Federal Ministry
of Education
and Research

Key technologies for the future of Europe

The Federal Minstry of Education and Research (BMBF) takes a look at key technologies in the 10th EU Framework Programme for Research and Innovation

This paper supplements the "German Discussion Paper in Preparation for the 10th EU Framework Programme for Research and Innovation"[1] of the Federal Government, which was published by the Federal Ministry of Education and Research (BMBF) in May 2024 and submitted to the European Commission. It is therefore part of a series of BMBF papers that go into more detail on individual aspects of the preliminary German position on the next EU Framework Programme for Research and Innovation.

The ninth European Framework Programme for Research and Innovation, Horizon Europe, is the EU's best-funded research framework programme to date with 95.5 billion €. Horizon Europe will run from 2021 to 2027 and is thus now in its final phase from a strategic perspective. The tenth European Framework Programme for Research and Innovation (FP10 for short), which will start in 2028, is currently in the preparatory phase. **Strengthening essential key technologies and securing the EU's technological sovereignty** are the centre of the current debate.

Key technologies are characterised by their great potential for progress with far-reaching effects within the technology, but also in many other areas of technology and application. Thereby they are playing an essential role for the future of Europe. Due to their complementarity to other technologies and their broad applicability in a wide range of areas and industries, they also offer great potential for leaps in the performance, effectiveness and efficiency of current and future technologies, especially at their interfaces with each other. **Artificial intelligence, quantum technologies and innovative materials** in particular have many synergetic and complementary links to other areas of technology such as Industry 4.0, the manufacturing industry, software, high-performance computing, microelectronics, robotics, battery technologies, cyber security, communication systems and photonics. They have enormous application potential, for example in medicine, climate research or the circular economy. They play an important role in enabling a climate-neutral and resource-conserving economy – and accordingly in combining competitiveness, compliance with planetary boundaries and social resilience (see focus paper on Europe's competitiveness, prosperity and resilience within the Earth system boundaries). **Civil security requires key technologies that are sovereignly available in Europe** and that are further developed specifically for use by authorities and organisations with security tasks in Europe (see focus paper on civil security research).

1 bmbf.de/SharedDocs/Downloads/DE/2024/2024_05_dikussions-papier_horizont-europa_en.html

A technologically sovereign Europe must therefore accelerate the research and further development of these key technologies. No member state alone can tackle this complex task, which is essential for the future of Europe. **A joint European effort** is therefore required.

Focus on research and innovation of key technologies in collaborative research

Many outstanding and fundamental ideas for enhancing key technologies come from the EU, but there are currently weaknesses in developing these ideas further and bringing them to market maturity. In his report "The Future of European Competitiveness" published in September 2024[2], **Mario Draghi** also identifies **closing the innovation gap** in the EU as an important field of action and emphasises the importance of the European research and technology infrastructure landscape in this context. There is thus a need to **strengthen the middle Technology Readiness Level area**, which represents a **link in the innovation chain between basic research and the further development of already advanced innovations to market maturity**. Closing the innovation gap can only succeed if both basic research and application-orientated research and development topics are sufficiently addressed in FP10 to fill the technology pipeline. It is important to always keep an eye on the **entire innovation chain** for a topic and to facilitate transitions between the evolutionary stages of technological innovation.

Collaborative research is a central means of securing the EU's industrial competitiveness in the long term, as it makes possible to bring together **excellent players** in a technology area within the EU from science and industry and thus create **significant added value through the innovation of new key technologies and the further development of existing ones.** The importance

2 commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en?filename=The%20future%20of%20European%20competitiveness%20_%20A%20competitiveness%20strategy%20for%20Europe.pdf

of pan-European collaborative research projects with regard to Europe's industrial competitiveness is also clearly emphasised in recommendation no. 6 in the report "Align, Act, Accelerate"[3] of the **expert group for the interim evaluation of Horizon Europe.**

FP10 as an attractive programme for excellent players in key technologies

The success rates in Horizon Europe show that far more high-quality applications are submitted in the field of key technologies than can be funded. This must not lead to the withdrawal of key players from EU funding. Rather, it must be ensured that these players continue to be involved in the project consortia or become involved again. This is essential in order to achieve a clear "impact" of the research results, to remain technologically relevant and to strengthen European competitiveness – especially in the field of key technologies. To achieve this, **effective streamlining of the funding instruments and rates used** is required: whether a topic is called for centrally in the FP10 work programmes or in separate work programmes of institutionalised partnerships should not make any difference in terms of attractiveness for applicants. **Incentives** must also be created **for project coordination.**

