) and climate change. In connection with the public sector's strained financial situation, the aspect of cost optimisation also plays a significant role, especially in decentralised suburban or peripheral rural settlement areas (cf. e.g. Reidenbach et al. 2005).

Reacting to these long-term trends in ways that use resources and costs efficiently will mean **creating more flexible supply and disposal systems** that are characterised by long »life spans« and will require major research efforts and action at the technological level. There are currently some model and demonstration projects in which central supply and disposal infrastructures are being replaced by innovative decentralised concepts, which due to their cost benefits and flexibility will better meet future demands.[37] As well as technical circulation systems, the social infrastructure designed to ensure supply and the population's security (schools, the fire brigade and police), is also under pressure to change. Some concepts for small-scale materials cycles have also been developed as part of wider discussions about sustainability and research into life cycle analysis.

36 These include the 'Forschungsprogramm Stadtverkehr' (Urban Transport Research Programme) (FoPS) for improving transport conditions at a municipal level, the MORO (Modellvorhaben der Raumordnung – Development Projects of Spatial Planning) action programme and the ExWoSt (Experimenteller Wohnungs- und Städtebau – Experimental Housing and Urban Development) research programme, all run by the BMVBS and supported by the BBR. There are also research programmes dealing with globally relevant changes to living spaces, such as the BMBF's »nachhaltige Entwicklung der Megastädte von morgen« (Research for sustainable development of the megacities of tomorrow) and »Forschung für den Klimaschutz und Schutz vor Klimawirkungen« (Research on climate protection and climate change) (klimazwei) research projects.

37 One research project funded by the WestLB-Stiftung Zukunft NRW (West LB Foundation) »AKWA 2100 – Alternatives der kommunalen Wasserversorgung und Abwasserentsorgung« (AKWA 2100 – Options for Sustainable Urban Water Infrastructure Systems) (Hiessl et al. 2005) should be mentioned as an example here.

Beyond the purely technological aspect, it is also necessary to change spatial and settlement structure concepts, so the **dynamics** within **settlement concepts** are also a topic for research. This will require public financing to support model projects on the effects of climate change for example, but especially with regard to changes in dealing with water in living spaces. As part of the recently completed »Klimazwei – Research for Climate Protections and Protection from Climate Impacts« (www.klimazwei.de) funding measure for example, the »Water-Sensitive Urban Design« project was developed under the leadership of the RWTH University Aachen, which in cooperation with three cities in the Ruhr area developed concrete spatial measures for sustainably adapting water management systems to climate trends and extreme weather. The recently completed BMBF research priority programme »Klimzug« (www.klimzug.de), which promotes the development of innovative regional approaches for adapting to climate change and integrating expected climate changes in regional planning and development processes, also contributed to advancing developments in this area. The research community also identified deficits in terms of the competitiveness in the European domestic market in the area of technical, building-cultural and organisational innovations in the German building industry, which the »Zukunft BAU« (»Future Building«) research initiative of the Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry of Transport, Building and Urban Development) is designed to counter. This involves issues such as energy efficiency, new materials and optimising costs, among others.

Political management and planning will be essential in implementing the areas outline above, a fact also emphasised by the Bundesamt für Bauwesen und Raumordnung - BBR 2009 (Federal Office for Building and Regional Planning). There are already some research approaches for promoting **sustainable settlement management** and sustainable **services concepts** through innovations in the area of **governance**. These include all the optimisation approaches that can be achieved through new planning approaches, new actors' groups and political interventions. One example is the new challenge of coordinating between planning bodies and infrastructure operators in shrinking spaces, which became clear in expert interviews (see also Siedentop et al. 2006). There are currently many other approaches towards determining and allocating the costs of developing settlements. As part of the BMBF's[38] »REFINA« funding priority, a tool based on a geographical information system (GIS) was developed that can be used to forecast the effects of residential land development strategies , taking population developments and local budgets into account (cf. Koziol/ Walter 2006; Siedentop et al. 2006, Schiller et al. 2009).

38 = Forschung für die Reduzierung der Flächeninanspruchnahme and ein nachhaltiges Flächenmanagement (Research for the Reduction of Land Consumption and for Sustainable Land Management), in cooperation with the BMVBS and the BMUNR.

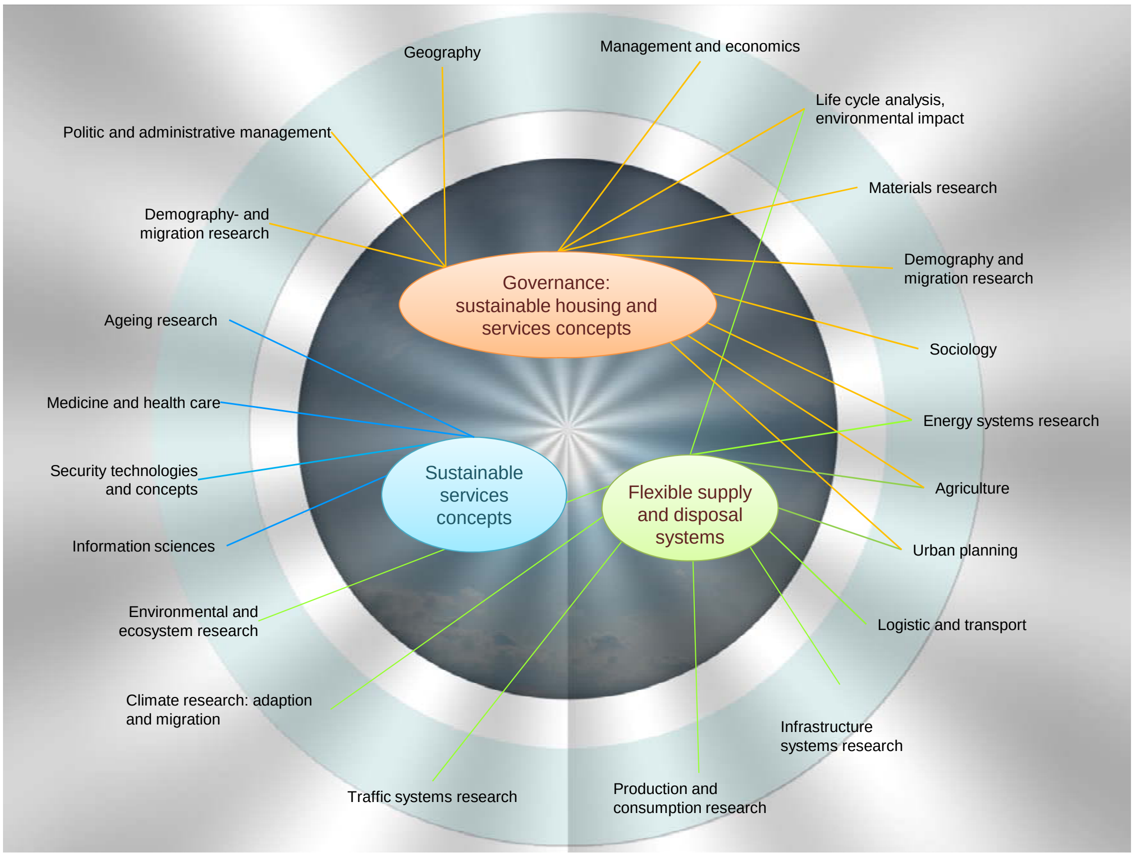


Figure 3: Future participating research areas

One major element of the future field's initial situation is the integration of individual research topics in other research areas and disciplines, as they are shown in the outer circle in Figure 3.

5.3 The long-term outlook for the future field

The previous chapter has shown that there are already many approaches towards confronting currently emerging problems in the area of infrastructures and living spaces. Most projects for dealing with the future challenges mentioned are however of the model kind and only partly result in universal recommendations for actors. One frequent impetus in current projects is demographic change, which will result in small-scale changes in housing density and age structures and in the technical and economic problems associated with under-utilised existing network infrastructure. In addition to these changes affecting space, there are countless other connections among the topographical, ecological, social, cultural and technical conditions of the respective living environments that have not yet been examined scientifically. For this reason, the dynamics of concepts and flexibility of technical systems and land use in both new buildings and existing stocks will be vital areas of research in the coming decade.

In order to represent the long-term prospects of the research topics described, they have been divided into various potential applications:

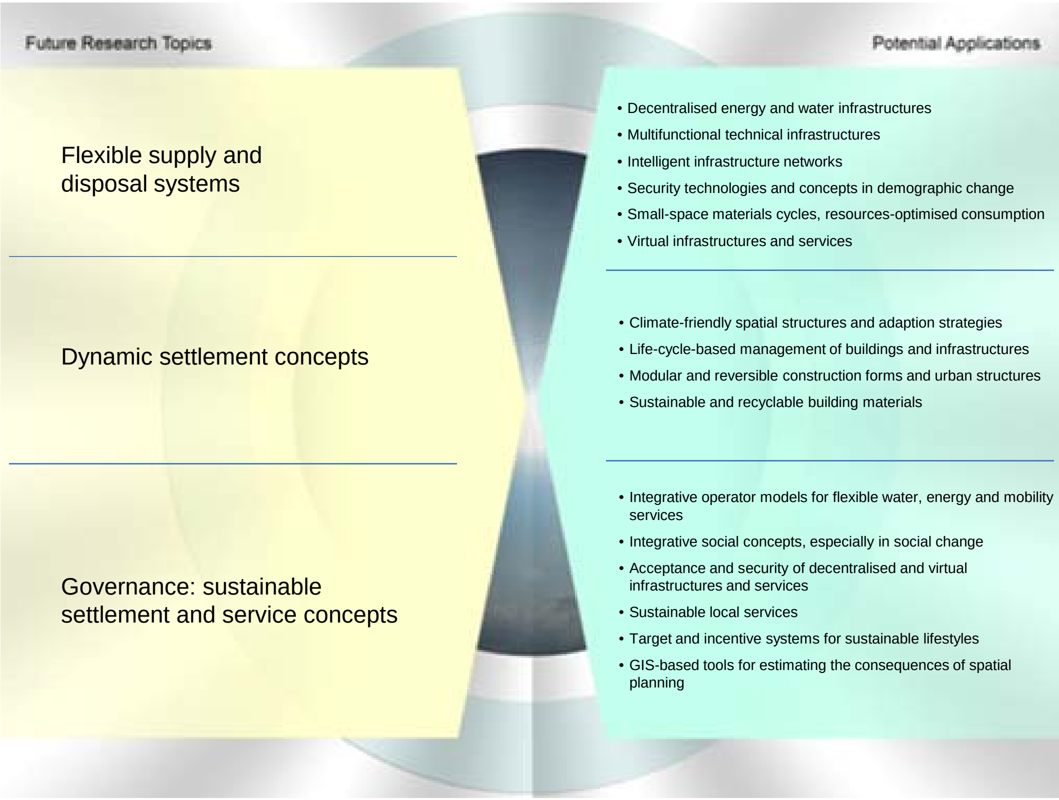


Figure 4: Future research topics and potential applications in the future field of »Sustainable living spaces«

Flexible supply and disposal systems

Most existing networked infrastructures, especially those parts of it laid underground, has a very long »lifespan« of up to 80 years. The general conditions of life however, especially those linked with megatrends in demography and climate change, are changing. Of central importance for sustainable infrastructure planning is the question of how networks, plants and facilities will have to be created in future so that they can be adapted with a minimum of effort to changing conditions or dismantled. How can existing networks be successively converted in this direction? Approaches range from the recycling individual infrastructure components through to making large structures easy to dismantle. One specific sub-aspect of this area is the issue of sustainable applications for decentralised concepts adapted to a small scale, such as further developing membrane technologies to increase the reliability of local sewage and filter systems so that they can cope with varying inputs and environmental conditions. While there are sustainable technological concepts for waste water treatment, the field of decentralised water supply still offers considerable research and development opportunities (cf. remarks on the topic of »water«).

The tighter public financial situations forecast for the future pose important research questions around the most efficient management of grid-bound infrastructures. How can systems be integrated to include multifunctional units to make investment and maintenance more efficient? Examples of solutions include integrated energy and information networks and modular and standardised line infrastructures with synchronised maintenance cycles. Modular road infrastructure concepts with standardised water, telecommunications and energy supply equipment are also conceivable in this context.

New services such as electro-mobility, the dynamic controlling and toll charging of traffic flows across large network areas, flexible water and electricity charges and the fluctuating input of renewable energies require the creation of »intelligent networks«. This represents a particular challenge as well as potential in the area of technological innovations. Approaches to solutions are emerging in the merging of energy and communication networks. Energy use will be transformed by the proliferation of electric vehicles and their significance as mobile energy stores (»vehicle-to-grid« concepts). This then raises the question of how charging stations can be technically designed and positioned in a way that will solve the current problem of the range of electric vehicles.

In the area of transport infrastructures, »network intelligence« pursues the goals of security and comfort. Future research topics here include the standardising of interfaces, in particular for connecting individual transport with public transport, and the simplicity and cost-efficiency of systems (cf. acatech 2006). Especially in respect of urban tolls and traffic management systems, there is still in Germany, measured against international activities, considerable pent-up demand in terms of practical applications. New supply infrastructures such as underground pipe systems, »People Movers« in urban areas and a more flexible use of existing systems also have potential for specific regional environments.

Another issue is the optimising of the resources used in consumer products. While the focus used to be on the finite nature of energy resources, in future other resources used in production (such as precious metals), and the risks connected with obtaining them will also come to the fore (cf. Angerer et al. 2009). Optimising recycling, especially on a small-scale basis, is therefore an important research area. The increasing proliferation of decentralised renewable energy sources also raises the issue of sustainable, self-sufficient energy supplies for remote regions.

As public funds become scarcer, regular police surveillance of remote regions will be limited, so virtual infrastructure to support or take over such tasks will come to the fore. In the private, domestic environment, support systems (»Ambient Assisted Living«) will play an increasing role, given society's changing age structures (cf. Georgieff 2010). Closely connected with this is the question of desired levels of virtual supply, the influence on alienation and social cohesion and the manifestation of distance due to a decreasing necessity for physical encounters. The further development of ongoing field tests as part of the BMBF's »Health Care Regions« programme in extending the benefits and reliability of technical systems, necessary IT infrastructure connections, operator models and implications for healthcare and nursing systems will continue to be vital in the long term. The healthcare system of the future (see also the future field of »Health«) will have to provide appropriate solutions in this area.

Dynamic settlement concepts

Settlement policy and the spatial planning it is based on must adapt to greater dynamism and react with corresponding concepts. Building on the diverse research that has been done in the search for the right strategies for adapting to climate change, the focus must be on action as opposed to reaction in the long term. A recent survey of regional planning bodies revealed that the role of spatial planning in dealing with the consequences of climate change has so far been barely defined, although providing protection from extreme events is regarded as the biggest regional planning challenge (Overbeck et al. 2009: 196, 199). According to the experts interviewed, a central challenge of today's settlement structures and infrastructures lies in making cities as resistant as possible to frequent extreme weather events. Approaches developed in Rotterdam, where the implementation of innovative climate adaption technology is being planned, are especially worth mentioning here. Various short-term water storage facilities are distributed throughout the city, including water basins that are used for skating in dry periods, and water tanks in residential developments and on greened house roofs (de Greef/ Zsiros 2008).

This also raises the question of how spatial structures can be created to be climate-friendly at an early stage of planning. Will new planning instruments be required (at a regional and municipal level) to keep particularly endangered areas near rivers and coasts free of buildings (e.g. obligatory implementation of regionalised climate data and small-scale surveys of potential dangers)? Building on the results of **Klimazwei** and **Klimzug**, research activities at a local level should be incorporated.

At the level of individual buildings, it can be assumed that despite existing research approaches, the topic of technical, building-cultural and organisational innovations will remain on the research agenda for the medium term. Given the massive type of construction now mainly in use, the durability of building forms and structures and their ability to adapt to changing general conditions will become a particular focus of public discussion. How can building forms and urban structures that are both built in modular fashion and can also be easily removed and recycled as required be planned and implemented? What innovations in the area of building materials will be necessary to achieve this kind of construction?

The public sector will be mainly relied on to provide investments in this area. In the opinion of some experts, such as the Sachverständigenrat der Bundesregierung (German Council of Economic Experts), German public investment in these areas is already at a low level when compared on an international level, so it will tend to increase in future.[39]

Governance – sustainable settlement and services concepts

Directly connected with the question of who will bear the costs of the necessary investments in this area, is the question of the actors and cooperation methods required to promote sustainable settlement management. One general challenge will lie in the institutional establishment of decentralised, modular and/or flexible systems in traditionally long-term, growth-based infrastructure areas. This requires a coordinated and targeted interplay of the relevant actors, so that the issue of governance and its form also plays an important role. The research question here is, how can an integrated infrastructure management be organised that covers all the infrastructures involved (electricity, gas, local and long-distance heating, water, effluents, telecommunications, road construction planners and public transport operators) at the same time over a large spatial area and reconciles economical resources use with the lifestyles of an increasingly pluralistic society? Which economic and regulatory incentive systems could help to achieve these goals?

Developing and introducing innovative operator and innovation models is a particular challenge in cases involving the market shares and business areas of established institutions. Sustainable business models take the economic, ecological and social impact on all participating actors into account, with catchphrases such as »use instead of ownership«, »central operation of decentralised facilities« and »variable charging systems«.

As well as technical infrastructures, social infrastructures will play a central role in shaping the living space of the future. Central challenges include dealing

[39] According to information provided by the Hans Böckler Foundation, the proportion of investment in roads and school buildings has declined greatly, from 4.7 percent of GDP in 1970 to 1.5 percent in 2007 (http://www.boeckler.de/32014_95645.html).

with the expected shortage of skilled workers, which will also impact the areas of nursing and care, financing and business models, visions and options of urban and residential development, and not least dealing with the conflict between people's need to stay in their homes and the necessity of dismantling settlements.

Promoting local production and consumption structures and the logistical networks adapted to them could contribute to maintaining the economic potential and quality of life of structurally-weak areas. Future challenges in this area will lie in designing and strengthening innovative local production, trading and logistics networks and analysing factors that have impeded previous pilot projects.

It must be noted however, that even in the face of the ongoing tendency towards liberalisation, privatisation and innovative operator models, some infrastructures and network-based services should, for various reasons, remain in state hands. Among these is the supply and disposal of water through traditional central systems, management of which is almost completely subject to a public usage regulations (Leist 2007:71). The establishment of decentralised systems could involve commercial operator models, although the necessary public authority regulatory framework raises further unresolved issues. The future actors' structure and networks and future legal framework conditions, especially at the EU level, are also still very vague.

The concrete organisation of life in settlements raises the question of how increasingly differentiated lifestyles could be put on a sustainable basis. What systems of goals and incentives would be required, how can the acceptance of lifestyles that use resources economically be increased in the long term and what role do regional and social conditions play here?

Small-scale prognoses that will enable »use-by dates« to be taken into account in the long-term of planning housing developments and their infrastructure from the outset are also necessary. Based on these, innovative instruments such as construction law and the marketing of specific areas of property could then be used, short-term building permits, heritable building rights and leasing concepts, for example. What has to be done to establish and standardise a life cycle-based management of buildings and infrastructures? How could this be technically implemented, measured and evaluated? The question is also raised of how the costs of existing residential development and infrastructure could be legally allocated to users and others causing them.

Local planning bodies play a decisive role in this research area. Their continuously improving IT equipment and skills will mean that in future small communities will have more options for managing planning than is currently the case.

There is also the question of how GIS-based tools could help in assessing the consequences of spatial planning and thus in evaluating residential development policy.

5.4 Why is this future field relevant?

Effective infrastructure is a fundamental precondition for the exercise of basic existential functions and the competitive production of goods and services. Without adequate educational institutions, healthcare and transport facilities, communications and supply and disposal services, high-quality living, the guaranteed provision of individual and collective educational standards, active participation in public life and a prosperous economy would be inconceivable (BBR 2005, BMVBW/ BBR 2005). A great deal of research is already being done in this future field. There is a partial lack of basic information and data here, but the real relevance of the topic results from the fact that there is often a lack of acceptance and political will to fundamentally change current settlement and infrastructure systems (cf. also Overbeck et al. 198). In order to achieve greater dynamism and flexibility, close coordination and strategic cooperation among a range of actors will be necessary.

