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MANUFUTURE©-DE

IDENTIFICATION OF PRIORITY RESEARCH TOPICS FOR THE SUSTAINABLE DEVELOPMENT OF EUROPEAN RESEARCH PROGRAMMES FOR THE MANUFACTURING INDUSTRY UNTIL 2030

ABRIDGED VERSION

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PREFACE

The rapid transformation of industrial structures, driven by digitization and the intensification of global competition, has led to numerous initiatives springing up over the past decade to strengthen and focus production in Europe, especially in Germany. These include, for example, the Industry 4.0 platform and, at European level, the European Factories of the Future Research Association (EFFRA).

As part of the European framework, an initial vision and strategic research agenda concerning the future of production were created as early as in 2006, encompassing a period of observation until 2020. These were prepared by the »European Technology Platform for Manufacturing – MANUFUTURE« initiative, which was flanked by national endorsement in many European countries.

The strategic research agenda of the MANUFUTURE-DE initiative in Germany formulates and prioritises current and future-relevant research needs for German industrial enterprises in the field of manufacturing engineering and production technology. The agenda consolidates the interests of different industry segments and sets priorities for funding research with a time horizon until 2030. It also aims to improve the competitive position of the manufacturing sector as a whole.

Constructive discussions have been held with representatives from business and research to develop a common strategic perspective on Production 2030 and to define and specify fields of action including priorities. Primarily, the findings should help the sector to interpret its research strategies and priorities in a focussed manner. Secondly, the findings should serve as a guide to the focused design of research funding programmes and offer suggestions for improving the innovation system.

The common will of industry, science and politics to reflect and shape within the framework of the MANUFUTURE-DE platform has made it possible to achieve comprehensive results. The basis has been created for integrating the priority research needs of German industrial enterprises in both national and European research funding programmes

I would like to express my thanks to the German Mechanical Engineering Industry Association (VDMA), and all those involved in the MANUFUTURE initiative, for their support. I would also thank the Federal Ministry of Education and Research (BMBF) and the Karlsruhe PTKA, as the lead partner, for promoting and supporting this project.

Dietmar Goericke
VDMA Research and Development

Mechanical and plant engineering undertaken by medium-sized companies forms the backbone of German industry. These companies are the largest employer in industry and are world leaders in innovation in almost all sub-sectors. Mechanical and plant engineering safeguards the competitiveness of its customer industries with its products and services, and offers highly innovative solutions for the pressing environmental and energy challenges of our times. The latest technologies are integrated and put to use. Modern and innovative mechanical and plant engineering plays a key role in the success of Industry 4.0, the mobility of tomorrow and the achievement of climate goals.

German manufacturing industry is facing major challenges. Under tough global competitive conditions, sustainable growth needs to be generated through constant innovation and its conversion into marketable value adding. The vision of the future involves the transformation from an industrial society into a knowledge-based economy, underpinned by an industry driven by research and innovation. To achieve this, mechanical engineering needs to form close links with value adding partners, and, above all, with the best minds in science, and needs to stand shoulder-to-shoulder with the German innovation system.

The MANUFUTURE-Germany roadmap, jointly developed by industry and science, had already succeeded in generating decisive impulses for production research as early as in 2007. The Federal Ministry of Education and Research (BMBF) made it possible to translate these into specific projects, and not least, large parts of the roadmap were used as a German contribution to the concepts of the European MANUFUTURE-EU technology platform. This led to additional resources being developed in the Factories of the Future Programme in the Horizon 2020 EU Framework Programme.

This success story now needs to be sustained and nurtured in the newly developed MANUFUTURE-2030 roadmap. Once again here, the challenges for the future of manufacturing and production have been gleaned and collected in close collaboration between science and industry with the support of leading industry associations. If the rigorous transformation of the roadmap into forward-looking research succeeds again, along with its subsequent conversion into attractive products, the success story of the German mechanical and plant engineering sector is set to continue.