Efficient management via thematically focused programme sections

Within the programme structure, the various programme sections should **be thematically focused** in order to enable an efficient "co-creation" process with targeted thematic discussions between the European Commission and the EU Member States. In FP10, attention should also be paid to **good networking and active exchange between the committees of programme sections in** order to avoid unnecessary duplication and compartmentalisation. The leadership and decision-making responsibility of the individual committees should not be hindered or restricted as a result. The **portfolio approach** proposed by the Federal Government in the discussion paper on FP10 can serve this purpose. Efficient and all-encompassing portfolio management is particularly relevant for the further development of key technologies, as these often have an impact as **cross-cutting issues in a wide variety of technology areas.** This approach enables a single committee to keep an eye on the entire innovation chain of each key technology. This ensures a better **overview of existing measures and avoids duplication of work.**

International cooperation in key technologies within the framework of FP10

In accordance with the **principle of subsidiarity**, FP10 should prioritise the achievement of European added value. This can best be achieved in close cooperation with the Member States through the efficient management structures described above. **International cooperation** should be strategic and strictly weigh up the benefits and risks. This is particularly necessary for security-relevant key technologies such as quantum and communication technologies. The exclusion of third countries and, in particular, associated countries from joint research and innovation projects (as provided for in Art. 22(5) of Regulation 2021/695 establishing Horizon Europe[4]) should only take place in **well-founded individual cases** and after consultation with the member states.

3 op.europa.eu/en/publication-detail/-/publication/2f9fc221-86bb-11ef-a67d-01aa75ed71a1/language-en

4 eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R0695

Specific aspects for FP10

This chapter emphasises the **importance and necessity of European cooperation within the framework of collaborative research projects for individual digital and industrial key technologies.** It describes important **technical priorities** from a German perspective for achieving strategic technological sovereignty in Europe. The identification was based on an analysis of previous national and European research activities and was conducted with **the involvement of stakeholders from industry and research.**

Manufacturing industry

Against the background of increasing raw material requirements, finite resources and the EU's high dependence on third countries for the import of critical raw materials, among other things, the aim must be to devise the manufacturing industry in Europe in a more sustainable and resource-efficient manner. In addition to technology and process innovation required for this, new EU-wide value creation networks are needed. These are already being established through EU collaborative research and thus contribute to strengthening the production capacities located in Europe.

The **circular economy approach** is a central element of green, sustainable and resource-efficient production and should be driven forward through technological development, innovation and capacity building. Digital technologies such as artificial intelligence and digital twins, but also **interoperable data ecosystems, digital and internet-based services and digital product passports** enable a longer functional service life for products and optimise recycling options at the end of their useful life. According to the notion of the circular economy, products and production systems must be designed from the onset for their ability to be **reprocessed or dismantled** and be easy to repair, reused and recycled – an objective that can be addressed through the holistic systems engineering approach. In order to respect the Paris Climate Agreement, new production processes should always be **clean and green**. They should use a **minimum amount of energy**, produce a minimum of scrap and waste and ideally process **secondary raw materials**. Overproduction should also be avoided – for this, technological developments in terms of **flexible, decentralised production on demand** are desirable.

Novel approaches such as **bio-intelligent production** as new, converging disciplines harbour a high potential for innovation and are capable of enabling the sustainability and robustness of products and processes. Some initial initiatives and steps already successful started in Europe and need to be developed further to pioneer the field internationally.

The automation of production is also an important aspect and addresses, among other things, the uncertainty regarding the availability of qualified personnel. **Advanced robotic systems** create new forms of collaboration between humans and machines, which requires detailed consideration and organisation. Research and developments in this area should be **human-centred** and based on **explainable artificial intelligence**.

One forward-looking topic is the far-reaching changes towards digitally networked value creation systems – made possible by digital platforms, for example – which create new development prospects based on Industry 4.0 technologies. It will be imperative to investigate and implement connectedness – technically, systemically and organisationally – and to model diverse aspects such as ecological and economic efficiency potentials (use of resources, circular economy), innovative business models, data and digital competence or questions of social inclusion in the European and international context in a compatible way.