Due to an often weak economic pressure to act, a systematic networking of actors, e.g. of municipal urban planners and »utility« companies, is lacking. Much greater cooperation among bodies currently responsible for housing in cities and regions is necessary. This would involve public planners but also the private sector, especially those responsible for infrastructure above and below ground (such as supply and disposal systems). To this are added the political-economy and legal dimensions of the problem, in particular the question of how costs can be allocated towards users and those causing them and the burden on the public purse be alleviated.

The need to supply populations with products and services on a more sustainable basis is a global challenge. Germany would also profit from potential technology exports if products that used resources more efficiently were developed and supply and disposal infrastructure could be more flexibly designed through new technologies.

Guaranteed personal and technical safety is another fundamental need of citizens. In view of the increase in external dangers (e.g. due to climate change) efforts must be increased to guarantee existing security levels in future through technological innovation.

5.5 Current actors in the innovation system

Given the breadth of this future field, there are many different actors who define the innovation system in this future field, e.g.

Actors in the area of sustainable living spaces

- ARL – Akademie für Raumforschung und Landesplanung (The Academy for Spatial Research and Planning)
- Bundesamt für Bauwesen und Raumordnung – BBR (Federal Office for Building and Regional Planning) (e.g. through the »Aufbau Ost« research programme), incl. the recently founded Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) (Federal Institute for Research on Building; Urban Affairs and Spatial Development) as a departmental research institute within the area of operations of the BMVBS
- Deutsches Institut für Urbanistik – DifU (The German Institute of Urban Affairs) (e.g. through the BMBF's research programme »REFINA – Research for the reduction of land consumption and sustainable land management«)
- Deutscher Städtetag, Städte- und Gemeindebund (German Association of Cities and Towns)
- Institutional networks of experts from the fields of science and practice (e.g. Deutsche Akademie für Raumforschung und Landesplanung – ARL (The Academy for Spatial Research and Planning); Deutsche Akademie für Städtebau und Landesplanung – DASL) (German Academy for Urban and Regional Spatial Planning); Vereinigung für Stadt-, Regional- und Landesplanung (SRL).
- Leibnitz-Institut für ökologische Raumentwicklung e. V. (Leibnitz-Institute of Ecological and Regional Development), (e.g. in the area of the resulting costs of infrastructure)

Table 4: Actors in the field of Sustainable Living Spaces in 2009

Central actors at a local level include municipalities, large housing associations and cooperatives, supply and disposal companies, municipal insurers (e.g. against flood damage), the construction industry, transport companies, industry, trades and services companies and various academic departments, institutes and planning offices that are contractors in current research projects.

It should also be noted here that the Academic Senate of the TU Berlin recently decided to set up the inter-faculty »Gestaltung von Lebensräumen« (Innovation Center for Habitat Design) innovation centre (IZ GvL, spokesman Professor Rudolf Schäfer) (cf. TU Dresden 2009). The innovation centre has taken on the task of ensuring comprehensive access to existing, researchable and configurable aspects of the built and unbuilt environment.

5.6 Sustainable actors' groups

The analysis of potential sustainable actors' groups is based on the bibliometric analysis of the innovation system and interviews with experts that were carried out during the Foresight Process.

The cross-sectoral topic of »sustainable living spaces« includes technological and spatial planning aspects as well as social topics and related governance issues. Because of the interdisciplinary nature of this future field, there are a large number of actors who could advance the topic in future. German actors are especially suited to playing a pioneering role here. Housing development and infrastructure developments in this area are already well-advanced. In the face of changing challenges, new concepts are being sought in many areas (e.g. in view of the regionally partly pronounced shrinking of the population in eastern Germany).

An evaluation of the Web of Science database with a combination of the most important key words in the areas of infrastructure, governance and living spaces showed that the networking of research communities in the topics mentioned overall is still at a very low level. Bibliometrics, based on scientific articles and conference contributions involving German participation from 2006 to 2009, shows that most publications issued from an institution (research institute, university etc.). There are also however approaches towards international networking – e.g. the University of Stuttgart and the Landesanstalt für Umweltschutz BW (environmental protection office of the state of Baden-Wurttemberg) with the ETH Zürich, who are jointly working on the future topic of flexible supply and disposal systems. Establishing interdisciplinary partnerships must therefore be another long-term goal in advancing research in this area.

The foreign experts interviewed are also integrated into international networks in the future fields listed above. Prof. Y. Hayashi from the School of Environmental Studies at Nagoya University is an important member of the Special Interest Group »Transport and Spatial Development« at the World Conference of Transport Research Society (WCTRS), where research is being promoted into the dynamic of spatial developments and infrastructures and into making them more flexible, with a particular focus on transport.

The German experts interviewed usually published together with other German researchers in this future field - spatial planner Prof. Siedentop from the Institute of regional Development Planning at the University of Stuttgart (and until 2007 at the Leibnitz Institute of Ecological and Regional Development - IÖR) has published several studies on the effects of demographic change with the TU Hamburg-Harburg (Jens-Martin Gutsche) and with Prof. M. Koziol, from the chair of Stadttechnik (urban technologies) at the TU Cottbus. Prof. Dirk Vallee from the RWTH Aachen University has, in his role as Technical Director of the »Verband Region Stuttgart« (Stuttgart regional association), also already dealt with this topic (VRS). There is therefore still great potential for future networking in this future field, especially at an international level.

The German Research Association's »Sonderforschungsbereiche« (Collaborative Research Centres) are dealing with this future field, but concentrating more on issues around settlement structures (SFB 564) and governance (SFB 700) outside Germany.

5.7 Recommendations

The literature research and survey of experts shows that in the case of sustainable living spaces, it is especially important to view new services in connection with technological developments. To advance research in this future field and develop and implement suitable instruments, it will be necessary to merge sciences that are currently pursued in individual sectors, such as infrastructure, demographic and spatial research, and establish an integrated scientific landscape for the research topics of *flexible supply and disposal systems, dynamic housing development concepts* and *governance*. This could also contribute to a strategic dialogue.

One promising step would in our view be the setting up of special research areas with national links to this topic. It would be important to involve not only research institutions, but actors from practical areas (i.e. infrastructure operators, the construction industry etc.) in research projects to implement model schemes or by launching competitions.

It is also recommended that existing loose international networks in which there is also German involvement be extended and the creation of new networks be made possible. The BBR, as an established and recognised research and policy consultation institution on all issues relevant to spatial development, could play a special role here.

6 ProductionConsumption2.0

The future field of ProductionConsumption2.0[40] aims to establish long-term sustainable »production and consumption« paradigms, involving research into new ways of supplying products and services according to need in the face of changing basic global conditions. At the same time, it addresses one of the greatest challenges of the future: maintaining the ecosphere, which is also vital to human survival.

Research in this area focuses on sustainable of industrial and social patterns of materials usage. Researchers in established areas in production research, services research, environmental research, biotechnology and materials sciences are all working with great drive on aspects of this topic area. They cannot however adequately make the necessary systemic transformation to the entire structure alone.

This future field is therefore developing methods and concepts that will enable it to consolidate these strands and analyse materials flow patterns in production and consumption in an integrated way. To achieve this, existing sustainability and innovation research concepts are being further developed and applied to concrete upcoming paradigm shifts, such as the generation of highly-consistent recycling management concepts[41].

This will enable new patterns of materials usage in industry and society that will address central social needs in a far more sustainable manner to be developed. Transformative innovations, connecting technological and organisational solutions in new ways, will make the transformation to such new patterns possible.

6.1 The future field

Research in the future field of ProductionConsumption2.0 investigates long-term, sustainable paradigms of »production and consumption«. The central challenge for research in this area is the generation of sustainable patterns of industrial and social materials usage. Instead of concentrating optimising individual elements in the value adding processes, ProductionConsumption2.0 fo-

40 2.0 stands for »new generation«.

41 For example the »cradle2cradle« principle: a model of industrial processes in which all materials move in closed biological or technical cycles. »Rubbish« in this sense doesn't exist, »rubbish« is – as in nature – the same as »nutrition«; cf. Braungart et al. (2007).

cuses on a systemic transformation of the entire structure, that is increasingly being demanded by actors from politics, research, economy and society in order to achieve the necessarily drastic reduction of the ecological »footprint« of human economic activity.[42] Clear methods and concepts for an integrated overview of production, environmental and services research will be developed and applied.

Motivation

As with all the new forms of future fields in the BMBF Foresight Process, ProductionConsumption2.0 is motivated by the dynamism of existing research fields and by the analysis of future demands. The generation of sustainable materials cycles and a fundamental paradigm shift in production and consumption emerged during the BMBF Foresight Process and in production and environmental research as vitally relevant research issues for the long term. Contributions to solutions from several future fields such as biotechnology, nanotechnology and materials sciences were also regarded as very important (cf. Table 5).

Efficient use of energy and resources in industrial production Outstanding future topic in the future field of industrial production with a focus on creating materials cycles
Management of global value-adding networks Very relevant future topic in the future field of industrial production
Paradigm shift to personalised production e.g. in generative processes A topic in the future field of industrial production that will be relevant in the long term
Biomass-based, sustainable biotechnical production A future topic in the future field of biotechnology
Molecular biological production A future topic in the future field of biotechnology
Bio-degenerative materials A future topic in the future field of materials
Hybrid value-adding A future topic in the area of services research
Bio-based production A future cluster in the future field of biotechnology
Energy-efficient applied technologies

42 cf. the Potsdam Memorandum on a »Great Transformation« drafted in 2007 http://www.nobel-cause.de/potsdam-memorandumger and BMU (2008).

A research area of outstanding relevance in the future area of energy
Energy-efficient behaviours A future topic in the future field of energy that will be relevant in the long term

Table 5: Aspects of materials flow patterns in the results of the Foresight Process

These results of the Foresight Process correspond with findings from climate and sustainability research, where it is regarded as proven that the massive reduction in the ecological »footprint« of fulfilling basic social functions that is necessary to maintain the ecosphere and its services, which are so vital to human life, can only be achieved by fundamentally reordering existing patterns of production and consumption (Liedtke/ Kuhndt 2009, Tukker/ Butter 2005, BMU 2008). The necessary magnitude of this »impact reduction« cannot be achieved through new environmental and energy technologies, nor by changing consumer behaviour, but only through systemic innovations in materials cycles in industrialised societies (cf. Figure 5). Such »transformative innovations«[43] in existing patterns of materials cycles, such as the transfer to advanced recycling management concepts or to carbon-neutral economic activity, will involve a range of organisational and technical innovations and in particular new ways of linking them.

These changes are however not occurring under stable general conditions. Many of the relevant global framework conditions of production and consumption are also in flux. Developments such as the global repositioning of production and markets, the emergence of a constantly learning society, new demands due to changing lifestyles and values, and new options from technological fields such as information and communication technologies, form the background against which successful transformative sustainability innovations will have to occur.

Proactive generation of new forms of materials turnover in industrial societies is being driven on the one hand by the pressure of problems in these areas. At the same time, the opening up of countless framework parameters could offer far-reaching chances for profound innovations that could open up the central leading markets of the future and fulfil social needs in a new quality.

43 Transformative innovations generate fundamentally new kinds of things to fulfil functions, so the focus can be on the technological and organisational elements of innovation. cf. Steward (2008).

6.2 The initial situation in the future field now (2009)

Germany is in a favourable position to launch the »Apollo-Mission« of a reordering of materials cycles in industrial societies and thus to exploit the opportunities described above. This future field can be linked with a series of activities:

- Strategic platforms such as the High-tech Strategy, Environmental Technologies Master Plan[44], Sustainability Strategy[45] and the BMBF's Forum for Sustainability (FONA) offer excellent possibilities of connections in this future field.
- Current research and development strands in environmental research, production systems, materials sciences, biotechnology and services research are addressing aspects of the challenges described above. Germany occupies an excellent position in many of the relevant technological fields.
- Under the umbrella of socio-ecological research, issues around sustainable consumption patterns have been dealt with intensively and in diverse ways.
- The social sciences, innovation research and economics are increasingly providing concepts for analysing co-evolution processes in business, technology and society.
- Globally-recognised institutes such as the Wuppertal Institute for Climate, Environment and Energy or the Institute for Ecological Economy Research (IÖW) are working on integrated concepts of sustainable economic activity.
- Advanced approaches for the holistic investigation of patterns of materials turnover are currently being developed in the field of »industrial ecology«[46].

None of the existing research fields alone can however generate the necessary complete perspective of the interaction of socio-technical innovations for sustainable material cycle regimes.

An exclusive focus on the efficient resources use in industrial production could, for example, actually distort the view of new paradigms with much greater potential for reducing resources use due to their better consistency with natural processes (cf. Braungart et al. 2007; Huber 2000). In a similar way, concentrating on reducing the use of energy resources and greenhouse gases could lead to extensive negative »rebound« effects[47] (Liedke and Kuhndt 2009). An »end-of-pipe« use of environmental technologies could also ruin chances of a much

44 http://www.bmbf.de/de/13176.php.
45 http://www.bmu.de/nachhaltige_entwicklung/stategie_und_umsetzung/nachhaltigkeitsstrategie/doc/38935.php.
46 For an overview of the current situation see v. Gleich and Gößling-Reisemann (2008).
47 Boomerang effects.

greater reduction of the »footprint« through the dematerialisation of functional performance of new business models.

Only an independent systemic perspective, according to the diagnosis of the Foresight Process, can produce the necessary transformative innovations and required »impact reduction«, by systematically integrating elements of these currently largely independently operating research areas and investigating sustainable materials turnover in terms of its transformative innovation potential. This is where the research area of ProductionConsumption2.0 gets involved.

6.3 The long-term outlook for the future field

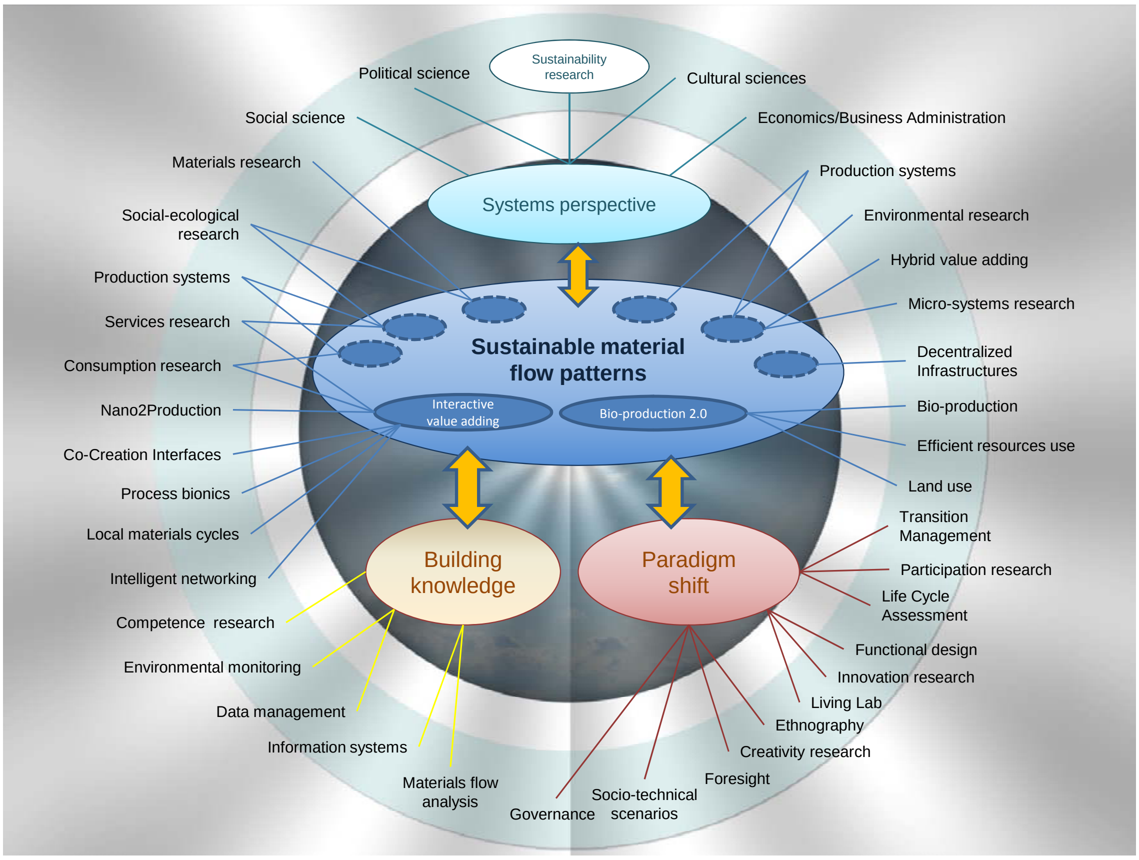


Figure 5: Possible structure of the future field

Definite concepts and methods will be required to achieve this. Approaches from sustainability research and especially from »industrial ecology« in researching materials cycles must be further developed and linked with technological and social sciences research strands in order to generate an interdisciplinary **systems perspective**. Methods will also be required to sound out not only the new patterns themselves, but also the **paradigm shift**. Anchoring

knowledge and skills in the innovation system is also an important element of the future field. A possible future structure of this future field with these elements is sketched out in Figure 5, which also makes the close interaction of four central topics clear.

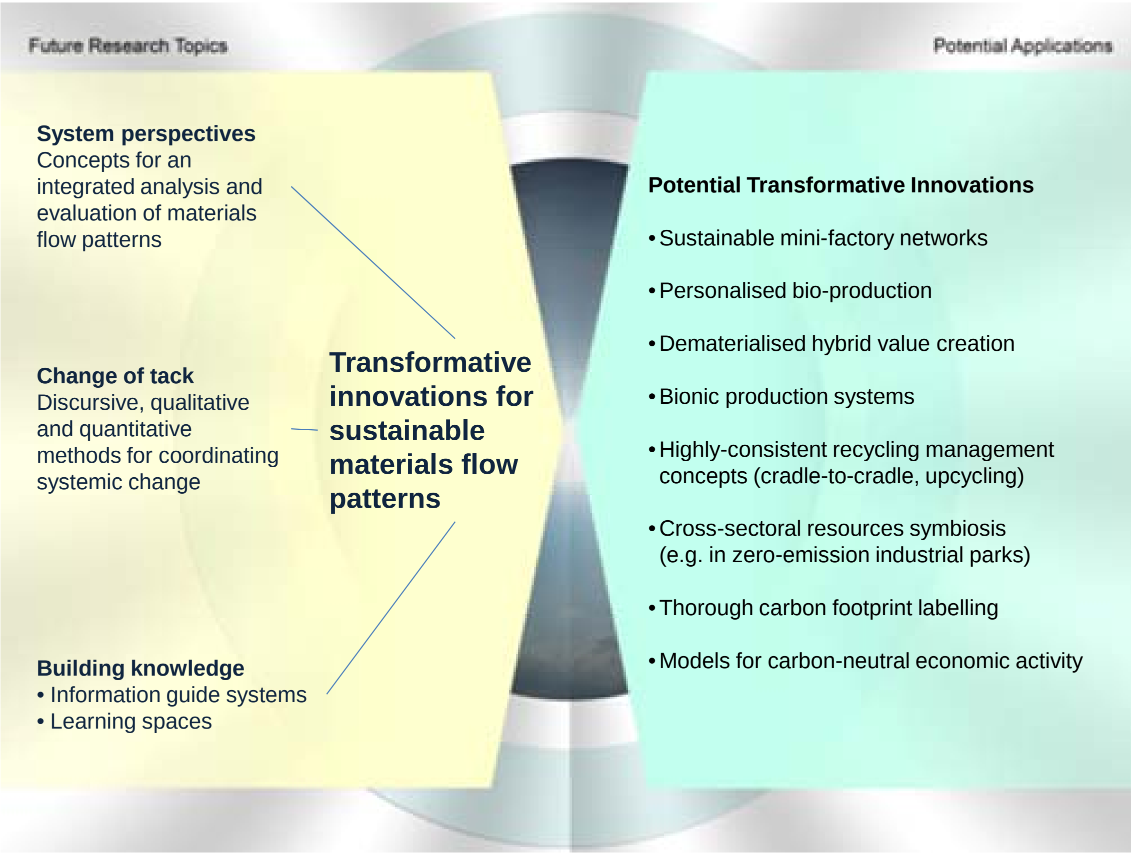


Figure 6: Future research topics and potential applications in the future field of »ProductionConsumption2.0«

Some of the innovations that could come out of this research field are shown in Figure 6. These are not individual products or technologies, but integrated concepts, including business models, organisational concepts and pathways to transformation.

