HIGHTECH FORUM

Bio-IT Innovations

Convergence of biosciences and information technologies

A discussion paper from the High-Tech Forum*

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HIGH-TECH STRATEGY 2025
Talents. Skills. Innovations.

1 Importance of Bio-IT innovations

The High-Tech Strategy 2025 (HTS) pursues the overarching goal of contributing to sustainable solutions to major social challenges. New, even radical, innovation potential is to be made accessible through the interaction of various key technologies. With respect to implementing some of the missions of the HTS [1] the High-Tech Forum considers the merging of biosciences and information technologies especially promising sees.

Bio-IT innovations: Rapid advances have been made in the life sciences since the mid-2000s. Technologies such as automated high-throughput screening,[2,3] DNA synthesis [4], and genome editing with CRISPR [5] resulted in an enormous increase in knowledge and possibilities of intervention. A large number of start-ups have emerged in these technology fields. Some groundbreaking bioeconomy innovations in medicine, health care and nutrition are already on the market.[15] Parallel advances in information technologies [6] played a major role in this. The digital collection, storage, networking and analysis of large data volumes became a central theme in the life sciences [7] and bioinformatics developed into a key discipline.

Advances in the biosciences and information technologies inspire new research questions and technology developments in the respective other scientific field. The research field of synthetic biology and bioengineering, for example, is concerned with the possibility of programming biological systems for certain tasks.[8,9] In the information technologies, visionary projects have emerged ranging from data storage in DNA [10] to neuromorphic computing, e.g. in the Human Brain Project.[11]

The High-Tech Forum observes that biosciences and information technologies are now increasingly being combined and merging, so to speak, with a new quality and intensity. This convergence of biology and IT goes hand in hand with a paradigm shift in both areas. On the one hand, "life" is becoming the object of digital methods and as digital information can be reproduced, researched, analyzed but also changed. In the opposite direction, digital information is being transferred into organic matter, as in the 3D printing of biological tissue based on digital "blueprints" or the IT-controlled cultivation of organisms.

This can result in groundbreaking Bio-IT innovations but they also bring with them new ethical and social challenges. Social and political relevance: Bio-IT innovations are developed for areas that are of fundamental importance for humanity. In particular, the Sustainable Development Goals (SDGs) on health and wellbeing, sustainable nutrition, climate and biodiversity protection are paramount.[a,12] This does not mean, however, that the development of technical "solutions" already shoulders the responsibility of science, politics and society. Key problems in the areas of health (of humans and animals), food, climate and biodiversity have essentially social, economic and political roots that cannot be solved by technical innovations alone. It is therefore imperative to involve society at an early stage, to develop ethical expert opinions and to advance Responsible Research and Innovation Frameworks (RRI). Bio-IT innovations must always be combined with social innovations from the outset.[13]

With this discussion paper, the High-Tech Forum underlines the need for political and societal action in the area of Bio-IT. According to the High-Tech Forum, the competition for scientific talents, data and market access, and economic implementation has already begun. In addition, there is increasing involvement of “big tech” in traditional and new markets.

The requirements for Bio-IT innovations in Germany are very good in some areas. Now it is a matter of unlocking the full potential. This also includes a broad debate in society on the ethical and social challenges of Bio-IT. If these developments are to be shaped on an equal footing internationally in future, the stakeholders in Germany and Europe will be called upon to invest over and above excellent basic research in the development of model products and applications that meet high ethical and sustainability standards, including new business models. Constructive involvement of society in innovation projects, e.g. via participatory product development, for the future-critical issues addressed here is of key importance and policymakers should keep it in mind and promote it.