The VDMA would like to express its thanks for these outstanding findings to Prof. Bauernhansl and his staff, and all contributors from industry and science who were involved in the process of creating the roadmap. Last but not least, our thanks go out to the Federal Ministry of Education and Research (BMBF) and the Karlsruhe PTKA, as the lead partner, for its financial and organisational support for Project MANUFUTURE-2030.

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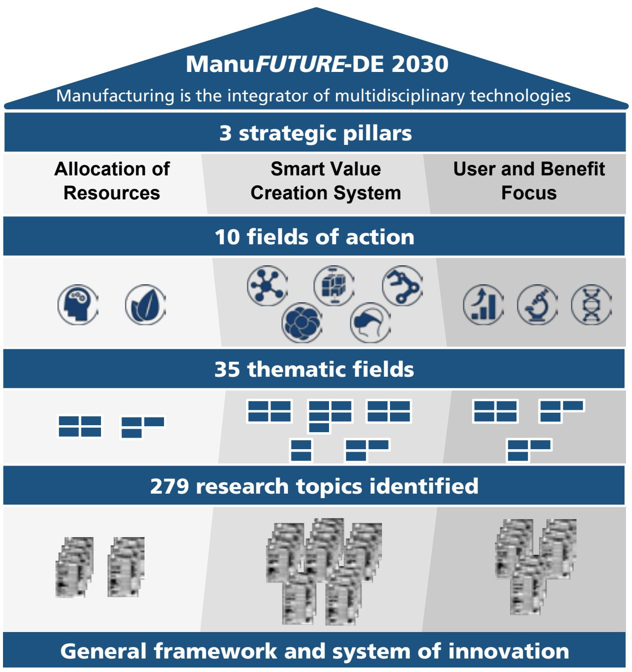
»We have to act decisively in order to maintain industry in Germany in the long-term!« can be seen as the motto of this study. However, this does not mean that industry has to be restructured from the ground up. Rather, that we need to secure and expand the outstanding position that our innovative, broadbased industry occupies. What is important here is to set a course in good time. There is a need for action, especially in two areas. Primarily, the requisite political, legal and infrastructural pre-conditions need to be created in order to boost our innovative strength. Secondly, the innovation system needs to be strategically aligned with technologies and research topics relevant in the future.