The four potential research areas are outlined below.

Topical focus – sustainable patterns of materials turnover

This future field centres on trans-disciplinary, systemic research into sustainable production and consumption patterns and possible development paths to these patterns. Advanced science and technology concepts are entered on the outer circle in Figure 5 and systematically combined to sound out sustainable configurations. Significant contributions to this process are expected in particular from production research, services research and sustainability research and socio-ecological research. Fields such as biotechnology, infrastructure technology, materials research, nanotechnology and information and communication technologies also contribute central research prospects.

To make the complexity of interactions between technological fields manageable, it would seem in our view reasonable to initially concentrate research on areas where a high level of potential synergies or on a branch of production and consumption patterns that will be critical in future for materials cycles in industrial societies is emerging. For these selected »focal points« the technology fields would be specifically combined and integrated developmental paths generated and evaluated. The focal points would be identified step by step – by an interdisciplinary panel of actors, for example.

Some possible changes to these patterns that could be investigated in this way are listed below. Two concrete examples will be provided in the following chapter.

Examples of possible changes to patterns of materials cycles

- Usage-centred business models (e.g. »value for use«)
- Hybrid value adding[48]
- Carbon-neutral economic activities[49]
- »Green Chemistry« (cf. Gesellschaft Deutscher Chemiker – German Chemical Society 2003)
- Dematerialised value adding
- Interactive value adding[50]
- Bionic process concepts (e.g. cascade models)
- Personalised value-added chains with second-generation bio-refineries (cf. the future field of biotechnology)
- Cross-sectoral recyclable materials symbioses (e.g. zero-emission industrial parks)

48 Systematic integration of products and services in service packages (cf. Ernst 2005).
49 Also »Post-Carbon Economy«, e.g. hydrogen systems (cf. Schellnhuber and Pietsch 2008).
50 Added value with an extensive contribution from customers/users (cf. Reichwald et al. 2006).

Example 1: Sustainable materials flow patterns – personalised bio-production

Second-generation bio-refineries make it possible to produce serviceable materials from plant-based raw materials, which would provide the prospect of producing raw materials »on site« from locally-available raw materials. This could make it possible to inexpensively and flexibly generate a range of materials, which at the same time would be largely consistent with recycling management processes and sustainability criteria (e.g. much lower energy consumption due to lower processing temperatures).

These would be significant advantages in the period after 2020, when much stricter environmental legislation and higher demands on »green« products will probably largely determine the framework conditions of industrial production. Long transport routes and complex logistics concepts could also be dispensed with if materials were produced on site. In view of the increasingly problematic global security situation, transport routes and raw materials supplies that are now taken for granted could be questioned and increasing energy costs also become a weighty criterion in this period. The local anchoring of raw materials could be part of a regionally-oriented business model.

On the other hand, the demand for personalised products that offer a range of applications will increase in this period and possibly be even greater than is now the case. Technologies such as the intelligent, agile production of individual products and concepts of »extreme personalisation« could also become more widely used. Many production systems will operate with in-situ quality control, complete real-time simulation and be integrated into global networks with high degrees of automation and levels of »self monitoring«. With many products, individual customer wishes may be able to be taken into account right up until the last moment. Both technological developments, bio-production and personalisation, are reactions to changing needs perceived today.

An integrated development path will be required to fully exploit the potential of both strands of research. Few advantages will result if biotechnological production processes are merely subsequently added to extremely personalised production »islands«. If however there is a focus on optimising existing paradigms towards integrated transformative innovation to »personalised bio-production«, sustainability potential could be opened up in new dimensions. At the same time, many challenges are posed for research and technology. How can in-situ quality control accompany biotechnologically produced materials? What kind of sensors will be needed? What is the optimal form of »material transfer«, which steps can be taken within the refinery, which within the manufacturing system and which even »in the field«? Can these materials be provided in the necessary diversity, can personalisation extend to materials production? How can natural fluctuations in the quality of raw materials be dealt with? Which business models would be conceivable for such an expansion? How can bio-refineries be integrated into real-time simulation and management?

Such questions must first be identified then tackled in a research project and evaluation methods of the sustainability of various concepts including a global perspective be used. In parallel, a bio-production2.0 pilot plant could serve as a learning space. not only for research and technology, but also for the bodies involved, such as plant operators, regional authorities, consumers' associations and organisations involved in supply and disposal.

Example 2: Sustainable materials flow patterns – sustainable networks of mini-factories

Miniaturisation has been a central research area in the field of production for many years. On the one hand, this is about manufacturing smaller and smaller and more highly-integrated micro-systems. At the same time, there is an increasing focus on the miniaturisation of production units themselves. Mini-factories are conceived of less for »tiny products« than for the on-site production of customised individual products (cf. Reinhart et al. 2000). In extreme cases, they could even be used by customers for products themselves (e.g. to produce replacement parts), in the factory or even in a domestic setting, in the form of 3D printers for example.

The vision of a network of mini-factories as an alternative to centralised mass production poses in turn considerable technological and organisational challenges. There is a lack of design concepts for highly-individualised distributed production. Suitable customer interfaces, in which individual demands are recorded and translated into implementable productions instructions, will also be required. This concept is also a response to future challenges being discerned today, due especially to diversifying lifestyles, but also to an increasing need for creative involvement in product production as part of the formation of identity. This in turn implies a new interaction of production and services with new demands on organisations and technologies for more creative services, and on the other hand for a significantly expanded spectrum of services with hybrid business models to accompany products, which will result in products and services being integrated in a new way.

It remains however completely unclear what the change to such added value paradigms would mean for ecological sustainability. On the one hand, there is great potential in the shorter routes and avoidance of surplus production. On the other hand, energy and resources consumption and inputs of pollutants into the environment could increase due to uncontrolled distributed production. Much would depend here on the course being set for »sustainability « at an early stage. Many research issues are raised in the area of technology – infrastructures for distributed mini-factories, equipment for semi-virtual co-creation spaces, suitable materials – and in the areas of services and production concepts.

At the same time, the knowledge of possible human behaviour patterns as offered by environmental psychology or socio-ecological research, but also ethnographic research and the cultural sciences, plays a major role here. Which forms of distributed value-adding would be conceivable and sustainable? These are questions that will only be able to be answered through new evaluation processes and creative methods.

Here too, learning spaces for actors and methods are necessary in designing these learning spaces. A »living lab« for various co-creation spaces with connected mini-factories might be conceivable, for example. Holistic evaluations of the ecological footprints of generated concepts will be indispensable in this context. Only those processes showing a significant reduction will be sustainable in an era characterised by significant climate change. The social component of sustainability of an ecologically-intelligent network of mini-factories would also have to be investigated, linking the global repositioning of roles and sites of value-adding elements with both hopes and fears concerning the locating of new production jobs for highly-qualified workers.

Topical focus - system outlook

Sustainable patterns and related transformative innovations cannot be directly generated with the »standard tools « of the disciplines involved. New research methods are needed that will allow for the integration of heterogeneous areas of knowledge and strands of research and the identification of possible paradigm shifts. Research into sustainable materials flows turnover must also be consistently incorporated into comprehensive globally-oriented concepts of sustainable forms of economic activity. On the other hand, there is a risk of parts of systems being optimised at the cost of the sustainability of the entire system. Holistic evaluation processes will be needed to estimate the sustainability of possible formations in order to avoid one-sided focuses and support a balance between conflicting goals.

For this reason, definite qualitative, quantitative and discursive methods for researching and evaluating the systemic transformation of patterns of materials flows will be developed as part of the topical focus on »system prospects«. These will emerge mainly out of sustainability research and in particular from »industrial ecology« (v. Gleich, Gößling-Reisemann 2008), the concepts of which will have to be further developed to include other disciplines such as environmental economics, innovation and complexity research, and system design.

Examples of methods and concepts of system prospects

- Innovation lifecycle analysis, product life-cycle analysis
- MIPS (MIPS: Material Input Per Service unit. Schmidt-Bleek 1993), carbon footprint, factor 10 analysis
- Eco-effectiveness
- Consistency analysis
- Socio-technical scenario building
- Environmental-economic modelling
- Innovation system dynamic (co-evolution, multi-level concept) (Geels et al. 2007)

Topical focus – the paradigm shift

This is a focus on investigating ways of moderating the transformation to patterns and paths that have been identified as sustainable.

Innovation processes emerge in the interaction of participating actors, so technical, sociological, educational and psychological evaluation and development methods will have to be integrated in order to understand and cause system change at the interfaces. Potential from disciplines outside those hitherto committed to sustainability transformation – such as design, market research, ethnography, the cultural sciences, behavioural research, innovation management, governance research, interaction research and creativity research – should also especially be made use of. Discursive methods for moderating discourses among players in the area of transition management (Rotmans and Kemp 2005) could in particular be taken up here.

Topic focus – systems knowledge and competence

A systematic expansion in the area of systems knowledge and competence will also be necessary in this context. This includes on the one hand developing an information control system in which micro and macroeconomic data for evaluating value-added networks is collected, consolidated and made available to actors in the innovation system. On the other hand, this area covers the establishing of distributed learning spaces for transformative innovation processes for relevant actors in the innovation system. This involves much more than just implementing configurations of solutions generated in the core area. The question is more one of how innovation systems could establish the learning processes necessary at all levels for transformative innovations. This question should be regarded as an independent research field. Research into skills and education will make central contributions here and governance instruments such as foresight and participative technology assessment, »living labs«, ethnography and approaches from the area of »open innovation« and user innovation will also be involved. Actors in the innovation system, in particular those from companies, educational institutions, associations and social initiatives, will all play active roles in this area.

6.4 Why is this future field relevant?

Establishing sustainable methods of economic activity is **the** central global challenge of the future. The drastic reduction of the ecological footprint of human economic activity necessary to maintain the ecosphere, which is also vital to human life, can only be achieved through systemic innovations in patterns of materials flows (cf. Figure 7).

Transformative innovations to reduce the ecological footprint of production and consumption will define the leading markets of the future.[51] Involvement in the research prospects of ProductionConsumption2.0 will ensure Germany's leading position in major future innovation fields over the next 15 years and beyond. This future field thus leads to the goals and approaches in the German government's High-tech and Sustainability Strategies.

51 »The demand of the global economy will, especially in difficult times, be oriented towards the most urgent areas of need«. BMBF, 'Research and Innovation for Germany. Results and outlook', p. 4.

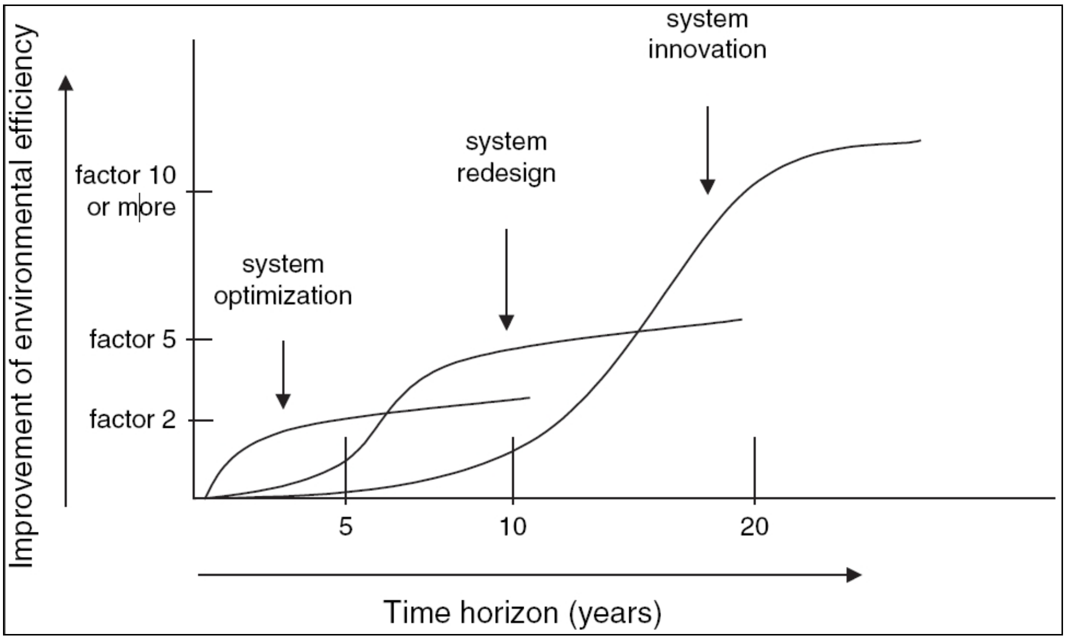


Figure 7: Increasing efficiency through system innovation (from Tukker and Butter, 2005)

The research prospects of ProdutionConsumption2.0 are of outstanding relevance for Germany's economic development and its citizens' quality of life and have a significant influential impact in many fields of research and technology.

6.5 Current actors in the innovation system

As indicated in the previous section, there are strong research connections in all individual areas relevant to this future field in Germany. In order to make use of these intersections however, as was outlined in the previous section for every topical focus, first the basic fields, then also entirely new disciplines must be involved. Table 6 provides a survey of a selection of current actors in the research landscape who are researching in future fields beyond their own and are thus connected to the future field.

Actors in ProductionConsumption2.0

- Institute for Advanced Sustainability Studies, Potsdam (still in development) (cross)
- Wuppertal Institut für Klima, Umwelt, Energie GmbH (Wuppertal Institute for Climate, Environment and Energy) (cross)
- UNEP/ Wuppertal Institute Collaborating Centre on Sustainable Consumption and Production (CSCP) (cross)
- Forschungszentrum Nachhaltigkeit Universität Bremen (University of Bremen Research Center for Sustainability Studies) (ARTEC) (cross)
- Lehrstuhl für Umweltmanagement Universität Hohenheim, Prof. Schulz (Patterns (Environment))
- Institut für Werkzeugmaschinen und Betriebswissenschaften (iwb) (Institute for Machine Tools and Industrial Management), Technische Universität München (Patterns (Production))
- Technische Universität Braunschweig, Institut für Werkzeugmaschinen und Fertigungstechnik, Product and Life Cycle Management Department, Lehrstuhl Produktion und Logistik, Arbeitsgruppe Wertschöpfungsnetzwerke (Patterns (Production))
- DFG-Exzellenzcluster der RWTH Aachen: »Integrative Produktionstechnik für Hochlohnländer« Schwerpunkte Individualisierung, die Virtualisierung, die Hybridisierung und die Selbstoptimierung der Produktion (DFG Cluster of Excellence at the RWTH Aachen) (Patterns (Production))

- Universität Bremen, Fachbereich Produktionstechnik, Fachgebiet Technikgestaltung und Technologieentwicklung (Universität Bremen -Faculty of Production Engineering), Prof. Dr. Arnim von Gleich (cross, Industrial Ecology)
- IÖW – Institut für ökologische Wirtschaftsforschung GmbH (Institute for Ecological Economy Research), Berlin (System)
- Ecologic – Institut für Internationale und Europäische Umweltpolitik (Ecologic Institute) gGmbH, Berlin (System)
- Öko-Institut für angewandte Ökologie e. V.(Institute for Applied Ecology), Freiburg (System)
- econcept – Agentur für Nachhaltiges Design (Sustainable Design Agency), Cologne (System)
- Technische Universität Berlin, Zentrum Technik und Gesellschaft (ZTG) (System)
- Lehrstuhl für Ökologische Ökonomie, Universität Oldenburg, Fakultät Informatik, Wirtschafts- und Rechtswissenschaften, (University of Oldenburg, Department of Business Management, Economic and Law), Oldenburg (System)
- Forschungszentrum Karlsruhe, Institut für Technikfolgenabschätzung und Systemanalyse(Institute for Technology Assessment and Systems Analysis), (ITAS) (System)
- Technische Universität Darmstadt, IANUS (Interdisziplinäre Arbeitsgruppe Naturwissenschaft, Technik und Sicherheit) (System)
- Professur für Nachhaltigkeitsmanagement an der Universität Lüneburg. (Centre for Sustainability Management), Prof. Dr. Stefan Schaltegger (System)
- Deutsche Materialeffizienzagentur VDI/ VDE Innovation + Technik GmbH, Berlin. (System)
- Universität Kaiserslautern, Fachbereich Volkswirtschaftslehre, insbesondere Wirtschaftspolitik und internationale Wirtschaftsbeziehungen, Prof. Dr. Michael von Hauff (System (Economy))
- Institut für Zukunftsstudien und Technologiebewertung (Institute for Future Studies and Technology Assessment) (IZT) GmbH, Berlin (Paradigm shift, System)
- DIALOGIK gemeinnützige Gesellschaft für Kommunikations- und Kooperationsforschung mbH (DIALOGIK Non-Profit Institute For Communication and Cooperation Research) (Stuttgart) (Paradigm shift (Discursive/participative processes))
- Kulturwissenschaftliches Institut Essen, Responsibility Research (Paradigm shift)
- Universität Lüneburg, Institut für Umweltkommunikation (Institute for Environmental Communication) (Paradigm shift)
- Helmholtz-Zentrum für Umweltforschung GmbH (UFZ) (Helmholtz-Centre for Environmental Research) (Patterns (Environment))
- Institut für sozial-ökologische Forschung (Institute for socio-ecological research), (ISOE) GmbH, Frankfurt. (Patterns (socio-ecological research))
- Sonderforschungsbereich/ Transregio 29, Engineering hybrider Leistungsbündel – Dynamische Wechselwirkungen von Sach- und Dienstleistungen in der Produktion (Collaborative Research Project/ Transregio 29, Industrial Product Service Systems – Dynamic Interdependency of Product and Service in the Production Area) (Patterns (Production, services))
- Technology & Innovation Management Group, RWTH Aachen, Prof. Frank Piller (Patterns (Production))
- Fraunhofer Gesellschaft Verbund Produktion (Fraunhofer Group for Production) in particular:
  - Institut für Industrielle Fertigung und Fabrikbetrieb IFF Universität Stuttgart Bereich Fabrikbetrieb/ Fraunhofer IPA (Wertstromdesign, Lean Manufacturing)
- Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik, Ressourcenmanagement (Umsicht) (Fraunhofer Institute for Environmental, Safety and Energy Technology, Resources management (Umsicht), Oberhausen (Patterns (Production))
- Fraunhofer-Allianz Generative Fertigung (Fraunhofer Additive Manufacturing Alliance) (Patterns (Production))
- VDI Rapid Manufacturing Platform (Patterns (Production))
- Technische Universität Darmstadt, Institut für Produktionsmanagement, Technologie und Werkzeugmaschinen, Prof. Dr.-Ing. Eberhard Abele, Forschungsgruppe umweltgerechte Produktion (Patterns (Production))
- Wissenschaftliche Gesellschaft für Produktion WGP Fachgruppe Produktionsmanagement (Patterns (Production))
- Ecosign/ Akademie für Gestaltung, Cologne, Muster (Design)
- Lehrstuhl Produktion und Umwelt, Institut für Betriebswirtschaftslehre und Wirtschaftspädagogik der Universität Oldenburg, Prof. Uwe Schneidewind (Patterns (Production))
- Münchner Projektgruppe für Sozialforschung e. V. Prof. Dr. Karl-Werner Brand, Technische Universität München, Munich (Patterns (Social change))
- Forschungsinstitut für Rationalisierung (Research Institute for Operations Management) (FIR), RWTH Aachen University, Dr. Volker Stich (Patterns (Services))
- Fraunhofer IAO, Geschäftsfeld Dienstleistungs- und Personalmanagement (Fraunhofer IAO, Service and Human Resources Management), Stuttgart (Patterns (Services))
- Fraunhofer ISI, Geschäftsfeld Industrielle Dienstleistungen (Fraunhofer ISI, Industrial and Service Innovations Competence Centre) (Patterns (Services))
- Universität Karlsruhe (TH), Fakultät für Wirtschaftswissenschaften, Karlsruhe Service Research Institute, Prof. Dr. Gerhard Satzger (Patterns (Services))
- Lehrstuhl für Informationssysteme, Schwerpunkt Innovation & Value Creation at the Friedrich-Alexander-Universität Erlangen-Nürnberg, Prof. Dr. Kathrin Möslein (Patterns (Services))
- International Business School of Service Management (ISS), Lehr- und Forschungsbiet Service Management in Hamburg, Prof. Dr. Tilo Böhmann (Patterns (Services))
- TU Harburg Technische Mikrobiologie (Institute for Technical Microbiology) (Life Science for future technologies) (Patterns (Bio-production))
- Universität Hamburg, Forschungsschwerpunkt Biotechnik, Gesellschaft und Umwelt (Patterns (Bio-production))

Table 6: Actors in ProductionConsumiption2.0

6.6 Sustainable actors' groups

This selection could at the same time serve as a starting point for forming sustainable actors' groups. The names of those operating in direct proximity to the future field that cover several topic areas are followed by the note, »cross«. Actors from industry and society would have to be systematically involved in building up this research field. Identifying actors in these areas would be another high- priority task in developing this future field.