This discussion paper addresses the following questions:

- What innovation potential is associated with the convergence of Bio-IT? (Section 2)
- How is the German innovation system for Bio-IT positioned in international comparison? (Section 3)
- What action is needed for innovation policy? (Section 4).

a The High-Tech Forum has commissioned six expert reports on Bio-IT innovations to illustrate the potentials and challenges of specific use cases Bio-IT results from the fusion of life sciences and IT

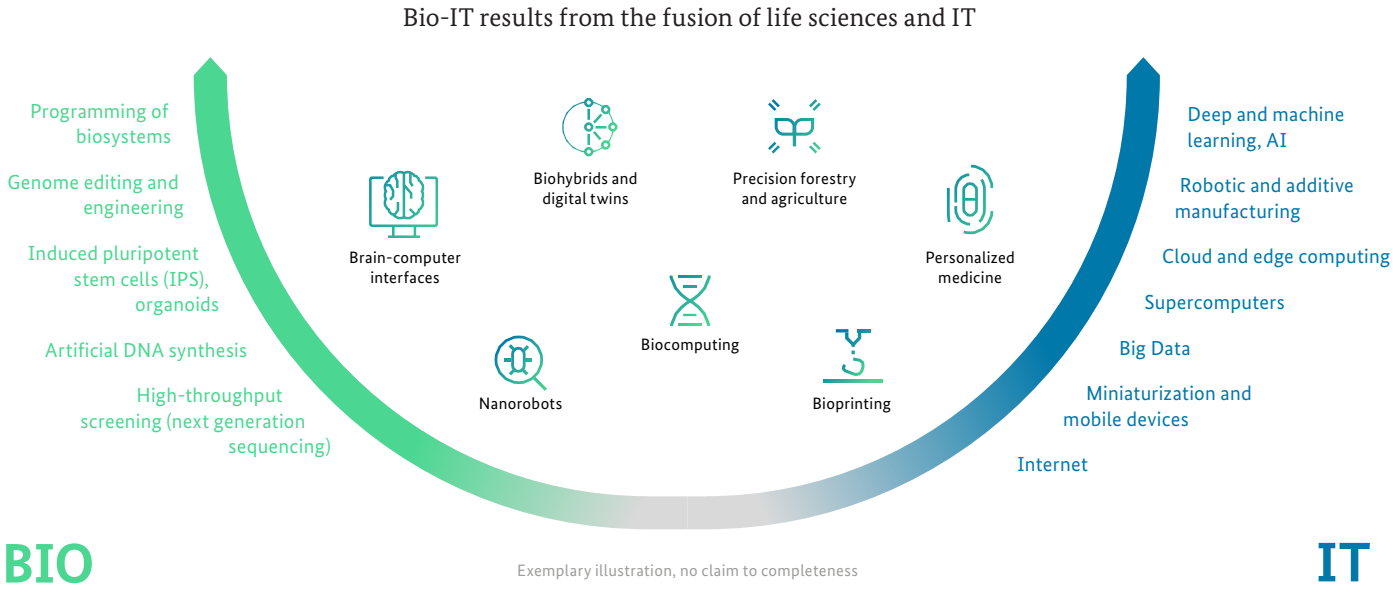

Fig.: Understanding Bio-IT

2 Innovation potential and significant international developments

The convergence of bio and information technologies may lead to radical innovations and changes in all areas of the economy and life.[14,15,16,17,18] On the one hand, "traditional players" from the health, forestry, agriculture and food sectors, as well as environmental technologies, which are already heavily penetrated by life sciences, are expanding their services. On the other hand, a growing number of "non-traditional" players – mainly from the digital economy – are entering these markets. At the same time, radically new products can be expected at the interface between biology and technology in other areas, such as electronics and robotics, which will lead to progress, also in the bioeconomy sector. Within a 15 to 20-year time frame, massive R&D investments, company collaborations, mergers and Bio-IT start-ups will result in an enormous knowledge gain and completely new scope for action but also challenges.