In the end, however, it is no longer just a matter of providing proof in the laboratory environment; all these approaches must also result in internationally competitive products – cost and resource-efficient in accordance with European values. Interdisciplinary scaling research helps in making the transfer to industrial application.

Materials/Advanced materials

Advanced materials are an important factor in ensuring the competitiveness, technological sovereignty and economic security of the European Union. In order to maintain its global industrial leadership and open strategic autonomy, the EU must continue to drive forward the research and development of advanced materials, scale up production capacities and accelerate industrial utilisation. Therefore, the EU initiative "Advanced Materials for Industrial Leadership (AM4IL)", published by the European Commission on 27 February 2024, aims to build a dynamic, safe and inclusive ecosystem for advanced materials in Europe. A new co-programmed partnership "Innovative Advanced Materials for EU (IAM4EU)" under Horizon Europe is also intended to further promote the EU's strategic cooperation with industry.

The research and development of functional materials is particularly important in order to keep the **technology pipeline** full. The production of materials is associated with the consumption of resources and the emission of greenhouse gases. However, advanced materials also provide the solution and offer an important **lever for the realisation of a circular economy**. They make an essential contribution to greater sustainability, **securing value creation** and creating a **circular society**. The avoidance, reuse, processing and recycling of materials has the potential to utilise resources more efficiently, conserve raw materials and, as a result, reduce greenhouse gas emissions and waste volumes. Against this backdrop, raw material safety and availability, innovative materials and product design with the characteristic **"circular by design"** are increasingly becoming the focus of attention. This form of design is particularly committed to optimising the product development process – from the design phase to the end of a product's life. In line with the EU's Critical Raw Material Act, the recycling of critical and strategic raw materials that are required for key technologies such as robotics, AI and digitalisation can also be promoted.

With regard to the circular economy, recycling and (bio)degradability, the **biologicalisation of materials research** offers great, previously untapped potential for innovation. Living nature uses only a few classes of materials (including proteins, sugars and mineral materials) and yet produces an enormous variety of structures and functionalities. It can therefore serve as a source of inspiration for progress in all important future fields such as mobility, (personalised) medicine, robotics, information processing and energy generation, storage and management. The field includes bio-inspired materials research as well as biohybrid and living material systems and should be pursued as an independent topic alongside biomanufacturing/biointelligence, utilising synergy effects.

In addition, the **digitalisation of materials research** is contributing to materials research and development in almost all areas and must be driven forward. There are considerable gaps concerning sustainable data management, common data standards and infrastructures. In particular, the standardisation of digital workflows for materials and processes in the industrial environment, taking into account national and European activities (MaterialDigital, DIADEM, BIG-MAP, etc.) and the linking of existing (material) information repositories are relevant for creating synergies. The prominent anchoring of the MaterialDigital platform within the framework of the European Materials Commons initiative represents a prelude to this, following a recommendation by Enrico Letta ("Much more than a Market"). Systems linked in this way also serve to derive verification documents, e.g. digital product passports, but are also an important basis for the upcoming transformation of existing processes in terms of efficiency, safety, sustainability and recycling of raw materials for chemicals in various areas of application (e.g. catalysis) and in relation to safety/hazardous substance databases.

Batteries

The aim of European battery research is to establish a technologically sovereign, competitive and sustainable **battery value chain in and for Europe**. The importance of this goal is further emphasised by the recently published Draghi report. Batteries are cited as one of the clean technologies in which the EU has an advantage and also great potential for growth. The latter is partly due to the wide range of applications (e.g. consumer electronics, BEV and stationary storage) and the current ramp-up of battery cell production. Necessary fields of action relate to materials and production research, scaling research and digitalisation, resource-conserving battery cycles, further development of the battery (research) ecosystem and the development of new technology variants. These fields of action are so comprehensive that they require the united research efforts of the broadest possible group of EU members and selected associated value partners. The continuation of European battery research is essential for the green transition. The technology areas mentioned below are not only reflected in the German "Dachkonzept Batterieforschung", but also in the strategic research and innovation agenda of the European Battery Partnership BEPA.