6.7 Recommendations

Setting up a PC2.0 research community

Setting up a research community is a central challenge in the view of the topic coordinators, because the relevant actors show few points of contact so far, although doing this too early could also be contra-productive. It would seem advisable to first survey individual selected actors from the circle shown above about possible points of contact and then in a next step form a steering committee with a core group of appropriate representatives from various research fields and organisations. It could then develop initial proposals for a research agenda and other fields could be integrated step by step in subsequent rounds.

Establishing a PC2.0 innovation system

A technological innovation system involves actors, networks and institutions that influence technological development (Bergek 2008). It makes research results accessible only by integrating them into a wide range of distributed learning processes. Building up a PC2.0 innovation system must therefore be a central field of action. A systematic mapping of components should be carried out as a first step.

Industry will be a major player in developing and implementing PC2.0 innovations. Actors from companies large and small in various industries must be involved in building up this area at an early stage. The systemic innovation of production and consumption patterns will involve socio-technical innovations in all social areas. The circle of central innovators therefore extends far beyond the more restricted research landscape and includes **civil society** actors such as foundations and citizens' initiatives as promoters of social and organisational innovations (»social entrepreneurs«). Thirdly, public sector actors and **politics** will play a major role here.

This »triangle of change« in the area of PC2.0 must however first be created. Building capacity and trusting relationships and jointly developing integrative approaches will be central here (Liedtke and Kuhndt 2009; Smits and

Kuhlmann 2004). The development of innovation research findings for the functioning of central elements[52] of technological innovation systems should be monitored and accompanied. Because this system is still at a very early phase of development, shared general principles and expectations on various actors in the innovation systems will be particularly relevant. Discursive processes such as dialogues on visions and scenarios could play a vital role here in our view.

The project team takes the view that it would be advisable for leading actors in the innovation systems to be represented in a PC2.0 steering committee as early as possible.

Field of activity: International connections

Given the necessity of a global orientation of research and development in the area of ProductionConsumption2.0, connection with the international research landscape is central. It is therefore our view that connecting points to related processes of community and strategy building at an EU and international level (OECD, UN) should be sounded out. The following processes could offer such possible connections:

- Strategic activities in thematic area 4 of the 7th Framework Programme (»Nanosciences, Nanotechnologies, Materials & New Production Technologies [NMP]«), such as the »Manufuture« platform[53]
- Strategic activities in thematic area 6 of the 7th Framework Programme (»Environment«), such as developing an »ERA Net« in the area of eco-innovation
- The EU »Sustainable Production and Consumption and Sustainable Industrial Policy Action Plan« (especially in terms of the development of key data and indicators)
- World Business Council for Sustainable Development (WBCSD) activities focusing on »Ecosystems«
- The UNEP's Marrakech Process »Towards a Global Framework for Action on Sustainable Consumption and Production«
- The development in the international research community of »Industrial Ecology« (International Society for Industrial Ecology)
- OECD activities in the area of the »environment« (especially indicators and modelling)

52 Knowledge development, resource mobilization, market formation, influence on the direction of search, entrepreneurial experimentation. cf. Bergek (2008) for possible approaches. These must however be adapted to an entirely new innovation system.
53 http://www.manufuture.org/index.html

One way to achieve a systematic connection with international processes could be to involve the UNEP/ Wuppertal Institute Collaborating Centre on Sustainable Consumption and Production (CSCP), which continuously monitors such processes.

Field of activity: »Strategic Niche Management«

ProductionConsumption2.0 aims to create systemic transformations to achieve sustainable patterns of materials flows in the long term. Such transformation cannot occur suddenly; rather, new forms of production and consumption will have to first be established within existing patterns.

One suitable innovation policy instrument, in the opinion of the topic coordinators, would be »Strategic Niche Management« (cf. Weber 2009), i.e. creating a protected space for learning processes designed to lead to new concepts and technologies. For ProductionConsumption2.0, such niches could be specially set up at critical points for the future, focuses identified by the steering committee. Here not only research and development, but also utility and social embedding should be taken into account. Demonstrators, pilot plants, social experiments and »living labs« for new production and consumption concepts, such as sustainable mini-factories (cf. example 2 above), would all be conceivable in this context.

7 Trans-disciplinary models and multi-scale simulation

Virtual systems analyses have now become indispensable in technical and social scientific research. System analyses have so far been used to form hypotheses about complex issues in physical, chemical and biological contexts, improving such data for use in projects in application-oriented research and development practice. Application-oriented projects deal with complex phenomena despite limited knowledge on the details of functional contexts. System analyses must be carried out using experiments if these projects are to be pursued promptly and involve reasonable amounts of time, effort and cost. Wherever developments and their biotic, social, technological and other environments can overlap in complex relationships, various observations and abstract models must be consolidated as a result.

The future challenge will lie in using suitable translation processes to exchange findings between contiguous or hitherto independent disciplines. Innovative simulation methods from the atomic level and algorithms for current and future problem areas could be developed out of combinations of new findings. Examples of research issues and areas for development include:

- How and using which models can ecosystem contexts such as climate change be simulated to achieve progress in the knowledge of the interconnection of systems? How can simulations be used for prognoses?
- How could phenomena of self-organised complexity, such as the behaviour of organic cells, be modelled and simulated, starting at the atomic level, to achieve further medical diagnosis and therapy breakthroughs?

7.1 The future field

Globalisation is making people's living conditions increasingly complex and confusing. Unstable balances in politics, economies and society are issues people have to deal with daily. The loss of familiar ownership rights on the one hand and opportunities for creative innovations and their stimulation in terms of new markets on the other hand follow principles of chaos, order and self-organisation. These develop in nature and in society in accordance with the laws of complex dynamic systems. Such systems are already being successfully investigated in the technical and natural sciences. Research into models and simulation processes from the atomic level through the meso-level up to macroscopic phenomena and a targeted reduction in complexity for each level could give rise to attempts to provide a complete causal correlation, which would make simulation models predictable. In the atomic and molecular systems of physics and chemistry, in cellular organisms and the ecological systems of biology, in the neuronal networks of brain research and computer networks in the Internet it has become clear that gaining knowledge depends largely on understanding the highly-dynamic interactions of »building blocks« in the system. This also applies to applications in economics and the social sciences. There is already a wide range of methods for modelling and simulating systems in the scientific areas, but these have so far been (further) developed mainly by scientists for their own specialist discipline (cf. Ionescu et al. 2009; Ehlers 2009).

Because the predictability of simulation models depends on computer performance, scientific progress in many disciplines also depends on further developing computer technologies and computing capacity. In future however, computing power beyond petaflops may be required. This kind of concentrated computing is provided by supercomputers, which can carry out computing tasks in parallel with the help of several processors. The computing and networking capacities (cf. »grid« and »cloud computing«) used to simulate complex systems and their behaviour today provide only simplistic insights. Further research activities may make it possible to use model-building and simulation to better deal with the complexity in systems. If there are breakthroughs in this area, phenomena with many more parameters than before could be virtually simulated in more realistic representations and more exact prognoses could be made. Theoretical systems research could also make a major contribution in this area by laying the groundwork for an understanding of the concepts involved.

7.2 The initial situation in the future field now (2009)

The state of research into the modelling and simulation of complex systems is characterised by individual strategies from various disciplines, theories and discretisation concepts, so methodical areas such as molecular dynamics, modern mechanics, numeric mathematics, systems analysis, data management, visualisation and high-performance computing are being investigated. In the future field of Transdisciplinary Models and Multi-scale Simulation, relevant developments from several research fields should therefore be consolidated and bundled to achieve synergy effects.

In systems and complexity research, »systems-in-contexts« phenomena are being investigated in many areas to develop new approaches for modelling behaviour in traffic systems or in dangerous situations, for example. Based on these concepts, approaches and tools can be developed to enable concepts and controls from the areas investigated to be concretely adapted in interdisciplinary processes such as analysis or presentation. The difficulties for existing modelling and simulation lie in designing and verifying so-called state spaces[54], relevant parameters for concrete situations and in the mathematical formalisation of the relationships of elements in an overall system in a way that makes them suitable for simulations. Theories of complex systems that are theoretically comprehensive, consistent, and applicable to models and simulations are also lacking in this context.

In a climate model for example, completely different results for the next years, decades or even centuries can be provided as a result of any minimal change in the basic values or inclusion of new variables. What is decisive for the quality of prognoses is the model of the system they are based on. If not all relevant variables are known, their interrelation is not transparent, or the input parameters and their development is inaccurately calculated, the prognoses will not be correct. Much more time and effort must be invested in model building if such calculations and prognoses are to be made at all possible (cf. also Mainzer 2009 – alpha Forum).

There is an interaction between new findings in specialist areas and the possibility of deriving improved models and simulations from them, which in turn encourages research in the respective area. The speed of knowledge growth in this area depends largely on the range and precision of models and simulation results.

Initial approaches are also being made towards more closely merging new ICT developments and recent findings from other sciences, such as neurophysiology, in simulations. At the same time, new simulation techniques and new algorithms are being further developed using computers working in parallel. This is usually in fact done with up to several thousand processors based on conventional architectures. The development of alternative computer architectures will also rely on findings from related disciplines such as materials research, biotechnology and numerical mathematics.

[54] i.e. dynamic systems in time

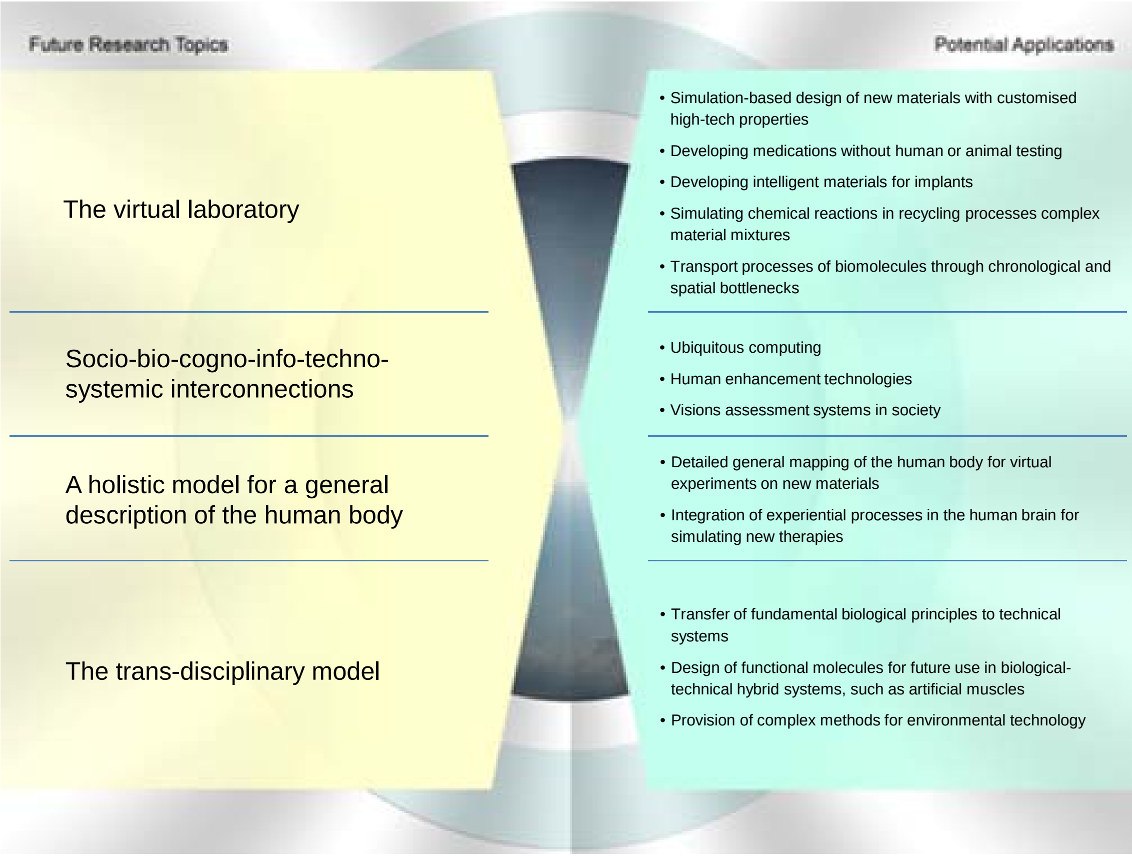


Figure 8: Future research topics and potential applications in the future field of »Trans-disciplinary Models and Multi-scale Simulation«

7.3 The long-term outlook in the future field

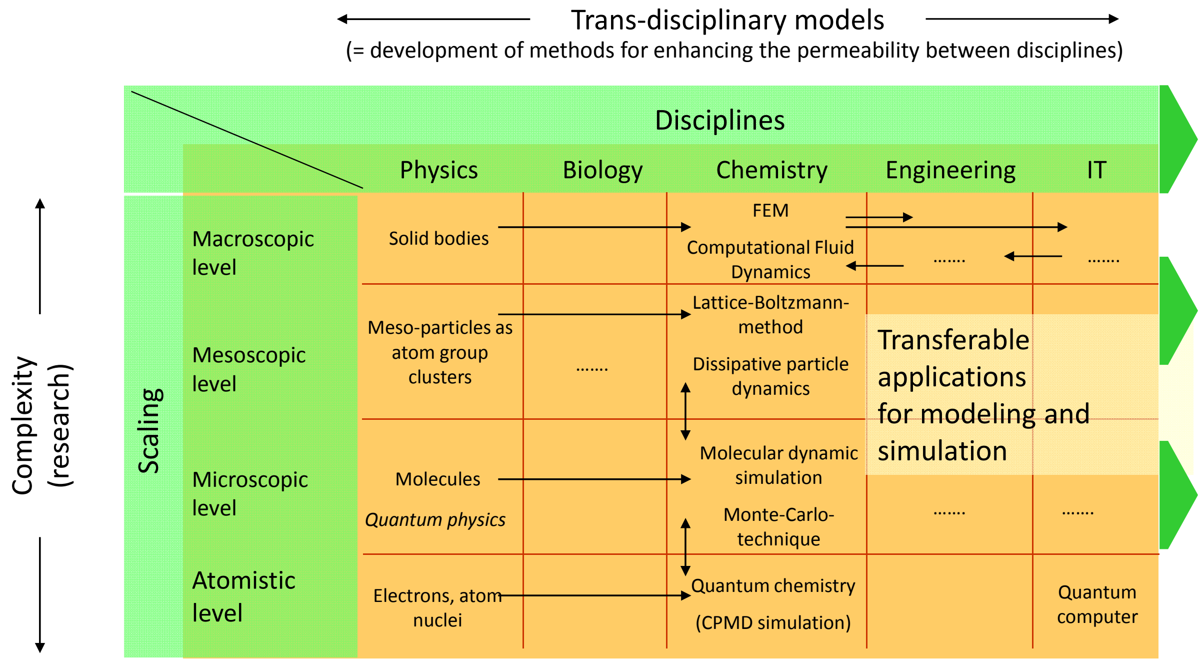
In the future it will be necessary to develop ways of improving transmissibility between different disciplines so that new scientific achievements and findings can be used to solve problems. If complex scientific phenomena cannot be modelled because a system's connections are not understood, it will be necessary to investigate the system from its lowest level of complexity. The goal will not be to undertake complicated trials, but to understand complex phenomena through virtual simulations and, depending on the problem, make reliable forecasts (see Figure 8).

Although research has been carried out in the future field of model building and simulation for a long time, it can now achieve a new quality. This especially applies to the merging of scientific and technical areas, e.g. in the areas of atoms (ab-initio), molecules and phenomena on a nano-scale. Breakthroughs can be expected from such interdisciplinary models. Methodically well-founded

»translational research«, which investigates the goals, content and limits of transferability, is an important precondition of this area.

The task of complexity research is to provide methods that make it possible to carry out a necessary reduction in complexity while retaining the main system variables in the transition from one scale to the next. One interdisciplinary application of complex systems is for example the human brain. The brain is a complex system of neurones (nerve cells), which interacts electrically or neurochemically via synapses and connect in behaviour patterns. The dynamic of brain states is modelled using equations of macroscopic order parameters that correspond with neuronal patterns of connection. Neurochemistry, a discipline within the neurosciences, investigates the activity of the molecules involved in neural activity using biochemical, molecular-biological, electrophysiological and microscopic methods. Biochemical reaction speeds depend on the time constants in chemistry and quantum physics (cf. Marx, Hutter 2009; Mainzer 2007, 2009; Luther et al. 2004).

Efficient modelling needs simulation methods that are adapted to the relevant length and time scales, although there has so far only been limited success in connecting simulation modules of different length scales (but also time scales). This connection should be made clear in Figure 9.



Source: Fraunhofer IAO

Figure 9: Modelling and simulation as a link between complexity and disciplines

Further disciplines beyond those disciplines shown in the graphic above can and should be considered. One link that should be mentioned is systems and complexity research; another is a sub-area of mathematics research, which deals in this context with generic approaches to mathematical modelling. A further aspect is the development of information and communications technical preconditions to enable simulation system models and virtual experimentation. Information and communications technical applications should in future increasingly integrate models from parallel or sequentially networked processes.

This implies that in ten or more years, parallel operations relying on up to several million processors will have to be managed in order to provide the computing capacity required for such simulations. This demand will not be able to be met in the medium term by computers using current architectures. For some areas of development (bio-detection, cryptography), the potential applications of fundamentally different, genuinely parallel architectures such as those of bio-molecular or quantum computing should be more clearly emerging or available in 10 to 15 years (cf. EC 2008; Schinarakis 2008).

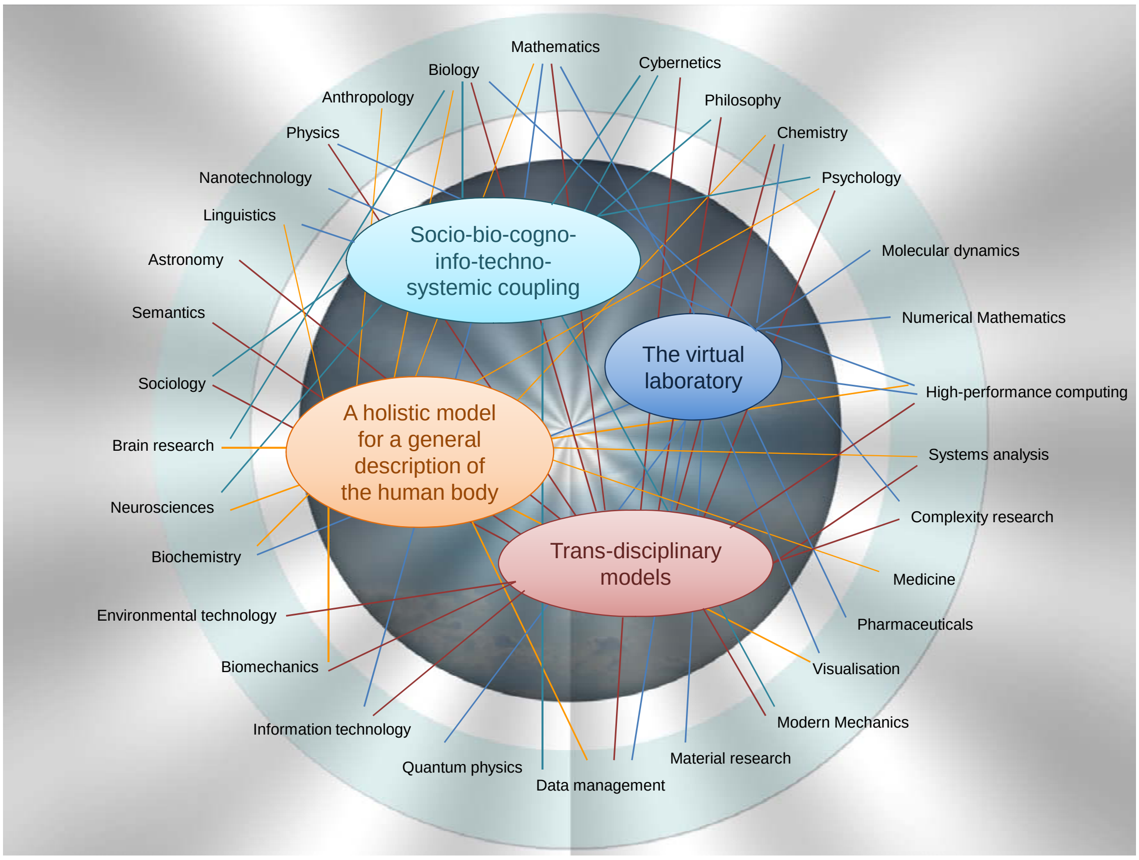


Figure 10: Future participating research areas

A further developmental prospect of this future field is the linking of simulation with the processes of human experience. Simulation is currently used to reproduce facts. In future it should also be used to provide an understanding of the experiential processes of the human brain, which can then be integrated into simulation. In achieving this however, basic ethical principles must be taken into consideration, because they play a major role in the growing importance of convergence at an EU level and in other countries (cf. Coenen 2008, p. 29). The modelling and simulation of human behaviour could then be further developed as a method in human-machine systems research (cf. Kindsmueller et al. 2004).