The following section presents the innovation and sustainability potentials of Bio-IT for the missions[1] defined in the HTS. Examples of initiatives by global companies illustrate international developments. These developments raise far-reaching ethical questions concerning both the use of technologies, the institutional and social framework conditions for the dynamics of Bio-IT development and also quite fundamentally the concept of man, our relationship with nature and our ideas of social coexistence. Broad discussion within society is integral to this and should be encouraged in a variety of formats.

Intelligent medicine and fighting cancer

The aim is to realign medicine towards more accurate treatment, particularly for cancer, immune and cardiovascular disorders, which are responsible for a large proportion of premature deaths in industrialized countries. The following will be made possible based on a systems biology understanding of the causes and progression of diseases at the genetic, cellular and metabolic level: [19]

- Individualized disease models and tailored treatments[20,21]
- Modelling of complete organs and tissue "In silico" in the sense of a digital twin (and thus also turning away from animal experiments) [20,22,23]
- Production of tissue and organ replacement from autologous cells based on digital models [24]
- Use of nanorobots in the body which detect diseases at an early stage, store health data and release active ingredients in a targeted manner as required.[8]

The Covid-19 pandemic shows that the global community has a lot of catching up to do in terms of pandemic management. One way of monitoring and rapidly controlling pandemics is repeated, population-wide series of tests which could be implemented, for example, by means of Bio-IT innovations and could significantly reduce the spread of the virus within a few weeks.[22,25]

Examples of initiatives by global players

→ In 2019, Alphabet bundled its data-driven healthcare business under "Google Health" with more than 500 employees. In addition, Bio-IT innovations are being promoted at the Verily (Life Sciences) and Calico (Ageing) subsidiaries, e.g. the 500 million Euro initiative "Galvani Bio-electronics" with Glaxo Smith Kline. Miniature implants are due to measure electrical nerve signals and correct irregularities in chronic diseases.[26]
→ In 2018, Apple started clinics for its own staff (AC Wellness) where Apple's new healthcare products were to be tested, e.g. applications based on genetic testing.[27]

Sustainability, climate protection and energy

Agriculture and forestry are responsible for almost a quarter of global CO_2 emissions. They have a high savings potential by preventing emissions and the additional storage of CO_2 in soils and vegetation.[28] Precision agriculture and forestry are intended to leverage this potential. Using data on seeds (genetics), soil condition (microbiome), pest infestation and diseases (taxonomy, genetics), and the local weather, it is possible to develop agricultural models that optimize sowing and harvesting times as well as the supply of nutrients, pesticides and water (digital farming).[29] In addition, autonomous small agricultural and forestry machines (e.g. field robots) are being developed which, supported by AI applications, can operate in swarms, work in a particularly soil-conserving manner and thus improve CO_2 storage among other things.[30] Data about various forms of land use are also used for modelling climate impacts and developing measures, see the BLIZ project[31] for example. Biodiversity can be regenerated, see the Lerchenbrot project "Skylark bread" for example.[32]

Examples of initiatives by global players

→ When Bayer acquired the agrochemicals group Monsanto for more than EUR 60 billion in 2018, it also acquired the digital subsidiary "The Climate Corporation" including the market-leading platform for precision agriculture. Monsanto had acquired the start-up for more than USD 1 billion in 2013.[33]
→ As a result of the Bayer-Monsanto deal, BASF purchased their xarvio digital platform.[34] Cloud-to-cloud access to the data collected by agricultural machinery and the platforms is increasingly being offered.[35]

The technically efficient replication of photosynthesis is deemed to be a bioeconomy flagship project for a greenhouse gas-neutral industry.[41,42] Carbon compounds of all kinds are to be produced sustainably from light, water and CO_2, irrespective of the limitations of plant cultivation. The projects are still in the basic research phase but there are promising breakthroughs. For example, it has been possible to produce artificial chloroplasts in the laboratory, designed "in silico", which are able to bind and convert CO_2 more efficiently than plants by means of light energy.[43]

With a view to food security and resource efficiencyof a growing global population, and particularly the supply in urban agglomerations, indoor and urban farming systems are being developed that do without arable land and recycle raw materials.[36] Increasing knowledge of the physiological needs of plants and of the interaction between micro-organisms, plants and animals in ecosystems enables cultivation in technical environments and under controlled, partly automated conditions.