The **development of next-generation batteries**, in particular **solid-state batteries and sodium-ion batteries**, is being pursued with particular interest. However, the development of new battery cell chemistries with a European value chain, such as lithium-sulphur, multivalent or cobalt- and nickel-free batteries, is also being targeted. Furthermore, the value chain of batteries in Europe – from raw materials to recycling – is to be secured. The use of batteries in households and vehicles to stabilise the power grid and to store excess supply from photovoltaics and wind power requires improved **digitalisation and AI methods** for control. That is why the topic of **"smart charging and energy management"** should also be considered.

However, overcoming challenges in the production of current-generation batteries (e.g. high reject rates, low degree of automation in some cases or high energy requirements) and thinking ahead for new batteries is key. **(Digitalised) Process and production research** and the development of energy-efficient processes, such as dry coating and laser drying as well as the optimisation of the production environment (e.g. through mini- or microenvironments), play an important role here. Closely linked to this is scaling research – including flexible aspects – where European cooperation is essential due to the cost and resource intensity. Initial successes have been achieved here, for example with the Li-Planet network[5] on a pilot scale. This must now be built upon. **New research and technology infrastructures** in the field of material synthesis and battery cell production, which provide blueprints for European production technologies, must be accelerated. With the Fraunhofer Research Institution for Battery Cell Production (FFB), Germany is contributing an important research infrastructure to European battery research, which not only serves to upscale technologies, but also addresses a central need of the European battery value chain with the European Learning Lab Battery Cells for the training and further education of skilled workers.

The establishment of a technologically sovereign, sustainable and at the same time competitive battery value chain in and for Europe not only represents an increase in the resilience of local industry and for the European energy system, but the development of this battery ecosystem will also become a test and real laboratory for innovative approaches from the manufacturing industry, materials research and the process industry. Innovations in batteries ultimately arise from new approaches in process, production and materials research, taking into account circularity, intelligent production, scaling and digitalisation or Industry 4.0. A high standard of sustainability can become a unique selling point for the EU here.

6G and Next Generation Internet

The development of 6G and the Next Generation Internet faces a number of challenges and opportunities that need to be addressed. One important aspect is the support and monitoring of the **standardisation process** to ensure that 6G technologies can be implemented uniformly worldwide. In the international race for technological supremacy in 6G, the EU member states must work closely together in order to exert a decisive influence on the specification of 6G in line with European values and interests. Furthermore, cooperation between the FP10 measures and the national 6G programmes is of great importance in order to jointly leverage synergies. This follows the recommendation of the Draghi report "The Future of European Competitiveness" to promote the strengthening of EU-based telecoms equipment and software providers in order to underpin the EU's open strategic autonomy. This goes hand in hand with the **examination of regulatory issues and the creation of regulations**. The aim of regulation should be to keep the introduction and expansion of 6G simple and accelerate it. Proposals for this can also be found in the Draghi report in section 3.1 as a starting point for the considerations. As 6G becomes a critical infrastructure as a platform for central, socially essential applications, it is important to consider **resilience in 6G networks** from the ground up, i.e. to

5 liplanet.eu

take reliability, network security and data protection aspects into account. Communication networks must be able to recover quickly from disruptions and ensure reliable connectivity. Another critical point is **preparing for the certification of 6G components** to ensure the interoperability and security of these technologies.

Energy efficiency plays a central role in 6G systems due to the exponentially growing volume of data on the internet and the associated energy consumption of mobile networks. Energy consumption has not only contributed to energy costs becoming an important factor for network operators, but has also significantly increased the ecological footprint. The **development of energy-efficient 6G networks** is therefore essential in order to cope with the otherwise massively increasing energy demand. In parallel, investigating the **interoperability of open 6G architectures** will be of great importance, supporting both cost efficiency and innovation capability.

Open network services, i. e. the opening of network functions for third-party developers and innovators using application protocol interfaces (APIs), are intended to make 6G a platform for digitised services. The **deep integration of 6G technologies into, for example, networked robotics** can revolutionise communication between devices and improve the interaction and collaboration of robots in a wide range of application areas such as industry, medicine and everyday life.

Chips and microelectronics

Global competition in research-intensive semiconductor technology and microelectronics is set to intensify over the next decade. Further development of the EU Chips Act, which dovetails research, regulation and security issues, is necessary in order to maintain and, if possible, expand a technologically sovereign basis in microelectronics in Europe. The value chains in microelectronics and the ecosystem including research, users and suppliers are only globally competitive at European level. European research cooperation is therefore essential. The tripartite partnership Chips Joint Undertaking has proven its worth in promoting such cross-border research projects and should be continued at a high level. The Chips Joint Undertaking has also proven itself in the transfer of research into application and through the appropriate balance between capacity and knowledge building.