Focuses for further consolidation in the new future field of **Trans-disciplinary Models and Multi-Scale Simulation** in the contexts of specific scientific, technological, social sciences or cognitive sciences investigations could include the following areas:

1. Theoretical research and model building to create systems and systemically heterogeneous alliances (cf. socio-bio-cogno-info-techno systemic couplings)[55]

2. Research into process and technical developments for multi-scale simulations in the areas listed at 1. (above)

3. Planning support and »knowledge transfer« in areas 1 and 2 in specific, concrete development applications beyond the various scientific and professional disciplines

These three points emerged from surveys in the areas of simulation research; IT, the sciences and social sciences, and desk research (cf. also Rogers 2003a; Saage 2006, 2007; Nordmann et al. 2006).

7.4 Why is this future field relevant?

This topic is relevant because many research questions in this area have so far been only insufficiently answered. Modelling methods and simulation technologies have proven to be necessary for solving complex problems in many areas of life. They influence developments in business and industry. New developments in the area of modelling and simulation techniques and hardware modules have also raised expectations on science and industry. The examples listed below are challenges that research has so far only been able to deal with to a limited extent. Opinions from experts from the »SimTech – Cluster of Ex-

55 Potential applications of ubiquitous computing, »human-enhancement« technologies and visual analysis systems in society should be mentioned here as examples.

cellence in Simulation Technology« at the University of Stuttgart and research results from the Max Planck Society, international studies and specialist literature were used to compile the examples (cf. also Marx and Hutter 2009; Hergersberg 2008; Thumann and Schnappauf 2008, Besold and Kremer 2004):

- Models and simulations of phenomena of (self) organised complexity[56]
- Further development of quantum simulators to provide a better understanding of the phenomenon of high-temperature super-conductivity and to develop useful, resistance-free electrical conduction materials
- Computer-based evaluation of biochemical processes for developing new drugs without animal or human experiments
- Simulation-based modelling of new substances with customised high-tech properties
- A system-biological view of technical and natural systems
- Merging of various individual biomechanics solutions in order to create a detailed general description of the human body
- Developing complex and comprehensive methods for environmental technologies
- Computer simulation of molecular and cellular bio-systems for bio-molecular transport processes through chronological and spatial »bottlenecks«

A range of disciplinary models exist for most of these fields. The merging of disciplinary models always raises the question of the extent to which such models and simulations in informational aggregations can be socially conveyed, cognitively processed and used in a way that will give rise to further findings. In what contexts are the models valid?

There is an assumption that this current future field will become increasingly relevant in some concrete problem areas,

- because the immanent complexity of developmental problems, such as those of mega-cities or networked transport systems (cf. m4d 2009; Ziv, Cox 2007) will increase and will therefore have to be better understood and
- because an increased need for models and simulation is expected in other future fields too, (life sciences, physics, transport, pharmaceuticals etc.) as a result of ongoing developmental progress (see also other future fields in the BMBF Foresight Process).

56 Examples include the behaviour and states of organic cells such as nerve, liver or skins cells.

For the BMBF, this results in a research field that can lead to cross-sectoral technologies and could thus provide an impetus for a range of different departments.

7.5 Current actors in the innovation system

This future field currently deals with generic concepts and presentational aspects of orientation frameworks. These aspects can be translated into research and development-related activities and thus integrated into various other areas, but they need to be specifically adapted to do so. Potentially interesting actors are therefore distributed across these other disciplinary fields.

A special role is played in the search for potentially interesting actors by the investigation of trans-disciplinary knowledge communities, interest groups and bodies of experts in areas such as.

- theoretical physics and chemistry,
- robotics, biology and other sciences,
- neurosciences and technology,
- theoretical and applied information technology,
- the humanities,
- the analysis of complex systems,
- by institutes clearly identified as relevant in the area of technical cybernetic, the cybernetics of monitoring systems and their mathematical-information technical implementation at universities and research institutions (Max Planck, Helmholtz, Fraunhofer etc.).

Certain organisations' profiles also indicate that these could be potentially interesting actors in the current future field (cf. Table 7).

Actors in the field of Transdisciplinary Models and Multi-scale Simulation

- Lehrstuhl für Theoretische Chemie, Ruhr-Universität Bochum
- Physikalisch-Chemisches Institut der Universität Zürich (Institute of Inorganic Chemistry at the University of Zurich)
- Excellence Cluster »Simulation Technology« (SimTech) in Stuttgart
- scientific and/ or professional inter- or multi disciplinarity (e.g. as historical prototyepe the Biological Computation Laboratory H. v. Foersters in Illinois)
- Institute for Advanced Simulation (IAS) – Forschungszentrum Jülich
- Technische Universität Clausthal (Clausthal University of Technology)
- Max-Planck-Institut für Quantenoptik (Max Planck Institute of Quantum Optics)
- Institut für Technikfolgenabschätzung und Systemanalyse (Institute for Technology Assessment and Systems Analysis), (ITAS) Karlsruhe
- Area of translation (in the field of medicine and pharmaceuticals) the European Advanced Translational Research Infrastructure in Medicine and the Hannover Center of Translational Medicine (HCTM)
- ITAT (Institut für Theoretische und Angewandte Translationswissenschaft – Universität (University of Graz, Department of Translation Studies) Graz, Austria). ITAT concentrates on research in three main areas: cultural and social-scientific research into translation, com-

- Hochleistungsrechnerzentrum Stuttgart - Technische Universität München, Lehrstuhl für Philosophie und Wissenschaftstheorie	municative and sign language interpreting, translation process research, and translation and terminology management.

Table 7: Actors in the field of Trans-disciplinary Models and Multi-scale Simulation in 2009

7.6 Sustainable actors' groups

The future field of »Trans-disciplinary Models and Multi-Scale Simulation« raises countless challenges. The Fraunhofer experts regard it as necessary for developing solutions for the purposes of open innovation, and for networking scientific institutions from various specialist areas, institutions involved in trans-disciplinary activities and centres that are developing modern methods in all areas of modelling and the simulation sciences. Funding projects and involving the right partners could help to secure the development and use of knowledge transfer methods within this network.

To start new activities within this future field, it would be helpful to involve a series of potential partners from existing German institutions. Experienced people from scientific institutions with future-oriented organisational structures, centres and clusters of excellence in their early stages and institutions pursuing trans-disciplinary research activities could form a basis here.

Major actors in this context could include:

- The Max Planck Institutes, especially the Max Planck Institutes for Meteorology, Polymer Research, Coal Research, Solid State Research, Brain Research and the MPI for Human Cognitive and Brain Sciences, which, according to analyses of actors is one of the most active institutes of the Max Planck Society. The MPI for the Dynamics of Complex Technical Systems, the MPI for Quantum Optics and the MPI for the Physics of Complex Systems should also be mentioned in this context.
- The international mathematics and science faculty of Bonn University is working on the topic of »numerical simulation«, among other things. Establishing »Interdisciplinary Centres« is viewed as another vital activity whose goal is to strengthen interdisciplinary cooperation within the University and support outstanding achievement in research.
- By opening the Stuttgart Research Centre for Simulation Technology and »Simulation Technology« (SimTech) excellence cluster, the University of Stuttgart has also opened up new prospects for further developing scientific methods and applications in all areas of modelling and the simulation sciences. By committing various institutions to the University of Stuttgart, they are aiming to transfer results within the scientific community and into applications.

- The »Centres of Excellence« at the Ruhr-Universität Bochum are characterised by their international and interdisciplinary approach, areas in which the university has a leading position due to the areas it covers in the centres. Research at the Ruhr-Universität Bochum is carried out by flexible, interdisciplinary »Research Departments (RD)«.
- Clausthal University of Technology, with its interdisciplinary scientific institutions and working groups, is also one of the most active institutions in the area of »Trans-disciplinary Models and Multi-Scale Simulation«. The Simulationswissenschaftliche Zentrum Clausthal-Göttingen (Clausthal-Göttingen simulation research centre), which is currently working on the topic of »simulation« within an interdisciplinary network, should in particular be mentioned in this context.
- Munich's Technische Universität is funded by the BMBF's Excellence Initiative and has strong connections to the life sciences as well as to the classic core areas of a university of applied sciences.
- Coordinated cooperation across various disciplines is also being pursued in research centres at the University of Wurzburg, which sees interdisciplinarity as a feature of »modern science«. Against this background, a series of research centres have been established there.

As well as the results of the bibliometric analysis of actors, major German institutions that are strongly connected to relevant areas of the future topic of »Trans-disciplinary Models and Multi-Scale Simulation« should be mentioned here:

- The Institute for Technology Assessment and Systems Analysis (ITAS) works on processing and transmitting knowledge about the consequences of human activities and the assessment of their consequences in terms of the development and use of new technologies. This also entails research into environmental, economic, social and political-institutional issues. ITAS is participating in the research programmes of the Karlsruhe Institute of Technology and the Helmholtz Association of German Research Centres (HGF) and cooperates with many scientific institutions in Germany and beyond, especially in EU projects.
- The Center for Interdisciplinary Research (ZiF) at Bielefeld University promotes interdisciplinary and innovative research projects through the university's »Institute for Advanced Study«. As a non-partisan, thematically-independent research institution, ZiF aims to identify innovative research fields in overlapping areas of science and the humanities.
- Within the Forschungszentrum Jülich, the »Institute for Advanced Simulation (IAS)« bundles disciplinary, methodical and technological skills in the area of

the simulation sciences and high-performance computing with the goal of meeting future challenges in the area of the simulation sciences.

One exciting strategic EU project worth mentioning that promotes cooperation and the exchange of knowledge between institutions working in the area of medicine, is the setting up of a »European Advanced Translational Research InfraStructure in Medicine (EATRIS) «. The goal of this project is to deploy new approaches to use basic research findings from various European institutions to advance the development of clinical applications. Its partners include European scientific institutions and various partners from governments, including the BMBF.

7.7 Recommendations

In the future field of »Trans-disciplinary Models und Multi-Scale Simulation« a range of R&D areas and disciplines are addressed that are required for extensive further development of scientific methods and applications in all areas of modelling and the simulation sciences. This should be able to achieve visions such as »the virtual laboratory« for replacing costly and time-consuming physical experiments in developing new substances, or »the holistic model for a general description of the human body«, to allow substances to be tested virtually, for example. The challenge is to develop generic approaches that collect and network existing and emerging new findings from various disciplines so as to use these findings to solve concrete problems. At the same time, the range of application of models must be made clear. To what extent is a model transferable? When does it make sense to use models at all? What can be simulated? What is the costs-benefits relation when increasing numbers of variables are used? Where are the boundaries?

These approaches should also help to identify the disciplines required for solving a certain problem and secure their cooperation in developing new methods in modelling and the simulation sciences. In various discussions with experts it was emphasised that discussions with potential strategic partners would be necessary at this point in order to generate ideas so as to determine the necessary programmes and projects.

The topic of transdisciplinarity was addressed in March 2008 by the TAB study »Converging Technologies«, which depicted the current state of debate and political activities in the area of »Converging Technologies«. This study recommended, for the area of »multi-disciplinary, inter-disciplinary and trans-disciplinary« research, that evaluations of already completed or existing activities to promote trans-disciplinarity technology developments across various converging areas be increased, including at the EU-level. The term »convergence« implies a prognosis of a coalescence of several technologies and an increase of synergy effects between various sciences with a particular focus on technologies such as nanotechnology, biotechnology, information and communication technologies (ICT), brain research, artificial intelligence (AI), robotics and other applied sciences. There is a perceived necessity for a (political) promotion of research and development in overlapping areas.

Existing activities in the area of »Nano-Bio-Info-Cogno (NBIC) « fields require an assessment of the German R&D landscape and activities to support it in terms of convergence. The goal is to identify actors involved in research and development in the various fields who have strong links to the coupling of these fields. This would create a basis for investigating extended interdisciplinary couplings such as the socio-bio-cogno-info-techno systemic coupling. In the view of the topic coordinators, it would be advisable to monitor these actors' activities so to be able to apply new ideas emerging from funded activities. The networking of actors could also lead to the development of new trans-disciplinary approaches.

The formation and networking of new or existing centres in Germany with international relationships in which activities in the areas of trans-disciplinary research and modelling and simulation sciences could be carried out, was also recommended by the Fraunhofer experts. It could also be useful to build up organisational units that would make it possible to develop new approaches to collecting and using knowledge across various disciplines and also be a link between the centres. By »across various disciplines« knowledge from the natural, engineering, structural, agricultural, social, human, legal and economic sciences and the humanities is meant here.

8 Time research

The factor »Time« is not yet adequately understood and is therefore a »bottleneck factor« in many developments. Research into »time« is the central aspect of a future field that extends into many applications, including issues such as the chronological order of complex processes in making applications faster and more efficient, cost-effective and intelligent, or in parallelising and synchronising processes (e.g. Internet servers, production processes). The issue of dynamic and chronological development on various time scales, especially of non-linear processes, can only be dealt with in the long term.

One very dynamic future topic within time research, according to the results of bibliometrics, is chronobiology, an area in which there are already initial findings on precisely-timed medication delivery. Chronobiology could boost developments in the area of automated pharmaceuticals (»missile drugs«, »depots«, »targeted drugs«), which could possibly help to alleviate the side effects of nocturnal or irregular working hours. It could also establish the optimum times for learning, for example. Now would be a good time to start a programme for transferring findings from basic research into clinical research.

A central research aspect of time research is understanding and being able to specifically control the factor of »time« with the help of time efficiency research, the precise measurement of time (e.g. for GPS applications such as precision agriculture, the remote maintenance of machines) and time-resolution (e.g. 4D precision). Advances in these areas could optimise existing technologies as well as lead to completely new kinds of »time technologies«.

8.1 The future field

The concept of »time« has various facets. On the one hand, time is physical and is introduced as a variable (t), while on the other hand, various other disciplines (sociology, environmental research, management, especially also philosophy) deal with time.

Time's role is still not understood in many developments. The factor of »time« is the »hook« this entire future field hangs on, raising many issues »of moment« that have very different backgrounds and areas of application but that are connected; the issue of the chronological order of complex processes in making applications faster and more efficient and cost-effective, for example. »Faster« alone is however often not enough; processes now also have to be parallelised or synchronised.

There is also an increasing focus on issues around dynamics and chronological development, especially in non-linear processes and different time scales. While we are familiar with timing in our everyday environment, processes and phenomena in the microcosm (e.g. atomic excitation in atoms, the movement of electrons in atoms and molecules or biochemical/ chemical reactions in (bio-) molecules, clusters, nano/ microstructures) occur on extremely short time scales unimaginable to us. These processes are however fundamental to our lives, so understanding them is vital to an increasing number of technical achievements. How, how quickly and how efficiently can intra-molecular energy be transported? How do molecules bond and how can they be separated? How do biological processes occur in real-time? When is the suitable point in time for (locally and) chronologically precise drug delivery?

Research topics that are already seen as particularly relevant and will be more so in future include the ultra-precise measurement of ultra-short time periods (femtophysics, attophysics or a future zeptophysics[57]), biological clocks (chronobiology) and the factor of time in synchronising and parallelising processes (efficiency).

8.2 The initial situation in the future field now (2009)

Time describes a sequence of events and is therefore perceived by humanity as directional, i.e. as progressing from the past through the present and into the future. Physical theories such as the theory of relativity and quantum theory also describe time (e.g. as four-dimensional »space-time « in the theory of relativity), but the two are currently still incongruous (e.g. continuous vs. quantised space-time). Although the smallest theoretical unit of time at the limits of the applicability of known physical laws, so-called »Planck time« (~ 10^{-43} seconds), will not be accessible through experimentation in the near future[58], the debate about more precise time measurement (e.g. by optical clocks using femtosecond lasers and frequency comb techniques[59] etc.) is new to physics. This is relevant in many applications and not only for basic research.

Philosophy investigates the nature of time, which also shapes our view of the world. In the physical, life, and human sciences, time is a central, measurable

57 A femtosecond is a millionth of a billionth of a second (10^{-15} seconds), an attosecond 10^{-18} s, and a zeptosecond 10^{21}s.

58 The record is currently for pulses with a duration of 80 x 10^{-18} s (80 attoseconds, state of the art in the year 2008).

59 The frequency comb technique, developed in 1998 by Theodor W. Hänsch (Nobel Prize laureate 2005, Director of the Max Planck Institute for Quantum Optics in Garching) makes it possible to count laser light oscillations without error (of a femtosecond laser) and could therefore be used to keep time in future optical clocks. Using the frequency comb technique to overlap an unknown frequency to be measured (»indirect time«) with ultra-short pulses and transmission at lower frequencies, i.e. dividing the visible light spectrum into individual sequences, makes it possible to make ultra-precise electronic time measurements. More research will however be required if this technique is to be expanded to include the UV light range and implemented in practical applications.

parameter, in all moving bodies (dynamics, development) and in chronobiology or chrono-sociology, for example. Psychology investigates perceptions of time and the sense of time. In linguistics, »time« is expressed in the grammatical forms of verb tenses. There are therefore different disciplinary approaches, ranging from physics through sociology, environmental research and management up to philosophy. The state of research into »social time« has been analysed by Rollwagen (2008). On the topic of ultra-precise time measurement, see also Jesse (2005). In addition to many individual research topics, the following future topics were regarded as especially relevant[60]:

Ultra-precise time measurement – a new era of time measurement using optical clocks: Today's atomic clocks are already very precise, yet the standard of time measurement in 2009 seems inadequate for optimised and improved satellite navigation (GPS applications), for example. Measurement and localisation must become increasingly chronologically and spatially precise. Optical clocks are regarded as promising successors to the 50 year-old caesium clock. These could lead to a redefinition of the second, with a precision up to 1,000 times higher, and open the door to various new applications (Peik and Sterr 2008) in the near future. Examples of potential applications in the GPS context might be very precise navigation in global transport and traffic, navigation over great distances, the positioning and localisation of very remote objects in space travel (space probes, spacecraft), the fertilising of individual plants in precision agriculture, and the remote maintenance and repair of machines. The optimised synchronisation of media and wireless communication, exact process control in production and environmental observation (e.g. using interferometers) could also be further central applications.

4D-imaging – real-time investigation of structures and microscopy down to the subatomic area: The area of femtosecond technology, already being promoted by the BMBF under the name »femtonics«, offers new possibilities of minimally invasive materials processing and the treatment of tissue with nanometer precision etc. Using movement imaging at a molecular level, ultra-fast processes (e. g. chemical, biochemical reactions) can be observed at a molecular level and time-resolved structural examinations of biological and chemical components made to observe the processes of living organisms. In the longer term, attophysics, which uses light pulses 1,000 times shorter, will enable time-resolved investigation of the movement of electrons in atoms, molecules and nanostructures. This is relevant for molecular biology and medical technology.