Figure 1: Structure of the findings

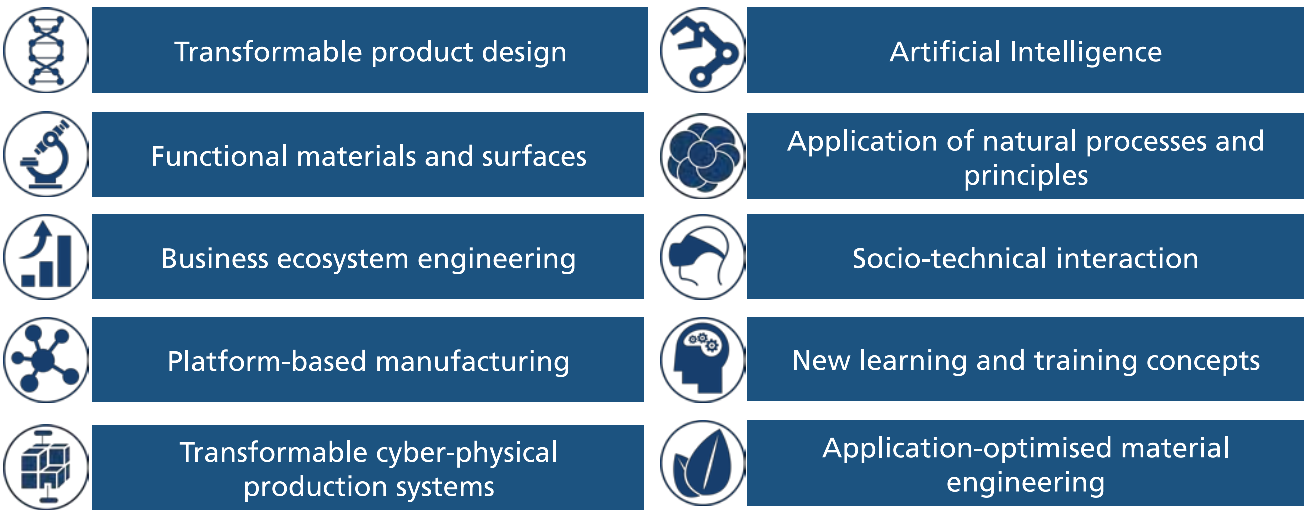


Under the lead of the Fraunhofer Institute for Manufacturing Engineering and Automation IPA and the German Mechanical Engineering Industry Association (VDMA), more than 140 representatives from industry, science and industry associations addressed the identification of priority research topics and activities for sustainable and practice-oriented innovation support. Challenges and research needs were identified, evaluated and prioritised in a total of seven industry workshops, in online surveys and in some 50 expert interviews. This resulted in a strategic research agenda for the manufacturing industry until 2030. Divided into three strategic pillars, the agenda includes ten fields of action which are structured into subordinate research fields (Figure 1). Each are detailed in further propositions and target states. In total, 279 research topics were able to be identified and evaluated in terms of their degree of technological maturity and strategic relevance, and arranged in chronological order. Finally, the iterative discussion and prioritisation process that took place allowed specific recommendations for action to be made for politics and industry.

This summary highlights the core findings and key research requirements of the study. A priority research field is named for each of the 10 fields of action (Figure 2). Likewise, the research fields indicated support the organisation of funding programmes for political research and for strategic orientation and focus in industrial research. Section 6 also discusses the improvement of the innovation system and makes corresponding recommendations.

The overall findings including detailed explanations can be found in the unabridged version, of this study at www.ipa.fraunhofer.de/studien (in German only).

Figure 2: Priority research fields



2. THE STARTING POINT

2.1 Industry and production research safeguard our prosperity

Industry is the cornerstone of our prosperity

Manufacturing industry remains one of the cornerstones of prosperity and employment in Germany and Europe. In terms of employment and value adding, manufacturing accounts for the largest share of the EU-28's real economy. Some two million industry enterprises employ around 30 million workers and contribute €1630 billion to the gross value added. This corresponds to almost 23% of the workforce in the real economy and more than a quarter of the net product output.[1] In addition, owing to social and economic links, each new workplace in industry leads to the creation and maintenance of up to two jobs in other sectors.[2] This makes industry the cornerstone of our prosperity.

We are factory equipment supplier to the world

The foundation of our economic power is formed by a broad-based industry characterised by medium-size enterprises with a long tradition of success. In terms of sales and exports, the automotive industry, mechanical and plant engineering, the process industry and the electrical industry represent the most important industries. Behind these key industries are the factory equipment suppliers, whose innovations allow industry to excel. Their products are excellently positioned worldwide and range from measurement technology, image processing technology, automation technology, process technologies, biotechnologies, packaging technology, information and communication technology and building technology, to system solutions for entire production systems and factories. This highly specialised, yet broad structure safeguards our leading position as factory equipment supplier to the world.

Our model for success: exporter of innovations

Germany is an export nation. Only China and the USA export more goods. Foreign trade focuses strongly on premium quality, mid and high-tech products. If we leave out the EU as an economic area, after China, Germany is the leading export nation in the field of high-tech products. This is impressive evidence of our industry's export strength and the global competitiveness of products »Made in Germany«. Despite a relative lack of resources, German industry manages to be a world leader and to continually set new standards. We owe this pioneering role to the close integration of an outstanding education system, top-class public research and innovative companies. This allows us to continuously develop our knowledge and export our innovations worldwide.