Several technological challenges are foreseeable in the coming years – the focus of research and development in Europe should be on those areas in which future dependencies can (still) be avoided and in which Europe can capitalise on the strengths of its microelectronics ecosystem: Chip design and advanced packaging.

To counteract dependencies on software for chip design, research into open source solutions in this area should be intensified. With RISC-V, processor innovations "made in Europe" can be created on an open basis. The development of AI chips with novel architectures and technologies such as neuromorphic computing should be given comprehensive consideration.

Advanced packaging, especially for heterointegration, should be strengthened in EU funding in order to develop innovations in the back-end area that meet the needs of local industry.

These R&D priorities must be translated into industrial scaling in Europe in a more targeted and effective manner. This requires new or revised instruments, such as the EU Chips Funds and the "Important Project of Common European Interest (IPCEI)".

Photonics

A large number of challenges need to be addressed in the field of photonics. To this end, the existing industrial structures of the photonics partnership should be utilised. Given the importance of photonics as a key technology for numerous strategic EU initiatives/partnerships such as Made in Europe, Smart Networks and Systems, Virtual Worlds, Quantum Flagship, EuroHPC JU, Chips JU, Innovative Health Initiative, the introduction of a new cooperation mechanism is advisable.

The area of **co-packaged optics** with high-speed digital silicon and **photonic integration**, including design tools or photonic integrated circuits, **Very-large-scale integrated (VLSI)-photonics and photonic neural** networks/neuromorphic adaptive programmable photonics, will contribute significantly to the further development of strategically important fields such as high-performance computing, AI and quantum computing, among others.

In the field of sensor technology and imaging, the focus is on **hardware miniaturisation** and the **combination of different technologies and frequency bands** (UV-VIS-IR-THz). One specific technology to be promoted is spectrally resolved **X-ray photon counting**. In addition, **new types of image sensors** are required **for accurate real-time assessment of biological processes.**

The development of **new materials such as new glass fibres** with high stability in signal transmission combined with very low losses and an operating range over a broad wavelength band also holds great potential for communication technologies, for example.

In the further development of **laser light sources**, the efficiency and flexibility of beam and pulse parameters should take centre stage. However, **ultra-high intensity lasers for use with secondary radiation sources** such as extreme ultraviolet, X-ray or particle radiation are also of great importance. Laser- and photonics-based applications should be increasingly investigated in the areas of production (e.g. sustainable additive manufacturing), medicine, biology and extended reality.

High performance and supercomputing – HPC

The EuroHPC JU partnership is a model for success. Only by pooling Union resources with national budgets it was possible to procure supercomputers at a globally competitive top level and to achieve a first-class research infrastructure for science and industry that is accessible to the whole of Europe. Nevertheless, it should not simply be "more of the same" in the coming period, but rather an advancement based on what has been achieved. It is particularly important that the increasingly cost-intensive **computers complement each other and are optimally equipped for the respective needs of the different user groups**. The greater diversity of the future architectures of the EuroHPC JU supercomputers that this calls for is not only necessary to better serve users, but also to reduce technological dependencies on individual companies. In order to be able to fulfil the needs of AI user groups in particular in the future, access to data should become an important element of EuroHPC JU. The aspects of **computing capacity and data** should be considered together. Only by **integrating new user groups and their data and codes** can the enormous potential of HPC be optimally utilised. This applies to various **applications, for example in the fields of AI, QC, cyber security, materials development, medicine or climate and ocean research**. For sustainable business models and innovative solutions, greater attention must be paid to the interfaces to user groups that can ensure **the implementation of the research and development results achieved in commercialised products.** This is the only way to ensure that the social and economic potential of HPC justifies the high investment costs. Chip development specifically geared towards HPC should be deprioritised in EuroHPC JU. Instead, chip development should take place in the Chips JU, where the necessary industrial integration is guaranteed. This will also ensure that the missions of the two European partnerships are more clearly delineated and overlaps are avoided.