60 These assessments are based on interviews with selected experts, bibliometrics, the online survey and the second wave of monitoring and further current specialist literature.

Today's attosecond lasers[61] already produce x-ray pulses of less than 100 attoseconds. If this generation of lasers can be made more powerful, 4D-imaging using compact x-ray sources providing extremely high resolutions (e.g. up to angstrom level) could become available in future. Areas of application for these would include medical diagnosis and treatment (e.g. targeted x-ray treatments, in-vivo bio-structural investigations and many other uses) (see also Stubenrauch 2005).

Atto (second) electronics – controlling processes on an atomic time scale: The possibility of understanding and controlling phenomena and processes on an atomic time scale (24 attoseconds) offers a wide range of further potential (Kienberger and Krausz 2009; Kapteyn et al. 2007). »Atto-electronics« could then develop. If researchers could master real-time observation of electrical charge transport and control the movement of electrons in molecules and nanostructures, high-speed electronic systems (e.g. molecular/ chemical computers) that could calculate a million times faster than today's computers could be developed in future. Investigations into the dynamics of charge transfer processes would provide a better understanding of intra-molecular energy transport. This could lead to more efficient energy applications – especially on the basis of nanotechnology.

Chronobiology/ Biological clock(s)

The topic of biological clock(s) was regarded as a relevant future topic in international research, or more precisely, in the Japanese foresight process (see NISTEP 2005). This was a starting point for the assumption that time research could be a vital future field. Bibliometrics carried out during the BMBF Foresight Process confirm the great dynamism of this overall future field, in particular with the increase in the number of publications on biological clock(s) and chronobiology. One issue discussed in publications is the fact that many people live against their biological clocks but it is still unclear what the consequences of this are (e.g. diseases).

Chronobiology, the study of rhythmical processes in living organisms, was not taken seriously by conventional science for a long time, but now offers new approaches in the early diagnosis of diseases and their more efficient treatment (»profil« 2006, p. 138, with an overview by Lemmer 2007), e.g. asthma, high blood pressure, certain tumours, arthritis and even the tendency towards ex-

[61] When a pulse from a femtosecond laser interacts with atomic material, electrons can be released and be accelerated through the electrical field of the femtosecond pulse. If the electrical field is reversed, the electrons are driven back to the atom and can recombine to emit a high-energy photon. This produces higher frequency radiation, so-called 'high harmonic radiation', in the range of attoseconds. A range of 80 attoseconds was reached in 2008.

treme obesity. Research into humanity's »internal clock« is another aspect of this field. Our biological »master clock« is in the brain, in the hypothalamus, or more precisely, in the suprachiasmatic nucleus (SCN), a neural core area comprising about 20,000 cells, but there are chronometers that are synchronised with the SCN in most bodily tissue and in organs, too. These clocks (so far three have been identified, CLOCK 1, 2, 3) enable their bearers to adapt »in anticipation « to cyclically recurring events and in this way to optimise their consumption of materials and energy.

Chronobiology also offers a new basis for medical applications. Even in conventional medication treatments, the right time for administering drugs plays a role in medicine. Effects could be optimised and side-effects reduced. Initial successes using so-called »chrono-therapy« have already been reported in connection with dialysis, chemotherapy (acute lymphatic leukaemia) and other targeted treatments. Sleep patterns are also controlled by an internal clock. What causes changes over the course of a lifetime and how the internal clock and its mechanisms themselves change, remains to be explained, so that sleep disorders can be better treated (Neue Zürcher Zeitung 02.04.2008, p. 65). At the same time, hormonal regulatory and energy absorption mechanisms are still largely unexplained. Many people for example, take melatonin to avoid jetlag or erroneously as a »soporific«, without really knowing how it works.

Other studies (Kelner 2008) have established a strong connection between a person's energy consumption and the biologically-adjusted timing of their day. This factor, added to research into hormonal regulation, would provide information on why shift workers, who work against their biological clocks, suffer more frequently than other people from obesity, depression and digestive problems (»profil« 2006). The general connection between the biological clock and metabolism has not yet been explained in detail. The »Sirt1« protein has already been identified as a central link between metabolism and circadian rhythms. If the important functions that »Sirt1« fulfils in metabolism can be precisely identified (mobilising fat, inhibiting cell ageing), it could provide a starting point for preventing and treating illnesses such as obesity, diabetes or metabolic syndrome. (Cell 2008, p. 134; 317-328; 329-340).

It is also assumed that there is a connection between biological rhythms and depression. The great influence of light and the light-dark rhythm on depression is known, but the exact processes at work have not yet been explained. Researchers assume that we will have new light sources adapted to biological rhythms within a few years (information from experts at the conference on 22.6.2009 in Bonn). This would »close the circle«, because the connection between light and hormones (e.g. earlier sexual maturity of boys due to exposure to artificial light) is also being researched, although the chronological context, exactly when which kind of light is not critical or is necessary, has so far not been taken into account.

Synchronisation and parallelisation, efficiency

Innovations and production processes are becoming faster and more complex. The focus here is usually project management and time management, but current demands on complexity are not satisfied (summary by Rollwagen 2008). The factor of time is also being increasingly discussed in the context of mobility and energy efficiency (e.g. at the conference in Tutzing in 2009). Optimising the synchronisation of Internet servers could, for example, yield massive energy savings.

8.3 The long-term outlook for this future field

These areas raise research questions at various levels. Figure 11 illustrates some of the long-term future topics.

Ultra-precise measurements of ultra-short time

- How can optical clocks be used in practice? Questions of standardisation that are relevant to research are also raised here. The current standard is the caesium-based second.
- How can today's attosecond lasers be made more powerful to enable 4D-imaging using extremely high-resolution (up to angstrom) compact x-ray sources for medical diagnosis and treatment, in-vivo investigation of bio-structures and many further applications through a new 4D microscopy?
- How could atto(second) electronics be used to make molecular or chemical computers or efficient energy transmission possible?

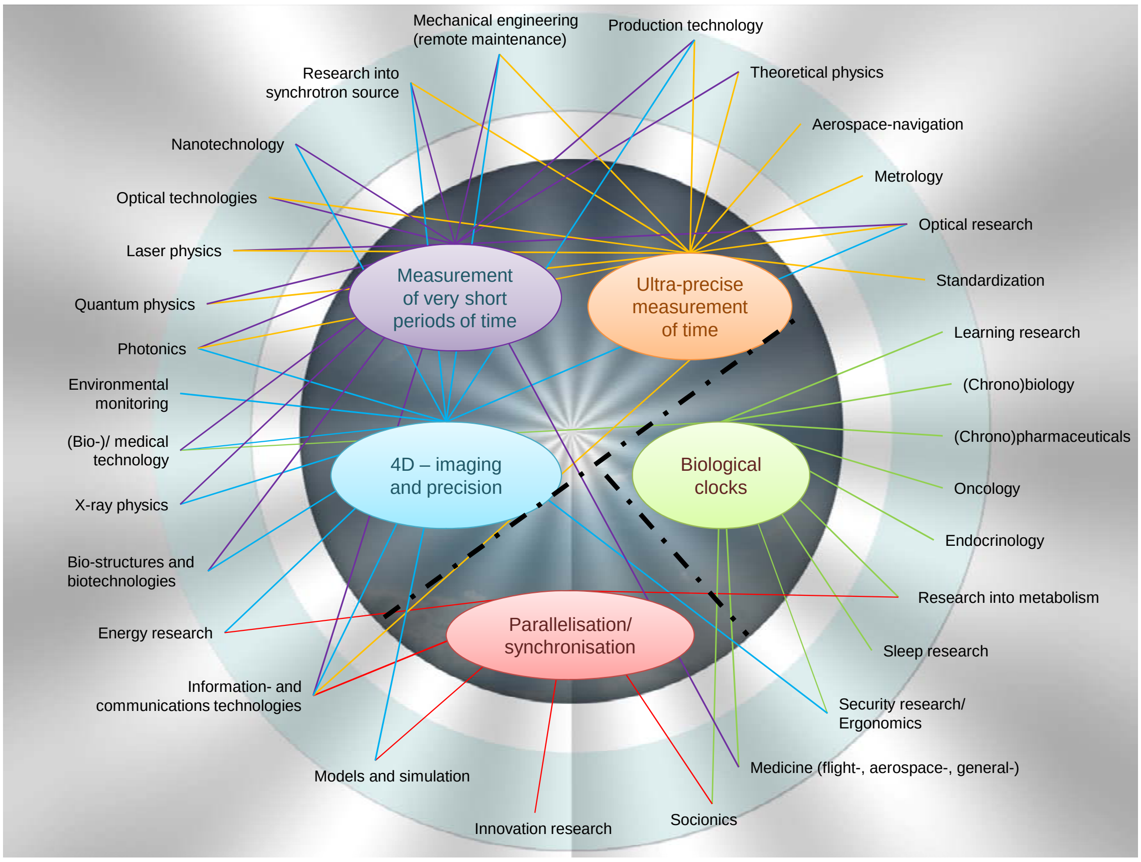


Figure 11: Future participating research areas

Chronobiology/ Biological clocks

- What possibilities could chronobiology yield for medicine? What role could »timing« play in providing gentler treatments (e.g. in dialysis, chemotherapy etc.) and in the area of pharmaceuticals? Could certain medications be reduced or dispensed with altogether by differently timing dosages, thereby improving quality of life for patients? Could a combination of the precisely-timed administering of drugs (pharmaceuticals) and micro-systems technology-based systems (automated measurement of bodily parameters, then chronologically-coordinated drug delivery via sensors, depots, »missile drugs«, implants etc.) boost innovation and reduce costs?
- Could sleep disorders be better treated if findings could be made on the functions of different chronometers in living organisms? How can depression be avoided?
- Understanding biological clocks seems to be crucial in learning, improving drug delivery, in working hours and structures and in understanding human behaviour. What processes and interactions are at work here? If it is estab-

lished that people's energy absorption depends on timing, how could negative effects such as obesity be avoided among shift workers and other people who work against their biological clocks?

- How could chronobiology contribute to security issues? Most major accidents happen at night due to decreased attentiveness in the people charged with monitoring processes (e.g. Chernobyl).

Efficiency in processes: synchronisation and parallelisation

- How can processes run efficiently, i.e. be synchronised and parallelised, without simply becoming »faster« and overwhelming people? How could Internet servers (for energy savings), energy systems (managing regenerative and conventional energy in networks) or the development of new products be better synchronised?
- How is time economically »valued« (in an exchange of time for time)? Could passengers hold a railway company liable for example, if a train arrives late and just time is »taken« from them? Such regulatory issues will arise far more frequently in future.

How people deal with time was regarded as particularly important in the online survey of the BMBF's Foresight Process, especially against the background of making work more flexible, de-coupling working hours and results, and in terms of the issue of time beyond just time management and accelerating and decelerating processes. New time structures in an »ageing society« will be a socially-relevant topic in the next 20 years. Novel methods of future research were also regarded as especially relevant in this context, although these topics were not considered in depth in the further course of the BMBF Foresight Process. Time research is »scattered« across various disciplines and would gain further momentum from more targeted cooperation.

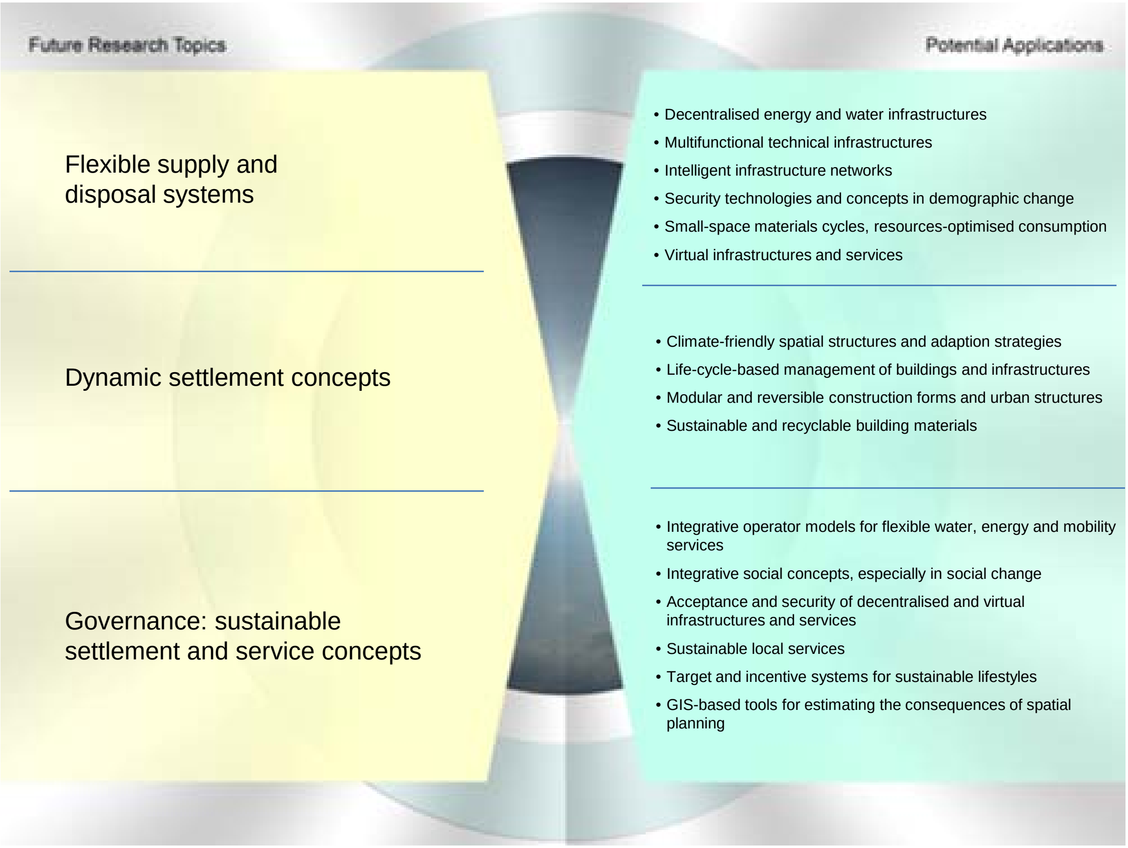


Figure 12: Future research topics and potential applications in the future field of »time research«

8.4 Why is this future field relevant?

Being able to understand and control the microcosm's ultra-short timescale would offer humanity and technical progress a potential that can hardly be underestimated. The life spans of individual atomic and molecular through to complex configurations can be controlled by manipulating chemical, biochemical bonds/ reactions and electronic states. There are potential applications here for practically all disciplines and technologies pursuing greater chronological and spatial precision: metrology, nanotechnology, biotechnology, medical technology/ healthcare, information and communications technologies, production, and security and energy technologies etc.

Ultra-precise and ultra-short time measurements, 4D-imaging and attophysics could result in many new applications in research (real-time observation) and in products. Ultra-precise, real-time medical diagnoses and treatment could for example be possible.

An understanding of people's different chronometers could contribute to disease prevention, new kinds of diagnoses and treatments, and the better use of time in everyday life and thus to improving quality of life. A new »automation« of drug delivery could also provide impetus for other technical areas (microsystems) and some risks (occupational health and safety, but also nocturnal surveillance of facilities) could be better avoided.

The factor of time is also present in many processes (production processes, energy transmission, human life etc.) that could be better parallelised and synchronised and so made more efficient if this factor were better understood. Time research therefore impacts all other disciplines. Research results could be made useful to people not only directly (e.g. treatments, medications, drug delivery and organising learning and working), but also indirectly (e. g. optimised adaptation of social and working environmental conditions to meet human needs). Such results could be relevant in building spatial planning or in infrastructure planning and design (variations of light and dark, natural and artificial light sources to increase efficiency, well-being and health while reducing stress), for planning the opening and closing times of public institutions, businesses, etc. or for regulating teaching, working times and much more.

8.5 Current actors in the innovation system

Germany, with groups of researchers at the Max Planck Institute for Quantum Optics (MPQ) in Munich, the Physikalisch-Technische Bundesanstalt (PTB) (German national metrology institute) in Braunschweig and many other universities (e.g. Munich and Bielefeld) and research institutions (e.g. Max Born Institute for Non-linear Optics and Short Pulse Spectroscopy) is now, in addition to the USA, the leader in the area of **ultra-short time research**, especially in the still very new area of attophysics (created in 2002 with the production of sub-femtosecond pulses). After the USA and Germany, China, France, Russia and Japan are the other major countries now active in the area of ultra-short time research. The number of publications in the still small area of attophysics has increased more than tenfold in the last ten years, for example, (to 200 in 2008), while the number of publications in the area of ultra-short time research has tripled over this comparative period.[62]

In addition to developments in the areas of laser physics and ultra-short time research, convergence and mutual influence between so-called »table-top«-laser applications on a laboratory scale and ultra-short time technologies is growing, with major research institutions such as the Deutsche Elektronen Syn-

62 Based on a key-word-based bibliometric analysis in the ISI »Web of Knowledge«.

chrotron (German electron synchrotron) (DESY) active in this area. The soft x-ray and vacuum ultraviolet area, designed to be made accessible by »table-top« laser sources (although these still lack intensity and power), were previously the uncontested domains of synchrotron radiation or new laser sources, such as the free electron laser (FEL). With the XFEL (x-ray FEL)[63] at DESY, planned for 2012, electron energies of 10 to 20 GeV will be made available, but the x-ray laser pulses will not be shorter than about 100 femto-seconds (laser physics can now already produce pulses of less than 100 atto-seconds). Laser physicists, ultra-short time researchers and researchers in the area of synchrotron radiation could profit greatly from more communication with each other in future.

Actors in the area of real time

- Ludwig-Maximilians-Universität Munich
- Max-Planck-Institut für Quantenoptik (Max Planck Institute for Quantum Optics)
- Unviersität Heidelberg
- Freie Universität Berlin
- Universität Hamburg
- Friedrich-Schiller-Universität Jena
- Technische Universität Dresden
- Technische Universität Munich
- Laser Zentrum Hannover e. V.
- Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Max Born Institute for Non-linear Optics and Short Pulse Spectroscopy) in the Forschungsverbund Berlin e. V.

Actors in the area of optical clocks

- Max-Planck-Institut für Quantenoptik (Max Planck Institute for Quantum Optics)
- Ludwig-Maximilians-Universität Munich
- Universität Bielefeld
- Physikalisch-Technische Bundesanstalt (PTB)
- Heinrich-Heine-Universität Düsseldorf
- Friedrich-Alexander-Universität Erlangen-Nürnberg
- Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Max Born Institute for Non-linear Optics and Short Pulse Spectroscopy) in the Forschungsverbund Berlin e. V.
- Max-Planck-Institut für Physik komplexer Systeme (Max Planck Institute for the Physics of Complex Systems)
- Leibniz Universität Hannover
- Max-Planck-Institut für Kernphysik (Max Planck Institute for Nuclear Physics)

Actors in the area of attophysics

- Max-Planck-Institut für Quantenoptik (Max Planck Institute for Quantum Optics)
- Ludwig-Maximilians-Universität Munich
- Universität Bielefeld
- Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Max Born Institute for Non-linear Optics and Short Pulse Spectroscopy) in the Forschungsverbund Berlin e. V.
- Max-Planck-Institut für Physik komplexer Systeme (Max Planck Institute for the Physics of Complex Systems)
- Max-Planck-Institut für Kernphysik (Max Planck Institute for Nuclear Physics)
- Heinrich-Heine-Universität Düsseldorf
- Universität Hamburg
- FOM Fachhochschule für Oekonomie & Management (FOM University of Applied Sciences)
- Julius-Maximilians-Universität Wurzburg
- Johann Wolfgang Goethe-Universität Frankfurt
- Deutsches Elektronen-Synchrotron DESY
- Freie Universität Berlin
- Universität Kassel
- Leibniz Universität Hannover

Table 8: Actors in the area of ultra-short time research in 2009

63 http://xfel.desy.de/.

These »communities« are merging at an EU level as part of the »European Strategy Forum on Research Infrastructures« (ESFRI)[64] and other large-scale projects. Examples include ELI (»Extreme Light Infrastructure«, funding: 400 mill. Euros, preparation phase 2008 to 2010)[65], investigating the interaction between materials and light at extremely high intensities and short timescales (the MPQ is also represented here) and the HiPER (High Power laser Energy Research) facility, (funding: 1 bill. Euros, preparation phase 2008-2011)[66], which represents an approach towards using laser fusion to solve the global energy problem.