The necessary and interlocking Bio-IT innovations are extensive. Demand ranges from breeding optimized plants and micro-organisms to biological sensors and automatic lighting, irrigation and combined cultivation systems, such as in aeroponics, aquaponics or insect breeding.[37]

Examples of initiatives by global players

→ Google Ventures is investing significant sums in sustainable food and urban farming, for example the foodtech start-up Impossible Foods[38] and the urban farming start-up Bowery.[39]
→ In 2019, Miele AG acquired the insolvent indoor farming start-up Agrilution.[40] Special seed mats, a nutrient solution, LED light and an irrigation system housed in a kind of refrigerator enable the semi-automated cultivation of salads and herbs.

Preserving biological diversity

In less than 50 years, wildlife populations globally have been reduced by more than two thirds.[44] A large number of other biodiversity indicators (e.g. GBO-5[88]) show that our ecosystems are changing dramatically and rapidly. For the first time, big data and interdisciplinary research enable humankind to grasp the drastic effects of its own actions. This also includes the knowledge of natural varieties and man-made changes. This is slowly leading to an understanding of ecosystem processes with an improved forecasting character. Reducing land use and the many pressures on natural areas are essential for the regeneration of nature.[45] Bio-IT innovations, for example in the bioeconomy sector, can make a significant contribution to this.[42] In addition, Bio-IT plays a huge role in the development of automated monitoring, e.g. with the aid of biohybrid robots and bioinformatics modelling, and the breeding of varieties adapted to climate change (e.g. based on digital sequence information).[46] Not least, the biodiversity represents an invaluable reservoir for sustainable innovations which can be harnessed for humanity using Bio-IT.

Developing and designing technology for people

Almost all large digital companies are investing substantial sums in applications which, by combining biosciences and IT, are intended to expand the scope of human action and thus raise questions particularly about the concept of man and ethical standards. For example, the mind control of digital devices and human-machine interfaces, e.g. Bio-IT brain implants which enable hearing, seeing or feeling digital stimuli.

Examples of initiatives by global players

→ In 2019, Facebook purchased the start-up CTRL-Labs for more than half a billion US dollars.[47] A mind control for digital terminals is to be developed.
→ Microsoft launched Station B, its first molecular biology laboratory, in Cambridge in 2019 and is developing "biological computing". Together with the University of Washington, it developed the first automated system for DNA data storage and retrieval in the Molecular Information Systems Laboratory in 2019.[48]
→ In 2016, Elon Musk founded the neurotechnology company Neuralink. In 2020, he presented a chip whose 1,000 electrodes are connected to brain tissue. The aim is to develop a bidirectional communication interface, for example to listen to music directly in the brain or control video games.[49]

3 Innovation system for Bio-IT in international comparison

The leading IT, biotech and life sciences innovation hubs, above all the east and west coast of the USA, but also China, Japan and Great Britain, are regarded as pioneers in challenging Bio-IT developments.[14,50,51] Germany is internationally competitive in some key R&D areas. In addition to excellent basic research and application-oriented technology development, Germany is home to subsidiaries of almost all global life science corporations representing considerable industrial expertise. There is however a need to catch up in terms of networking and transferring academic research and unconventional ideas to application. In this respect, the financing and commercialization of visionary ideas, particularly by start-ups, as well as social participation and involvement will be critical for the future.

The innovation system approach assumes that innovations are the result of the exchange and relationships between the stakeholders who produce, pass on and apply new knowledge.[52,53] This paper can only make an initial, qualitative assessment of the innovation system based on the desk research, expert reports and discussions that have been carried out. The availability of data is poor, particularly in new fields of technology that do not (yet) form an industry in their own right.