AI, data, robotics

The aim in the field of AI should be to strengthen cooperation at European level in order to position Europe as a leading global player. This requires a vision that goes beyond a purely regulatory perspective, but is based on "smart regulation". **"AI made in Europe" should be trustworthy, safe and innovative**. To this end, the EU should take a holistic view of the **AI innovation ecosystem** in Europe and create opportunities to flexibly adapt the initiatives to strengthen the ecosystem to changing conditions. The goal must be a **strategically driven and harmonised portfolio of measures**.

- First, the **excellent research base** should be **strengthened, and research with a broad range of applications** should be conducted, rather **than insular research**, e.g. exclusively on Large Language Models (LLMs). Specifically, foundation models should be explored that can standardise AI approaches across a wide range of application fields (e.g. basic models that can be used modularly for application in different areas of embodied and non-embodied AI). The **risks of AI** should also be analysed through **accompanying research**. Appropriate **methodological research** is needed to implement the AI Act and its technical requirements.

- Second, **transfer** should be **encouraged** to drive growth and exploit economic opportunities.

- Third, the **training, recruitment and retention of specialists, including top researchers in the field of AI**, should play a central role in the future European AI strategy and be implemented, for example, through a joint European initiative for the exchange of young AI researchers and their recruitment from abroad.

- Fourth, the **ecosystem for AI computing infrastructures** should be further strengthened.

- Fifth, on **the hardware side** of the Chips JU, further research is needed on the application/production of AI-accelerated chips (NPUs, organics, memristors, SNN-capable chips).

Access to extensive training data is essential for the development of powerful AI models. **It should be possible to share such data in Europe and use it across sectors** to develop (autonomous) robotic systems, implement **holistic and circular engineering and service approaches**, but also, for example, to access health data to develop innovative medical technology and reliable medical decision-making and support systems. An **"AI-ready" infrastructure** in Europe, which also enables companies to **access AI services**, is a prerequisite for this.

Systems technology and **interoperability** are also important enablers for innovation. **Modular, model-oriented approaches to system integration**, particularly in the software area, can significantly reduce the development costs of new automation technologies in an industrial context and thus create a European market for software-defined automation components. Advanced digital and AI technologies should be developed for **green, flexible and advanced production**. Important fields of application are, for example, **logistics or medical technology**, where research into AI, autonomous or supporting robots and digital twins is needed for sustainable, autonomous implementation. In principle, AI and robotics must **also be considered outside of industry**. In the field of **medical technology**, for example, the corresponding innovation potential must be realised (see focus paper on "Health research and innovation for the future of Europe"). In particular, the technical, legal and social prerequisites and obstacles for comprehensive practical application (e.g. in healthcare and nursing) must be analysed. The focus should be **on human-centeredness** and the interaction between humans and new technologies. **AI-supported healthcare technologies** must also have a high degree of explainability. Furthermore, **open source solutions** serve as a basis for (de facto) standards and facilitate cooperation between companies (collaboration and co-innovation). A pan-European strategy for intelligent robotics that strengthens the innovation ecosystem sustainably and along a common European roadmap is therefore necessary.

Current robotics research is strongly driven by AI. There is particular potential to be realised in robotics research in the interlinking of robotics-specific AI with mechatronic autonomous systems. As both the research community and the robotics industry are different from the AI industry in general, the funding instruments for robotics research should be customised in the future. It would make sense to link research funding from the framework programme with capacity building from the Digital Europe Programme, for example to include industrial real laboratories, testing facilities and the necessary standardisation and regulation at the research stage.

A corresponding pan-European strategy for smart robotics is therefore necessary, which builds on the activities of the member states and prepares solutions compatible with the internal market along a common European roadmap.

Quantum technologies

Quantum technologies offer enormous potential for a large number of key European industries. Building on European measures such as the Quantum Flagship, the Chips Joint Undertaking or the European Quantum Computing & Simulation Infrastructure, which cover research, industrialisation and infrastructure measures, national initiatives are to work together under one European umbrella in FP10. To this end, the EU member states have already signed the European Quantum Declaration, which is currently being implemented.