1 *Eurostat 2017*
2 *European Commission 2016*
3 *European Commission 2014*
4 *HNI & WZL 2016*

2.2 The importance of production research needs to be enhanced!

Reindustrialisation in Europe is only progressing slowly

Failure to make industry sustainably competitive will inevitably have a massive impact on society and prosperity. MANUFUTURE started with this wakeup call as many as twelve years ago. Industry first experienced an adequate appreciation of this in the political discussion and public perception in the wake of the financial and economic crisis. As a result, in 2012, the EU Commission set the target of increasing the industry share in Europe in terms of gross value added from 16% to 20% by 2020.[3] However, a reindustrialisation of Europe is still not in sight. A look at the individual member states shows an enormous heterogeneity. Countries like the Czech Republic, Hungary and Germany have a sound industrial base and are already meeting the EU target today. In contrast, there are countries like Greece and France whose industry share is only around 10%.

Other industrial nations have already recognised the trend

Other industrial nations have recognised the importance of reindustrialisation. In doing so, they are attempting to develop their strengths and are focussing on different priorities. In contrast to Europe, the USA is focussing on the software component in the product and its value to the customer. New digital business models and software-based product technologies are rapidly being established in the marketplace. The focus here is being placed on interoperability and user-friendly standards. China is facing the challenge of moving straight from the second into the fourth phase of industrialisation. In contrast to other industrialised nations, the Chinese government is pursuing a long-term overall strategy which will continue until 2049. In an initial stage, the »Made in China 2025« strategy formulates ambitious goals for the modernisation of Chinese industry. To achieve this, a strong network of suppliers and competence clusters has been created in recent years, which adapts dynamically to new products with major government support and produces more and more of its own innovations.[4]

2.3 We are faced with old and new challenges

The future challenges for industry result from the complex interplay of ecological, social, economic and technological changes. In simple terms, these developments determine which resources we use to produce which products for which customers and markets using which technologies in future (Figure 3).

Decoupling of growth and the consumption of resources

The finite nature of fossil fuels and strategic resources creates critical supply risks for industry. Aggravating factors include production and transit countries that are increasingly unstable both economically and politically, and local and global crises. This has a massive impact on industry in the form of rising commodity prices and more difficult to access production factors. Furthermore, legal requirements and international agreements require a reduction in emissions and waste. This results in the increased internalisation of external effects. In order to achieve the goals that have been set for the environment and climate while keeping industry competitive, resource consumption and growth need to be decoupled. The scarcity in resources must not be allowed to decelerate growth. Rather, it is important to recognise and exploit the enormous economic potential behind this challenge.

Productivity increase and skilled workers shortage

The future prosperity of our society depends significantly on an increase in the level of efficiency contributed by each person in employment. However, labour productivity has demonstrated a negative growth trend since the 1970s. Although digitization is expected to significantly increase productivity, it is not yet being reflected in a positive trend in productivity. Growing administrative workloads are increasingly adding to the situation in companies. The shortage of skilled labour also affects the performance of industry in Germany. Although current studies show a short-term increase in the population, in the long-term, the forecasts predict that the population in Germany will decrease significantly.[5] This, coupled with the brain drain for highly skilled and research personnel, has a dramatic impact on the availability of skilled workers. This is already noticeable today in almost all sectors of the economy. Hardest hit is the manufacturing sector.[6] One third of industry enterprises already have problems filling vacancies today. By 2030, the impending loss in economic growth is estimated to reach 4,600 billion Euros.[7]

Global competition for dynamic markets

Economic change is reflected in a shift in demand from west to east. Growing populations and increasing prosperity in developing and emerging economies are the root cause for this. Companies from China and India are establishing themselves as competitors of equal value and are causing a shift in economic powerhouses. In line with the trend towards increased national protectionism and the reduction in free

5 *Destatis 2015; European Commission 2015; Deschermeier 2017*
6 *Prognos 2015*
7 *Prognos 2009*

trade zones, access to new and existing markets is being hampered. At the same time, customer requirements are changing and becoming more individual and service-oriented. This poses new challenges for industrial design and innovation speed. Against the background of the strong dependence of our industry on export, this is a development that we have to address.