Education: Young scientists in Germany are considered to be well educated in the life sciences and IT and the costs for scientific staff are considered competitive. Proof of the students' high performance is, for example, the success of German teams in the annual iGem competition in synthetic biology which plays a major role in Bio-IT. [54,55]

Unconventional Bio-IT innovations require a high degree of multidisciplinarity, i.e. knowledge of molecular biology, physics, chemistry, mathematics, computer science, electrical engineering, robotics, etc. In this respect, education at German universities is still not sufficiently flexible and interdisciplinary. In most cases, fully-fledged second degree courses have to be completed, whereas universities in the USA have multidisciplinary bioengineering faculties [56] for example and can also offer individually tailored programs.

Science: Similarly to education, Germany is regarded as competent and well equipped in basic research at the interfaces between the life and information technologies. In the life sciences, German research centers, together with the USA, are leading in high-impact publications. Likewise, biochemistry (e.g. RNA and DNA research), biophysics, bionanotechnology and, to some extent, bioinformatics are considered to be internationally competitive. The situation is different, however, for patent applications and spin-offs.[59] Application- and product-oriented as well as interdisciplinary research is not yet a strength of German science centers. In addition, Bio-IT research is highly fragmented and directed towards traditional fields of application, above all biomedicine. Less conventional technological applications are the exception, e.g. there is only one project on "DNA data storage".[57] So far, even robotics and electronics, which are strong in Germany, have hardly discovered biological technologies for themselves. In Japan [58] and the USA [59], for example, convergence is taking place to a greater extent.

Research also shows that in Germany there is no internationally leading center for visionary Bio-IT research which combines all relevant expertise. There is not yet sufficient networking among research groups and economic stakeholders. In bioinformatics, around 40 research groups have been bundled via a federative cloud solution in the German Network for Bioinformatics Infrastructure (de.NBI). [60] However, the European centers of excellence (e.g. EMBL-EBI [61] or the hub of the European ELIXIR network [62]) are located in Great Britain. Collaboration after Brexit is still to be clarified.

Technology transfer and collaboration between science and industry: Germany has competent innovation stakeholders in Bio-IT fields. Collaboration in joint projects and clusters is also publicly funded. Nevertheless, the transfer performance does not match the results at the globally leading Bio-IT hubs. For the market launch of an innovation it is particularly important to bring together technological developments and extensive expertise from a wide variety of fields within a short period of time. The USA leads the way here with start-ups. However, China's cluster approach, in which the entire development chain from research laboratory to commercialization is pooled by companies in one place, also shows success. [46,47,63]

In Germany, the fragmenting regionalization of clusters and the strict separation between top academic research and commercial application in the Bio-IT sector are cited as obstacles. There is no gravitational center where scientific expertise and entrepreneurial motivation meet. There is no such thing as "the" center or "the" spin-out laboratory for Bio-IT innovations. It is true that there are many accelerators, business incubators and technology transfer agencies which are located at or in the vicinity of universities. Scientists, however, receive little academic recognition and support for developing prototypes and validating research results with industry. The universities and science organizations, as employers, hold the intellectual property rights to their inventions (sections [13, 14] German Law on Employees' Inventions (§ § 13, 14 ArbnErfG). For spin-offs that depend on patents or exclusive licenses for financing, in practice some hurdles emerge if the patent application, maintenance and utilization are handled by the employer.

Production and industrial stakeholders: While companies from the pharmaceutical, chemical, life sciences, plant

breeding, agricultural engineering and nutrition sectors in Germany are already developing and investing in Bio-IT innovations, there is a lack of large digital companies and AI pioneers who are driving the field forward in the USA, Israel and Asia, for example. Technology platforms for automated production and quality assurance have yet to be developed, e.g. in personalized medicine and synthetic biology. It is difficult at present to assess the competitiveness of German stakeholders.