In order to surpass classical computers, approaches for a fault-tolerant, universal quantum computer are to be pursued. This requires an increase in the level of maturity and scalability of the approaches for the physical realisation of qubits. **Quantum processors with quantum error correction** and **robust qubits** should be developed for this purpose. The promotion of **quantum algorithms** is crucial for developing **hardware- and software-independent benchmarks**, optimising compilers and libraries and **opening up practical use cases** for research and industry. The development of highly sensitive and **cost-efficient quantum sensor technologies** and their **industrial application in European lead markets** are of significant importance for strengthening the innovative power of key European industries.

Quantum simulators are an important building block for demonstrating a "quantum advantage" for **industry-related applications** in a timely manner. The development of **higher-level quantum programming languages** and the promotion of **design tools for quantum-based circuits** also play a major role. It is also important to further develop **enabling technologies for quantum technologies** such as laser technology, cryogenics and cryoelectronics.

The early implementation of **quantum computing-based solutions in industry**, for example for **simulations and machine learning**, is important for rapid industrial realisation. This also includes promoting **quantum AI** in order to improve the efficiency and performance of AI applications. This includes the development of computing modules and algorithms that enable future practical applications. The creation of a framework for the necessary infrastructure and the subsequent development of suitable regulatory guidelines are of central importance here.

Cybersecurity

The objectives of the European Union include promoting European values, safeguarding peace and freedom, ensuring security, the well-being of citizens and the sustainable growth of the economy and prosperity. In the digital world, these goals are **inextricably linked to cybersecurity**. The intensifying geopolitical situation clearly shows that only those who can protect their digital infrastructures can maintain sovereignty in the long term.

However, the development of disruptive technologies such as **artificial intelligence (AI)** also pose major challenges to maintaining a human- and ethics-centred digitalisation. Security, freedom and economic growth are challenged by ever-changing cyber threats, which consequently requires **continuous research efforts and innovation**. AI, as the disruptive technology of today, is currently bringing new aspects of cybersecurity to the table: not only must the safe and **responsible use of AI** be ensured in accordance with European values, but effective **measures against AI-based threats** and, in turn, **AI-based cybersecurity measures** themselves must be developed.

Digital disinformation and influence peddling that threaten democracy and freedom must also be countered with suitable measures. In order to counter such new threats in the digital society, an **awareness of the importance of cyber defence and cyber security** in the sense of a **resilient digital infrastructure** for **secure and sovereign data exchange**, as well as the **protection of privacy, supply chains**, but also **ethical and democratic values**, is essential.

In light of advances in quantum computing, digital networks must be resilient to future cryptographic challenges and cyberattacks. One example of a potentially disruptive technology here is **quantum communication**, which in the form of an **efficient European quantum communication infrastructure** should enable a new level of protection against surveillance and the detection of attacks in the future.

Cybersecurity forms a central basis for **human-centred digitalisation in line with European values** and for securing peace, freedom, democracy and economic prosperity in the long term.

Biotechnology

Biotechnology is a key technology of the 21st century. European capabilities in this field should be strong, competitive and sustainable. The extremely broad spectrum of applications ranges from medicine (**"red" biotechnology**) to agriculture (**"green" biotechnology**) and industry (**"white" biotechnology**). **There are many links to other key technologies and applications**, including AI, a sustainable circular economy, advanced materials or new biomedical possibilities such as genome editing or gene and cell therapies. In addition to these opportunities, it should be taken into account that this technology can also be misused. It is therefore necessary for Europe's future viability to create standardised European framework conditions, both in terms of regulation and research funding.

Basic biotechnological research in Europe is currently still well positioned, but there is a **considerable innovation gap** when it comes to transferring this research into practice. This is due to the very high funding requirements compared to other technologies, the high regulatory requirements and the long development times. Strengthening the current pillar "Global Challenges and European Industrial Competitiveness" is therefore of particular importance for biotechnology.

Red biotechnology in particular can make an important contribution to achieving the goals of the current **EU pharmaceutical package**. Green biotechnology offers valuable solutions for the necessary adaptations of the agricultural and food industry to the consequences of climate change with modern approaches and methods of plant research and breeding research, especially in combination with other state-of-the-art key technologies (digitalisation, miniaturisation, information technology, food biotechnology and agricultural engineering, aquaculture, broad crop rotations and mixed crops, innovative materials and beneficial organisms). When implemented in the field, improved crops have the potential to actively contribute to combating the **biodiversity crisis** alongside food security and sustainable biomass production. Research in the field of biotechnology should be significantly increased in order to prevent the gap to the current technology leaders from widening.