In order to consolidate and expand Germany's current leading international role, a prompt and more extensive networking of relevant »communities« (i.e. including of users to instruments to be developed) may become increasingly important and should already be underway.

Chronobiology is established in Germany, but not yet widespread. Actors in this field are working in medical centres, in sleep laboratories and in the pharmaceuticals industry (see Table 9).

Actors in the area of chronobiology

- Institut für Pharmakologie & Toxikologie Mannheim/ Universität Heidelberg (Prof. Lemmer, em., Dr. Gorbey)
- Chronobiology Lab at the Charité, Universitätsmedizin Berlin (Prof. Kramer)
- Arbeitsgemeinschaft Schlafforschung und klinische Chronobiologie, Institut für Physiologie, at the Charité, Berlin (Dr. Kunz)
- AK Neurobiologie Circadianer Rhythmen (Neurobiology of Circadian Rhythms working group), Johann W. Goethe Universität, Frankfurt am Main (Prof. Korff, Prof. Fleissner)
- Zentrum für Chronobiologie, Ludwig-Maximilians-Universität Munich (Prof. Rönneberg)
- Albert-Ludwigs-Universität Freiburg, Institut für Biologie II (Prof. Wagner)
- Universität Halle, Medizin- und Pflegewissenschaften (Prof. Peschke)
- Gottlieb-Daimler- und Karl-Benz-Stiftung (Gottlieb Daimler und Karl Benz Foundation)
- Arbeitsschutz und Arbeitssicherheit (Bundesanstalt für Arbeitsschutz und Arbeitssicherheit – Federal Institute for Occupational Health and Safety)

Table 9: Actors involved in the area of chronobiology in 2009

The European research network EUCLOCK[67] (headed by Prof. Roenneberg, LMU Munich), which is investigating »entrainment«, the synchronisation of our internal clocks with external conditions, was established in 2006 under German leadership (LMU Munich). The Gottlieb Daimler and Karl Benz Foundation have taken up the topic together with EUCLOCK[68], involving industry in preliminary discussions.

64 http://cordis.europa.eu/esfri/, one of the strategic technology platforms.
65 http://www.extreme-light-infrastructure.eu/.
66 http://www.hiper-laser.org/.
67 http://www.euclock.org.
68 http://www.clock-work.org.

Bibliometrics identified many articles from Switzerland and France and some from the Netherlands, where this field seems to be more strongly established (e.g. the Centre for Chronobiology, university psychiatric clinics, the CH Basel, the Groningen Center of Behavioural and Cognitive Neuroscience (BCN), and the Rijksuniversiteit at Groningen in the Netherlands). One institute in Japan (the Institute for Biological Resources and Functions) is examining jetlag and its consequences. At the University of Manchester, research is being conducted into »Chronobiology and Sport«. Researchers into time taking broad social, economical and political scientific approaches are also partly organised under the umbrella of the »Deutsche Gesellschaft für Zeitpolitik«.[69]

8.6 Sustainable actors' groups

It is difficult to deal with the entire area of time research, which is very diverse and has a social-science aspect – not described in detail here – in a single strategic dialogue. There are therefore in our opinion two different focuses for potential partnerships that could provide a starting point, but which could subsequently be consolidated.

1st focus: Actors in the area of ultra-precise/ ultra-short time measurement come from various research areas. The areas of laser physics and research into ultra-short times (e.g. »table-top lasers«) and synchrotron laser sources (e.g. FEL, XFEL) are (further) developing **instruments and methods** that make an increasingly precise spatial resolution of structures and especially the chronological resolution of processes (dynamic, kinetics) possible. Strategic partnerships and joint research initiatives could help network these actors more closely to advance research into future photon instruments and methods and consolidate and further extend Germany's current international leading role.

Actors involved in this research topic and in areas such as attophysics, nonlinear optics, nanophotonics/optics, theoretical modelling and simulation and metrology connected with optical clocks and time measurement, which are crucial to the development of (research) **methods and processes,** should also be mentioned in this context.

At major research institutions, e.g. the Deutschen Elektronen Synchrotron (DESY), broad groups of users from very different research disciplines are profiting from radiation sources. These include biotechnology (e.g. protein folding processes), chemistry and materials sciences (e.g. catalysers), nanotechnology (e.g. nanostructures sub-dynamics), medical technology (e.g. 4D-imaging, x-ray

69 For a list of names go to www.zeitpolitik.de

tomography) and energy technology. Future compact ultra-short period/ ultra-short pulse sources could become increasingly important in these applications and for other **users**. Chronobiologists could in future investigate the interaction of genes with the help of molecular biology using ultra-precise 4D-imaging. Researchers and users of ultra-precise/ultra-short time measurements must therefore be brought together and jointly supported in order to make the range of applications of these future ultra-short time instruments evident to other potential users.

2nd focus: Starting in the area of research into **biological clocks**/ chronobiology, strategic partnerships should also be considered and initiated, in particular a new cooperation between chronobiologists and safety and security researchers, to sound out new possibilities of minimising the inherent risks of human operators.

Research into metabolism also entails another sustainable actors' group in addition to the existing field of chrono-pharmacology, which brings the pharmaceuticals industry and researchers together. Work is being carried out in this area by (molecular) biologists, medical scientists etc., but currently only rarely includes time as a factor. Cooperation with chronobiologists will be necessary to explain the metabolic syndrome, for example. It is assumed that in the metabolic syndrome (an illness involving a combination of high blood pressure, diabetes and often obesity, as well as other factors) metabolic processes have become »decoupled« from each other and can no longer be properly chronologically synchronised. To identify these processes, industry is currently collecting data (e.g. the LMU Munich with the Siemens company), to identify patterns that trace back metabolic disorders to shift work. Chronobiologists have expressed a wish for closer cooperation with micro-systems engineers in order to obtain better measuring devices and to develop targeted drugs that would enable simultaneous measurement and dosage.

Cooperation among sleep researchers, medical scientists, doctors treating depression in practice, endocrinologists (to explain how melatonin works etc.) and chronobiology will be necessary in improving the treatment of sleep disorders and depression. During subsequent implementation, concrete cooperation with researchers working on new light sources and dosages will also be advisable. Light strongly influences chronological processes in the human body (see Spork 2004 and literature cited there), so sleep disorders and depression could be avoided with the help of chronologically-coordinated »doses« of light. This could also be relevant for shift workers. Experiments are already being conducted to reproduce conditions similar to daylight so as to provide the body with a different chronological rhythm. Findings from aviation medicine and space research (space medical technology) could also be used here.

In a subsequent phase, researchers working on labour and industrial issues and labour law experts will also have to be involved in these dialogues, because findings made in chronobiology are increasingly showing that health problems are caused by people working against their biological clocks. The chronological structure of society is also taken into account in time research, thus addressing further actors in the innovation system: education policy-makers on the right »timing« of learning, managers on the optimal deployment of different age groups in company staff, and groups of people often affected by jetlag. An interdisciplinary approach must be taken if solutions are to be found.

Time researchers, who already think in an interdisciplinary way and involve politics, have in Germany also joined forces in a society (»Deutsche Gesellschaft für Zeitpolitik«[70]). It consists of actors taking very interdisciplinary approaches from very different backgrounds, who should also be involved in discussions.

Some sustainable actors' groups in chronobiology are already covered by the EU's EUCLOCK research platform. To implement results more quickly at a national level, broadening this area with a complementary national network should be considered. Industry is already very interested in this topic, as shown by the involvement of the Gottlieb Daimler and Karl Benz Foundation. The early involvement of companies, for whom chronological organisation, chronobiology and parallelisation and synchronisation processes may be of interest, is essential in our view.

8.7 Recommendations

In the opinion of the topic coordinators, the two focuses mentioned should first be pursued and strategically extended so as to cover time research in all its breadth. Different approaches could then be integrated step by step and extended to include the social sciences and in particular sociological research.

In respect of the first focus, ultra-short time measurement, major projects such as ELI (Extreme Light Infrastructure, funding: 400 mio. Euros, preparation phase 2008 to 2010) investigating the interaction between materials and light at extremely high intensities and short timescales, should be supported at the EU level in future. There are also large national research institutions which could incorporate complementary projects and programmes into their work in the short term without great additional cost. The relevant »communities« should be well networked. Strategic dialogues between researchers from science and industry could be of optimal help here in identifying future measures.

70 See www.zeitpolitik.de

On the other hand, setting up a national platform could help to bring together researchers working on developing compact short-pulse laser systems and new methods and processes (e.g. through institutional funding, because specific actors are leading in this area) and could make it possible to open up new areas of research and applications (e.g. through funding programmes that help actors to network in specific thematic areas).

In terms of innovation research, demand-oriented research would seem to be more advantageous than technology-driven research. There is an increasing reliance on »beacon projects« and pioneering programmes that address global issues such as energy, climate change, demographic change etc. Time research comes however from both sides: on the one hand out of new findings from basic research, which conceives of new applications in the first place (e.g. new findings about our internal clocks), and on the other hand from the demands of new, application-oriented basic research (e.g. GPS applications that require more precise time measurement). It is the view of the topic coordinators therefore, that the following research aspects in the future topics should be monitored as »applications« in the long term and the integration of time research pursued thereby:

Understanding the processes of life, e. g. investigating ageing, chronobiology etc. at a molecular level through »molecular dynamics«; drug development/design, based on research into protein folding processes. There is insufficient basic research being done in this area, which could be remedied by institutional funding and promotion, and there is in particular a lack of clinical studies to prepare for the transfer of findings into practical applications.

»Healing in real time«, e.g. diagnosis through 4D-imaging and treatment using spatially and chronologically targeted drug applications, x-ray treatments.

Energy efficiency, e.g. optimising materials, structures and systems, such as solar cells, batteries and fuel cells, for efficient energy transport, information processing at light speeds with optical computers or ultra-fast computing through attosecond electronics.

Efficient environmental processes, e.g. time-resolved structural investigations of nano-particles during catalytic reactions for developing better heterogeneous catalyser materials.

Efficient production, e.g. precision agriculture using ultra-precise time measurement and GPS applications, synchronised/ parallel production processes.

In respect of the second focus, chronobiology: If German researchers in the dynamic future field of chronobiology want to take on and maintain a leading position, institutions will have to be funded and promoted (extending research at some universities and research institutions). On the other hand, it would be advisable to fund and promote clinical studies and translational research in targeted projects so as to implement the results of basic research currently expected and forecast for coming years in applications (ranging from chronopharmaceuticals to security) as quickly as possible. This would have to involve many different actors. Findings in the area of chronobiology will also transform the (social) handling of time in the long term. This was the clear result of individual thematic discussions at the concluding conference in June 2009.

Chronobiology has developed such an international dynamic that the option of strengthening the few actors in Germany, including at an institutional level, should be considered. The financing of clinical studies, e.g. in a programme to research connections between time (chronobiology) and human metabolism, would be money well invested, because many applications could emerge here. At the top of chronobiologists' »wish list« is on the one hand more staff, especially those willing to work against their own biological clocks, so that **clinical studies** can be carried out. On the other hand, they would like to see more practical medical and technological support from micro-systems technology, which could help them open up possibilities beyond the administering of »targeted drugs«, also delivering new kinds of timepieces, for example.

Many different actors will have to be involved. An integrative strategic dialogue, which would help to identify a strategic orientation and actors of interest, would also surely advance time research. Industry would profit from this future field and in particular, people's quality of life could be improved.

9 Sustainable energy solutions

German researchers are working on issues for the provision and efficient use of energy as a matter of highest priority.

Two starting points were identified in the BMBF's Foresight Process, indicating scope for action beyond current activities:

1. Methodically-supported long-term coordination of energy-relevant findings from various research fields not directly involved with energy (»energy concert«) and
2. Identifying new ways to use ambient micro-energy to operate mobile devices (micro-energy from the surrounding).

While (1) »the energy concert« is a field of activity for research coordination and involves large quantities of energy, (2) »micro-energy from the surrounding« will require intensive research in various areas. The harvesting of micro-energy is also not solely an energy topic. The amounts of energy involved are so small that they are irrelevant to energy experts, so this field plays no role in the broader »energy concert«. Harvesting micro-energy is a research and innovation topic that especially incorporates microelectronics, so this research topic is also included in the future field of information and communications technologies.

The two fields will be presented below.

9.1 Field of activity – energy concert

Coordinated research diversity for sustainable energy landscapes

It should first be noted that the »energy concert«, apart from its methodical aspects, is not a research field in the true sense, but a field of activity for coordinated research. Because of the urgency of this challenge, which was repeatedly emphasised by all experts participating in the BMBF Foresight Process, it was proposed there as an area for interdisciplinary research activities (Objective 2) and is documented here together with other new forms of future fields.

The »energy concert« aims to strategically bundle the contributions of various research fields for the sustainable production and use of energy. To achieve this, we propose a future-oriented, structured monitoring of the research landscape. Integrated analyses of scenarios and »meta roadmapping« should help to identify synergies and inconsistencies and indicate opportunities that could arise out of strategic bundling at various points. In our view, the BMBF Foresight Process results point towards the following fields for such an energy-related »strategic coordination«:

- Materials sciences/ nanotechnology/ electro-mobility
- Energy-efficient production technology/ bio-production
- The intelligent house / photonics

This field could build on current BMBF activities in the area of system-oriented energy research (BMBF 2008: Basic Energy Research 2020+. p. 20ff).

9.1.1 The energy concert – the motivation

Securing an affordable, secure and climate-compatible energy supply is a central global challenge and an outstanding leading future market with high relevance for the economy and quality of life and a powerful influential impact in many research fields. Sustainable, coordinated solutions for production, distribution and use are all equally important in this context. Many different research projects outside the direct area of energy research could make significant contributions here. This was impressively confirmed by the BMBF Foresight Process's online survey of experts. In almost every future field, energy-related research topics were highlighted as especially relevant for the future (cf. Figure 13).

Every research area follows its own »roadmap« and focuses on certain energy »landscapes«, i.e. future forms of energy production and use. Such energy landscapes are however also undergoing dynamic change. New technological and organisational concepts in areas such as mobility, housing development, agriculture, information and communication, production and not least energy production itself are changing energy use and energy production. Such dynamism is characteristic of innovation processes and is usually transmitted through market mechanisms and other social selection processes.

Biotechnology for generating energy

- Area with 2nd highest relevance in the field of biotechnology and the life sciences, highest level for the economy, quality of life and technology

Efficient use of energy and resources in industrial production

- Major area and the top of the list in all relevance categories in the field of Industrial Production Systems

Energy-consumption optimised and energy self-sufficient production plants

- 2nd most important research task in the field Industrial Production Systems

ICT for highly-efficient decentrally-organised energy supply systems

- Most important research task in the field of Information and Communication Technologies

Harvesting ambient energy

- Selected future topic with long-term relevance in the field of Information and Communication Technologies

Economic activity that uses resources an raw materials efficiently

- Most important area in the field of Environmental protection and sustainable development in the overall survey

Using photonics to generate energy

- Most important research task in the field of Optical Technologies

Nano-materials for generating/converting energy

- Most important research task in the field of Nanotechnology

New insulation materials

- Most important research task in the field of human living spaces

Materials systems for a new generation of energy storage and coating materials for the cost-effective harvesting of solar energy

- The two most important research tasks in the field of Materials

Figure 13: Evaluation of future energy-related topics in the BMBF Foresight Process's online survey (extract)

The area of energy research occupies a special position due to the extreme longevity of innovation cycles and the overriding social interest in a climate-compatible, secure energy supply. It is therefore in our view necessary, beyond direct energy research, to »flank« the process by which optimal energy efficiency adaptations to various technologies and concepts emerge with appropriate measures, without limiting the diversity of solutions generated in research.

9.1.2 The energy concert – the approach

The »energy concert« field of action aims to open up the potential for a strategic bundling of various actors in the research landscape in terms of sustainable energy scenarios at an early stage.

In a first step, the »energy concert« requires a systematic monitoring of the various findings made in energy efficiency research and associated future energy landscapes (»roadmap-screening«). In a second step, the various objectives could be compared and contrasted with different environmental scenarios. Integrated socio-technical scenario analyses and interdisciplinary »meta-roadmapping« could be used to reveal potential synergies and identify the opportunities of research efforts through strategic bundling at certain points.

In a further step, it is conceivable that flanking, coordinating or joint research projects across several technology fields could be initiated at this point. Such a process could be launched with a relevant research project, which must then be continued in a dialogue between participating disciplines and actors in order to lead to specific interface research projects.

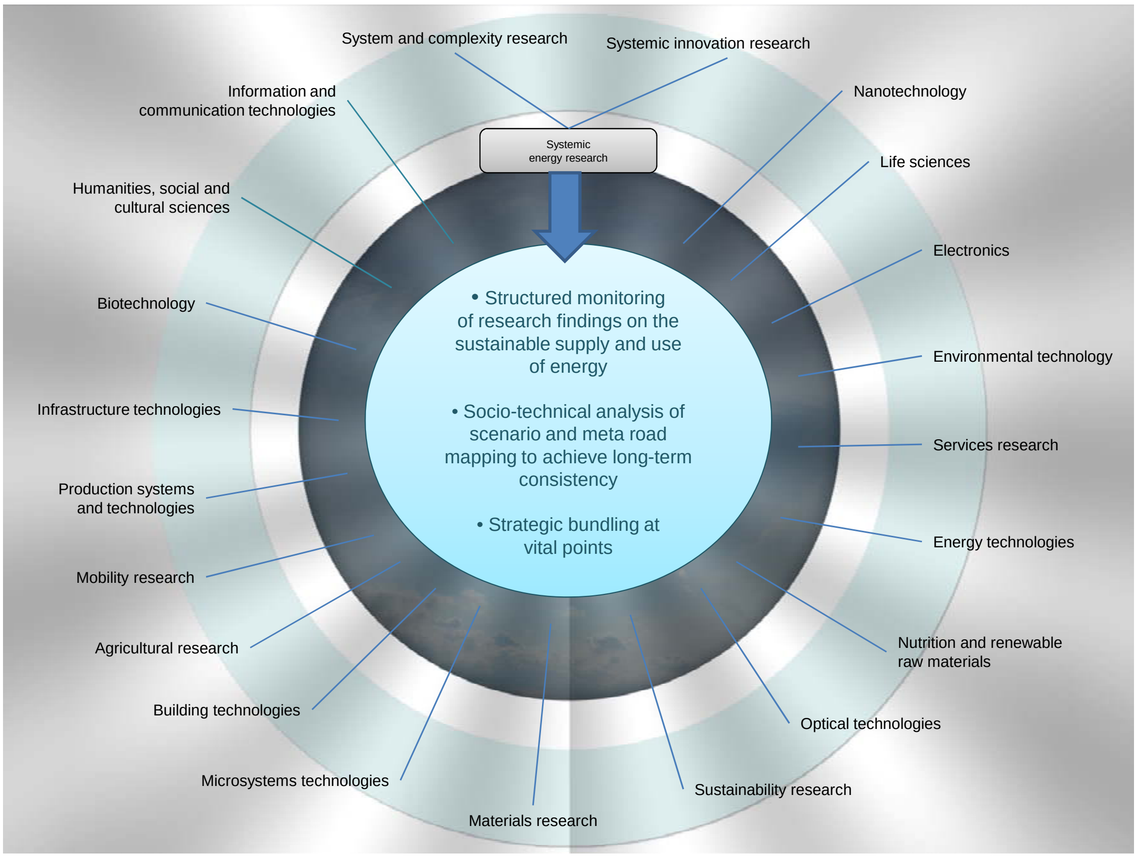


Figure 14: Structure of the »energy concert«

The »energy concert« could be based on approaches towards system-oriented research currently being pursued by the BMBF (BMBF 2008: Basic Energy Research 2020+. p. 20 ff.). Integrated research initiatives such as the »energy-efficient city« point the way in the direction shown here. The »energy concert« however covers a greater observational radius and takes up contributions from individual research fields at an early stage (cf. Figure 14). Instruments such as qualitative and quantitative scenario analyses can also make significant contributions to coordinating long-term prospects.