Society, demand and basic political conditions:
A good basic requirement for Bio-IT innovations in Germany is broad public support for climate and biodiversity protection and for a transition towards sustainable development. However, the role played by Bio-IT here is still poorly understood.[64] The market prospects for Bio-IT innovations are varied, depending on social factors. These developments often require the use of biotechnology and state-of-the-art genetic engineering. While the general public mostly accept this in medicine,[65,66] it is still largely rejected for applications in agriculture, forestry and the food industry.[67,68] It must therefore be clarified how sustainability can already be integrated during the development of Bio-IT innovations. In addition, the High-Tech Forum's deliberations highlighted that an uncertain regulatory environment for Bio-IT innovations is seen as a key barrier to financing and commercialization.[69]

Capital markets and financing: in Germany, access to private venture and growth capital for visionary high-tech start-ups is unsufficient.[70,71,72] Bio-IT innovations are still in an early application phase and require a long-term investment horizon ("patient capital"). The development of marketable "products" often costs several hundred million euros.[14,15,73] Compared with the USA, Great Britain, but also Switzerland and France, the investment incentives (e.g. loss carry-forwards and tax-free reinvestment of profits from company sales) and framework conditions (e.g. for scientific spin-offs) in Germany are considered less conducive to private investors. [72,73,89]

4 Recommendations for action

Bio-IT innovations are highly relevant for Germany. The fusion of bio sciences and IT in connection with the healthcare and nutrition sectors, process technology, automation and sensor technology offers enormous potential for rapidly growing future markets. Other global players, particularly the big digital companies, have understood this. In view of the massive investments furthering the convergence of technologies globally, Germany must make every effort to keep up and contribute on an equal footing.

Implement the Bio-IT agenda and set up innovative funding programs: Innovation promotion should treat Bio-IT as a multidisciplinary cross-cutting issue. The High-Tech Forum recommends that the "Agenda from Biology to Innovation" anchored in the coalition agreement be defined more clearly and comprehensively in the direction of Bio-IT and implemented as a strategy. Before the end of the current legislative period, an implementation concept including innovative funding programs for interdisciplinary networking of the stakeholders and for societal participation should be presented and initiated. Due to their high social and economic relevance, Bio-IT innovations should become a core component of the next High-Tech-Strategy.

Establish an ambitious Bio-IT research center: The High-Tech Forum recommends establishing a Bio-IT center that combines all relevant specialist competencies and promotes R&D at an international level. This requires the setting up of a new institution, combined with networking existing nuclei and initiatives. A network of institutions from basic research, applied research and industry throughout Germany should work together in the center in an integrative manner, including Bio-IT-relevant clusters. The center should build particularly on the de.NBI network[56], bundling and making available relevant software, methods and data inventories in Germany and Europe, for example those of the National Research Data Infrastructure (NFDI)[74] or the European Distributed System of Scientific Collections (DiSSCo)[75].

Leverage the potential of biological data: Biological data, collections and data sciences are the indispensable basis for a large number of Bio-IT innovations. There is a great need for research and training in bioinformatics and in AI and automation technologies and it should be supported by application-oriented Bio-IT funding programs.

The High-Tech Forum is convinced that a common European market for data and cloud computing is indispensable for Europe's innovation capacity and competitiveness, particularly in the areas addressed by the High-Tech Strategy in its missions. The Data Ethics Commission[76] and the Competition Commission 4.0[77] have submitted numerous recommendations for designing the necessary legal framework and ethical standards.

The High-Tech Forum recommends that the Federal Government take these up quickly – where this has not yet been done – and also introduce them at European level within the framework of Germany's Presidency of the Council of the European Union.

Prototyping and access to Bio-IT infrastructure: Low-threshold prototype funding support should be set up to promote the transfer of Bio-IT research results into applications. Access to state-of-the-art infrastructure and technical services is fundamental for start-ups. This can be provided by specialized companies or institutions of applied research.