White biotechnology can contribute to solving a number of current social and economic challenges. Climate change and limited resources require a move away from fossil raw materials and a sustainable **circular economy**. The industrial bioeconomy can replace fossil fuels with **renewable raw materials**, close cycles and thus shape the **resource-efficient, climate-neutral industry of the future**. At the same time, it opens up paths to new types of **bio-based products** with high added value.

Hydrogen

Hydrogen plays a crucial role for the future European economy, particularly with regard to sustainability and the decarbonisation of domestic industry. A new global market is currently emerging in the hydrogen sector. Research and innovation are making it possible to enter this market with technologies that are currently on the verge of application and are necessary for the transformation of global energy systems.

As part of the Strategic Research and Innovation Agenda (SRIA) developed in the EU agenda process, important collaborations have already been initiated with countries such as **Italy, Scotland and Ireland** to analyse European research needs in the field of hydrogen. There are also **bilateral research partnerships** in Europe **with the Netherlands, France and Greece**. This cooperation should be intensified at European level, as **hydrogen is a key building block for the energy transition and a sustainable industry**.

Important future research areas in which Germany is already working intensively and in which **greater cooperation at EU level** is desirable include the **development of innovative solutions for transporting hydrogen over long distances** and **materials research to create new catalysts**. One promising approach is research into highly efficient **electrolysis processes with a reduced need for precious metals**. These processes can make a significant contribution to **reducing costs and increasing the efficiency** of hydrogen production. In addition, **offshore hydrogen production** should be researched more intensively. Linking research and industry is important here. The BMBF-funded flagship projects and international partnerships, for example with Australia or various African countries, provide examples of collaborative research projects between research institutions and industrial companies.

In FP10, hydrogen **could become an example of a pan-European innovation chain** – from basic research to the further development of advanced technologies through to market maturity. It would be crucial to consistently consider and promote innovations along the entire innovation chain in order to create smooth transitions between the individual phases of technological development. In this way, hydrogen could be established as a **key factor for a sustainable and future-proof European industry** and thus strengthen Europe's competitiveness in the long term.

Fusion energy

In recent years, it has become clear that Europe is facing considerable challenges in the area of energy supply due to its far-reaching dependence on available fossil fuels. In view of the growing demand for electricity, it is crucial to organise Europe's future supply sustainably and securely in order to contribute to climate protection at the same time.

A central component of the future energy supply, which is also relevant beyond the energy transition, is the development of **fusion energy. Fusion energy opens up the possibility of generating electricity in a clean, safe, resource-conserving, base-load-capable and cost-effective manner and, in principle, in unlimited quantities**. The research and development and utilisation of fusion energy has the potential to be one of the **central pillars of the European high-tech economy** in the future. **The utilisation of fusion energy can make Europe's energy supply independent and therefore secure**.

In this light, the Draghi report classifies fusion as a disruptive technology and emphasises its prospects as the energy source of the future. This categorisation confirms this: Fusion is one of the technologies to leverage the innovation performance of the EU internal market. Fusion research also makes a significant contribution to the development of other relevant technologies (e.g. magnet technology, plasma technologies, optical technologies, etc.).

However, this great potential is accompanied by major challenges that can only be overcome to a limited extent, if at all, at national level. This is illustrated by ITER (International Thermonuclear Experimental Reactor), which is being built in southern France in cooperation with seven partners, including the European Union and its member states, and represents a decisive milestone on the way to a fusion power plant. With these major challenges and the necessary international approach in mind, the Draghi report also recommends an overarching EU strategy. The implementation of the fusion also requires private and public investment. The Draghi report thus emphasises the particular importance of collaborative research in the field of fusion.

One particular area in the EU strategy and therefore in **FP10** is the **supply** of fusion reactors with **sufficient quantities of tritium fuel** and the handling of this within supply chains. Even if tritium is to be incubated in fusion reactors during later operation, a not inconsiderable amount of tritium is still required to start the fusion process and thus the tritium incubation process. A European approach is needed here, especially if facilities for producing the necessary quantities of tritium cannot be realised in certain Member States. The promotion of fusion in FP10 should be closely coordinated with other European activities in order to utilise synergies and avoid duplication. This includes in particular the activities of EURATOM and the planned European Fusion Industry Platform (EFIP).

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