9.1.3 Potential players in the energy concert

All research and innovation fields are potentially relevant to the »energy concert«. Actors in the area of research policy and from research institutions dealing with the strategic long-term orientation of their area, who are involved in activities such as the innovation alliance »Lithium Ion Battery LIB 2015«, the

»Werkstoffinnovationen für Industrie und Gesellschaft – WING« research programme and the »Solarenergietechnik der nächsten Generation« (next generation solar energy) funding initiative, must be included. A comprehensive identification of relevant activities and actors for »orchestrating« the »energy concert« would be the first task in this field of activity.

9.2 The research field Micro-energy from the surrounding

Every day we consciously or unconsciously use a range of different devices that need energy. These devices are becoming smaller (miniaturisation) and integrated into systems, some in the form of implants, even into people. Applications increasingly need to run autonomously, be decentralised or mobile, or operate without a power supply or even without batteries. The use of micro-energy drawn direct from the surrounding is therefore a precondition for new applications and decentralised systems in many cases.

Examples of this might include permanent power supplies for heart pacemakers, the permanent, mobile measurement and transmission of bodily functions such as heart rate and blood pressure and autonomous, distributed sensor systems with monitoring functions etc. The innovation potential for mobile devices requiring just a little energy is not nearly fully exploited yet and would seem to be a major precondition for developments such as the »Internet of Things« or »ambient intelligence«.

Technologies for using »energy sources« such as mechanical energy from vibrations or movements of air, thermal energy from waste heat, frictional heat or body heat, radiation from the sun or artificial light, electromagnetic energy from transformers or from chemical and biological processes could serve as »enablers« for innovative microelectronics applications that would otherwise seem completely impossible. How this can be achieved and in which cases it would be economically and ecologically reasonable, is still to be researched. The use of such micro-energy sources also requires corresponding applications that can use the small amounts of energy supplied.

9.2.1 Why micro-energy?

General scientific-technical progress leads to the development and dissemination of new technical applications that replace or complement existing devices or open up completely novel application areas. This progress is characterised by two central and connected trends: miniaturisation and increasing functional integration, so increasing numbers of new objects can be elevated to the rank of »intelligent products«. Many of these products can »recognise« their environment within selected parameters and react (independently) to changes within certain limits (acatech 2009a). Different devices also increasingly act in combination and communicate in order to coordinate with each other. This goes well beyond »classic« ICT applications and also affects regular daily objects.

All these processes need energy, usually electricity. Existing supply concepts for the applications mentioned currently assume either access to the electricity network or to powerful energy storage units (primary batteries, rechargeable batteries). Despite comparatively high power density, existing solutions are often unsatisfactory and/or expensive in terms of their availability and operational life.

The progressive »technicalisation« of our environment and the accompanying need for a permanent and mobile energy supply beyond current infrastructures mean that new energy availability concepts have to be developed. The technologies and innovations addressed here could however only fill a small gap. This future field would »disappear« within the »energy concert« because the focus there is not on energy amounts, but on technological demands. This »future topic«, initially viewed as a minor field, emerged in the area of information and communication technologies. It could however, if creatively pursued, have significant effects and take on the character of a »future field«.

A range of »energy sources« mentioned above, such as mechanical energy from vibrations or movements of air, thermal energy from waste heat, frictional heat or body heat, radiation from the sun or artificial light, electromagnetic energy from transformers or energy from chemical and biological processes, could be used in applications. These could supply amounts of energy roughly corresponding with that of button cell batteries, but they would not have to be changed and their power production costs per kilowatt hour could be in the range of three to four Euros. New material combinations will be needed to create new applications in the area of microelectronics. As well as these diverse kinds of energy converters, such an energy supply system would also require storage and management systems to provide the necessary amounts of energy of the required current, voltage and frequency at all times.

9.2.2 The initial situation in the future field today (2009)

There are various, practically-trialed technologies available that can use ambient micro-energy, so each application must be separately considered in terms of its overall energy balance and efficiency:

- photovoltaic generators, in which the direct photovoltaic energy conversion is carried out based on various solar cell principles,
- piezoelectric generators, that convert mechanical energy into electrical energy using special piezo crystals,

- thermoelectric generators that generate electricity from the differences in temperature in two different metals (Seebeck Effect),
- electromagnetic generators, which convert electromagnetic energy using the well-known dynamo principle,
- capacitive and electrostatic generators use capacitive or electrostatic charges in an electrical field to generate electricity,
- Micro fuel cells (energy converters that use a specific energy sources such as hydrogen, methanol or glucose) and
- Thermo-mechanical generators, which in contrast to thermo-electrical generators, mechanically generate intermediate energy, which must undergo a further conversion process to create electrical energy.

Most studies and events refer to this area under the heading of »Energy Harvesting« (e.g. Bartsch et al. 2007; Chalasani and Conrad 2008; Fleischhauer et al. 2007; studies by Frost & Sullivan 2007; Kloub et al. 2008; König 2009; Maurath et al. 2008; Müller et al. 2009 and 2008; Paradiso/ Starner 2005; Spreemann/ Becker 2008; Spreemann et al. 2006; and Ungan/ Reindl 2008).

Promising research is currently being carried out in the area of micro-mechanical systems, in which energy from vibrations is transformed into electrical energy via a piezoelectric[71] coating. Such systems could be used to supply energy to sensors in aircraft, vehicles or vibrating industrial plant. These piezoelectric systems can provide up to 60 µW and can therefore supply simple sensors in vehicles, such as tyre pressure sensors in cars, with energy. Further developments will rely on finding new piezoelectric materials that will deliver the required electricity and voltage parameters whatever the oscillation frequencies and accelerations occurring in individual cases.

Further promising work is being done in the area of thermo-electrics (see also König 2009), which use the Seebeck Effect to generate electricity from temperature differentials. There is currently a strong focus on the so-called ZT value, which describes the efficiency of thermo-electrical materials (conversion of heat into electricity). In the last 15 years, the ZT value has been improved from 1 to 2.4 and further improvements are expected. The efficiency of materials alone is not however decisive for a thermo-electrical generator's efficiency; the temperature range in which the ZT value reaches its maximum is just as important. Progress could be made in the area of thermo-electrics if a material could be developed that would maintain a constant ZT value over a wide temperature range, even if this were relatively low. About 30 different materials of

71 Piezoelectric materials create electrical charges through deformation (and vice-versa).

interest for the area of thermo-electrics are currently being discussed. A few materials should be selected from this range and intensively developed. The experts and topic coordinators were also of the opinion that reducing module prices, which still make many applications uneconomic due to materials costs, and in particular due to the high manufacturing costs connected with the low efficiency of this kind of electricity generation, must be a goal of further research.

In the area of photovoltaics, research is concentrating on the one hand on high efficiency and on the other hand on reducing manufacturing costs. The field of micro-energy from the surrounding could directly profit from developments in both areas. The field of fuel cells is in a similar position of waiting for a technological breakthrough.

Progress is also emerging in the areas of storage and the energy management of systems, without which micro-energy harvesting cannot be used in practice.

9.2.3 The long-term outlook for the future field

In the past, energy topics were viewed mainly from the point of view of generating electricity in dimensions relevant to the energy industry and less on a micro-energy harvesting scale. The technical problems are still much too great and energy prices much too low for the topic to be of interest to power providers.

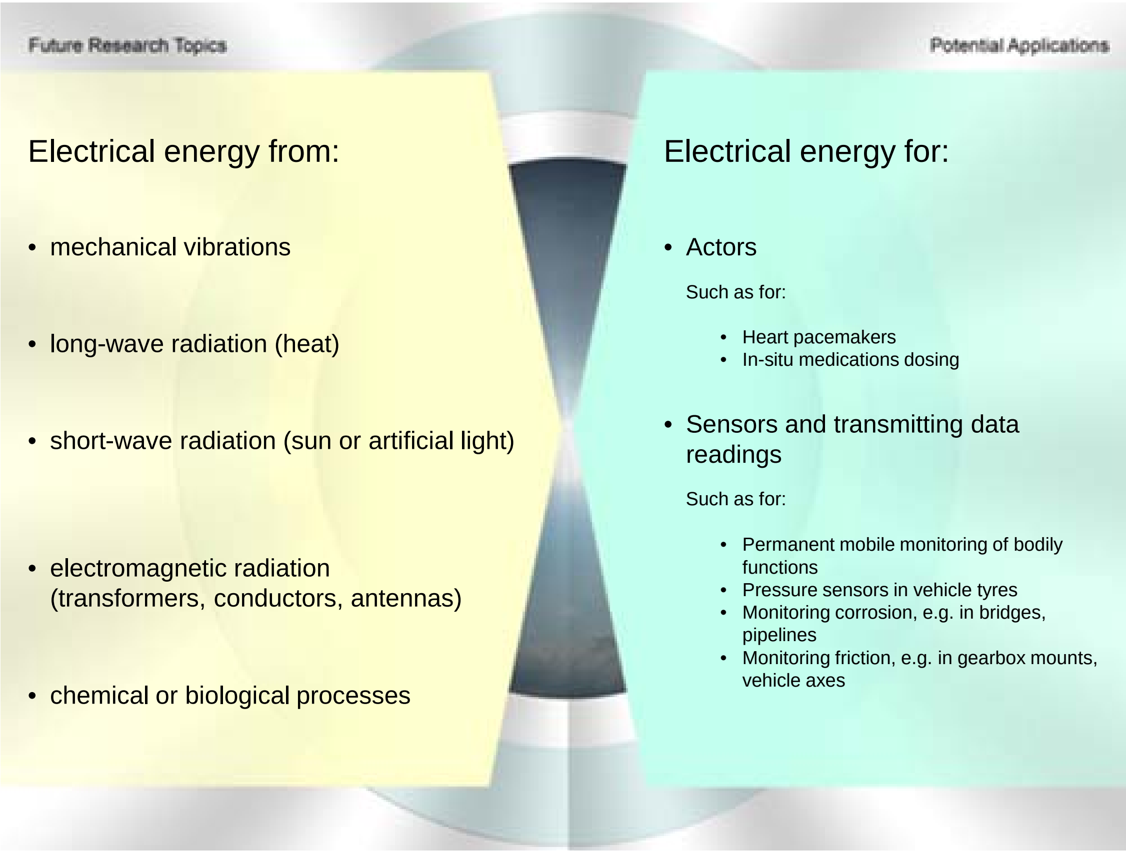


Figure 15: Future research topics and potential applications in the future field of »Harvesting micro-energy«

The car industry has been pursuing the topic of thermoelectric electricity generation out of economic interest, because using the heat from engine exhausts to provide vehicles with electricity could replace the »alternator«, with its ineffective systemic efficiency, and save about 1 litre of fuel per 100 km and the related CO_2 emissions. Should developments towards electrical vehicles be successful however, the car industry will no longer be a potential force in this area. Given high fuel prices and strict CO_2 emissions limits, this technology could also be interesting for trucks and ships. Industry is not yet pursuing materials development, but continues to rely mainly on classic materials combinations.

The use of this kind of power supply to run mobile phones, MP3 players (and later MP5 players) or even laptops may only be possible in the long term for physical as well as economic reasons. Such prospects will however only be realistic when these devices use much less energy than they do now. Interesting mass markets, apart from replacing the batteries supplying electricity to sensors as described above, could also emerge in medical technology, such as in pacemakers for the heart or brain, where an operation is currently required to change the batteries.

The main demand for micro-energy harvesting comes from micro-systems technology applications. While central manufacturing and systems integration issues have been resolved in this area, supplying energy to decentralised and distributed micro-systems with the current state of technology is still a largely unsolved problem.

The research required to implement »micro-energy harvesting« is in many cases very interdisciplinary and its overall dimensions and networking so far barely realised. The »power plant in the micro-system« must not only supply energy, it must also cope with the specific and diverse conditions of distributed systems. Further demands on energy convertors include adaptation to the application's size and function, high conversion efficiency, complete abolition of the need for maintenance and direct implementation in the desired form of energy. The different time profiles of energy and conversion and consumption make efficient storage necessary. Electrical conversion mechanisms often produce levels of voltage and electricity that do not harmonise with the levels users need, so electronic converters that provide an optimal energy transformation between source and load are required. These are currently extremely rare. Finally, there is a need for the simplest possible and most cost-effective methods of manufacturing and systemic integration of micro-systems and »energy harvesting«.

Electricity transmission using electromagnetic resonance could become established relatively quickly as a competing technology for generating micro-electricity for some applications, as might be expected in the next few years from its current development at MIT and first commercial applications. While the resulting electromagnetic radiation causes problems in applications with outputs of just a few watts, these may be negligible in those operating at milliwatt and microwatt levels.

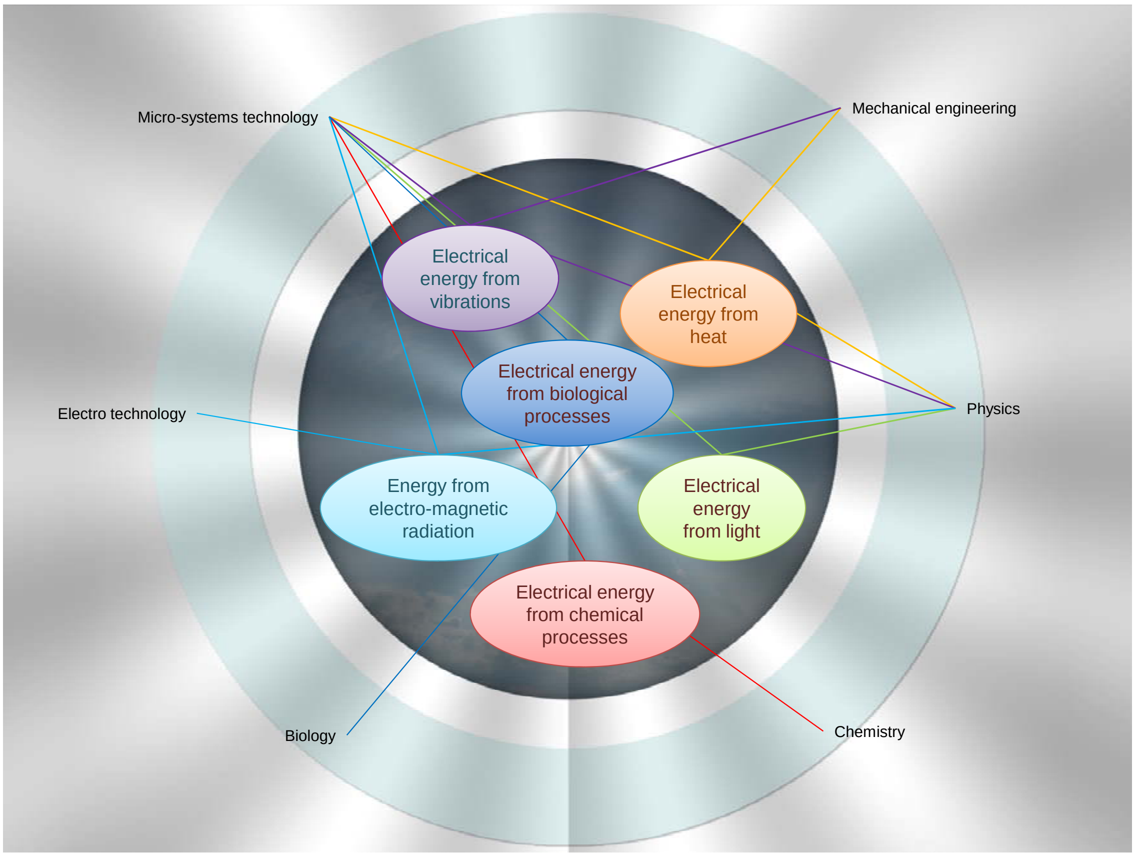


Figure 16: Future participating research areas

9.2.4 Why is this future field relevant?

Micro-electricity generation will remain a relevant fundamental research topic and its commercial applications could lead to entirely new micro-systems technology applications.

When the »Internet of Things« has become established and »ambient intelligence« has found its way into households, many devices will have to be controlled using micro-energy, because there will be no direct access to electricity. This will make either wireless power transmission without negative effects or the direct use of micro-energy harvesting necessary.

In the area of implants, especially those necessary to life such as heart pacemakers, these technologies could improve quality of life, by dispensing with operations to change batteries. Many other applications such as sensors, on-site measuring devices, traffic light operations and mobile electronic devices could be very »practical« and would, if technically feasible, certainly find a market.

9.2.5 Current actors in the innovation system

Research into micro-energy harvesting requires a strongly interdisciplinary and systemic approach. One example of the necessary extensively networked cooperation would seem to be the »Center for Energy Harvesting Materials and Systems« (CEHMS), which is carrying out research in all areas of micro-energy technology. It is a cooperative project between the 14 institutes of Virginia Polytechnic Institute and State University, Blacksburg, VA, Clemson University, Clemsen S.C. and the University of Texas, Dallas. It is also cooperating with the »Center for Intelligent Material Systems and Structures« (CIMSS) and »Center for Embedded Systems for Critical Applications« (CESCA).

The »Micro Energy Harvesting« post-graduate research programme hosted by the Department for Microsystems Engineering (IMTEK) and the Freiburg Materials Research Center (FMF), both departments of Freiburg University, is following a similar approach. The Fraunhofer Institute for Solar Energy Systems (FhG-ISE) is an associated partner in this programme. The modelling, design and optimisation of various conversion mechanisms is at the central core of research into energy harvesting there. Materials research is contributing by developing new materials for conversion mechanisms and storage methods. Adapting different levels of power and voltage and efficiently managing system energy are among the focuses of research into energy management. Research into the areas of manufacturing, system integration and applications is also accompanying this work.

Several academic and industrial groups such as Imperial College, London, MIT, Boston, the Georgia Institute of Technology in Atlanta, the University of California, Berkeley, Southampton University and the University of Singapore are carrying out research into converting the energy from oscillations and vibrations into electricity.

Many institutes and groups are also active in the area of thermo-electrics. In Germany the »Nano-structured Thermo-electrics« research programme, led by Hamburg University, should be mentioned here. It consists of 45 working groups carrying out research in the area of thermo-electrics. Six research institutes and six companies have merged to form the German Thermoelectric Society and there is also a corresponding international society.

9.2.6 Recommendations

Driven by a strong demand for an unlimited, mobile energy supply for new technologies such as RFID, GPS, mobile communications, and mobile entertainment and health care systems for an ageing population, this analysis has identified a significant increase in research activities in the area of energy harvesting. This is flanked by developments in micro-systems technology and nanotechnology that contribute to creating the necessary preconditions for progress in micro-energy harvesting.

The diverse range of conversion principles makes research more difficult but offers the advantage of having suitable technologies available for special applications. For this reason, this diversity should be supported in the view of the topic coordinators. Materials research into energy conversion and storage and systems technologies for complete systems, including the application, must also not be neglected.

The established institutes active in the area of micro-energy harvesting research should, according to this assessment, be strengthened and new research groups encouraged. In addition to government-financed basic research, institutes should be encouraged to cooperate with industry in carrying out application-oriented research.

Given the high level of international activities, a more intense promotion of networking among relevant research groups and disciplines in the area of micro-energy harvesting would be advisable so as to maintain and extend Germany's position in the promising future area of micro-systems technology. A strategic dialogue would be a fitting way, in the view of the topic coordinators, of bringing very different actors together and enabling new energy harvesting ideas to be discussed in creative ways. Ways of implementing these aspects should first be developed and established and could involve a programme or national network of actors with clearly-defined innovation alliances for pursuing individual approaches.

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Dateiname: 07_Dritter_Bericht_Teil II_englisch.doc
Verzeichnis: K:\V\Projekte\FORMON\berichte\Bericht3fuerBMBF2009\Langbericht Teil II englisch
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Titel: A4 doppelseitiger Text
Thema: Word 2002
Autor: Kathrin Schnalzer
Stichwörter:
Kommentar: Version 03-04-1
Erstelldatum: 06.07.2010 11:11:00
Änderung Nummer: 2
Letztes Speicherdatum: 06.07.2010 11:11:00
Zuletzt gespeichert von: maw
Letztes Druckdatum: 06.07.2010 11:12:00
Nach letztem vollständigen Druck
Anzahl Seiten: 139
Anzahl Wörter: 43.439 (ca.)
Anzahl Zeichen: 273.672 (ca.)