Free access to suitably equipped incubators or so-called bio-foundries[78] is important. Demonstrators and pilot plants for the development of new manufacturing technologies are also important for industry. The High-Tech Forum recommends establishing multidisciplinary hubs or foundries, particularly for unconventional Bio-IT innovations, with a high application orientation and close networking with society, applied research and industry.

Create incentives for spin-offs and high-tech start-ups: The transfer of excellent basic Bio-IT research in companies and especially start-ups must be improved. While cultural factors can only be influenced indirectly in political terms, the financing situation can be significantly improved in the short term.[72,89] The High-Tech Forum sees the necessity for greater promotion of transfer in collaborative projects and for clear investment incentives, e.g. new tax incentive models without bureaucratic red tape, and more regulatory scope for action regarding the release and utilization of property rights for spin-offs.[79]

Education and transfer programs for Bio-IT: To do justice to the combination of bio and IT approaches, independent structures, e.g. interfaculty centers and courses on Bio-IT or bioengineering, should be set up at universities. Making education more flexible in the form of freely selectable modules across natural, humanities and social sciences as well as IT and engineering disciplines is necessary without, however, neglecting the solid specialist training in a field.[80] Reflections on ethical and social issues must also be integrated here.

In the qualification of young Bio-IT scientists, there are already good initiatives focusing however mostly on life science applications.[81] They could be expanded so that unconventional and technical applications also come to the fore. In order to strengthen transfer competences and skills, dual career paths and temporary job changes between companies and science organizations have to be enabled and strengthened.[82]

Promote and secure social participation: Bio-IT innovations will change the lives of citizens in many different ways and raise fundamental questions about the understanding of organic and inorganic nature and of all things digital and analogue. This includes the understanding of biodiversity and sustainability as well as of autonomy, privacy and personal integrity. Against this backdrop, in the interests of responsible research and innovation, public involvement should be supported in research funding from the outset.[83] Since innovative participation formats, e.g. in the style of makerversities[84], have not yet been tested and researched much, this should be part of public support programs for the Bio-IT sector.

Improve legal certainty for the commercialization and governance of Bio-IT innovations: Legal uncertainties in the approval and operation of innovations developed using new technologies are a major barrier to commercialization. In particular, Germany should promote the development of innovative jurisprudential solutions for emerging and converging technologies, test them in living laboratories and also introduce them at EU level.

Shape the (inter)national dialogue on ethics and Bio-IT security: Germany has to actively participate in the discussions on ethics and safety of Bio-IT innovations happening in the context of existing laws and of ongoing (inter)national negotiations and agreements in biotechnology, medicine, artificial intelligence, biodiversity, etc., with the aim of ensuring that basic and human rights are respected and the principles of responsible research and innovation (RRI) and "ethics by design" are pursued.

With regard to the safety of Bio-IT innovations, risks inherent to the technology itself as well as risks due to misuse must be evaluated and monitored. The approaches to biosecurity of the German Ethics Council[85] and the DFG/Leopoldina[86] should be applied to the Bio-IT sector and adapted accordingly. In education and research programs Bio-IT risks need to be considered more systematically. Policy-makers must require and encourage greater commitment and dialogue among German stakeholders in (inter)national forums and working groups. In particular, not only should standards be developed and established in research institutions and at the state level, but the private sector and social stakeholders (organized civil society, biohackers, community labs, etc.) should also be involved.[87]

5 Annex

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The positions presented in this discussion paper do not necessarily reflect the views of the Federal Government.

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Fraunhofer-Forum Berlin
Anna-Louisa-Karsch-Straße 2, 10178 Berlin, Germany
www.hightech-forum.de/en

Dr. Beate El-Chichakli
Head of Program Management
Secretariat of the High-Tech Forum
chichakli@hightech-forum.de
T. +49 30 688 3759 1613

Contact | Press

Valerie Ponell
PR and Communications Manager
ponell@hightech-forum.de
T. +49 30 688 3759 1621

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