Disruptive technologies and business models

Digitization is acting as a driver of innovation and competition for the entire global economy. To solve increasingly complex tasks, information and communication technologies already have the essential components of value adding systems. They facilitate the coordination and synchronisation of business, logistics and production processes in one's own company and with external partners, and the integration of customers and communication with the same. However, these technical possibilities lead to new risks for established companies. They lead to elementary upheavals in existing business models and customer relationships. As a result, existing market barriers are dissolved or softened. In the future, the enhancement of hardware components – e.g. more powerful, high-precision manufacturing processes – will continue to be an important component for the success of the industry. Of even greater importance will be the integration of the software component.

Figure 3: Challenges for production

3. VISION »PRODUCTION 2030«

3.1 Production technology as an integrator of multidisciplinary approaches

Traditionally, production research combines the development of new production technologies and techniques with the economic and socio-cultural design of the entire production system. The increase in complexity and the ever-closer integration of technologies from different research disciplines mean that interfaces with other fields of research are becoming increasingly important. Today, production research combines technologies from a variety of research fields. These can be found in key enabling technologies (KET) that the European Commission and various technology foresights from the German Federal Government focus on in their innovation policy.[8] These include biotechnology, photonics, materials technology, micro and nano-electronics, information and communication technologies and the enhancement of mathematical procedures and methods (Figure 4). In developing these technologies, production technology plays a key role as a systemic integrator of multidisciplinary approaches, linking the individual areas.

In the future, these technologies will have a huge impact on production technology and life in society owing to their cross-

Figure 4: Key fields of technology in production research

8 *European Commission 2018*

sectional character. An exclusive focus on key technologies, however, is the wrong approach, since the advancement of basic technologies and traditional production processes beyond today's boundaries will be no less relevant to the competitiveness of the industry.

3.2 How will we produce in future?

3.2.1 Empowering excellence in the digital and biological transformation

The digital transformation remains the dominant theme in the next decade…

Digitization is one of the defining social and economic topics. In the context of the manufacturing industry, the digital transformation is discussed and researched under the term Industry 4.0. Currently, it is considered to be the most significant development for maintaining and increasing the competitiveness of the industry. Its implementation takes place in several successive stages. These range from digitization – the digital imaging of analogue processes – to virtualisation – the digital modelling of processes – to the networking of all components in a value added system through the Internet of Everything (IoE). The final stage thus far is seen as being in the autonomation of value adding systems, i.e. self-regulating and regulating systems. Great progress has already been made in this in recent years. Primarily due to German initiatives, the research and development landscape is largely structured now, even up to the point of standardisation processes that prepare the market for the adoption of relevant technologies. Nevertheless, much has still to be fully explored. For instance, in areas like artificial intelligence and smart materials, production research is just beginning. Years of effort by research, industry and politics will be required until full technical, organisational and legal implementation is achieved.

…and is complemented by a biological transformation of the value added system

In view of future challenges, the discussion revealed that the digital transformation of industrial value adding systems alone is not enough to adequately address future challenges, such as climate change, scarcity of resources or increasing complexity in business processes. Analyses of market, technology, scientific and industrial developments thus identified a further transformation in the value adding systems in addition to the digital transformation. This manifests itself in the vision of a biological transformation of industry value adding that is parallel to the digital transformation. The core idea behind this biological transformation is an increase in the efficiency and effectiveness of industry value adding, through the application of knowledge from and about nature and the integration of bioware (e.g. proteins, cells, micro-organisms) into production processes. Bio-intelligent systems form the basis for this. These result from the integration of information technology, biotechnology and conventional production technologies. The goal of this vision is to achieve value adding systems that act autonomously and are resource-conserving or even resource-creating, and which are resilient to changing environmental influences owing to their architecture which is adaptable on an ad hoc basis.

Enormous economic and social potential is expected in the future through the rigorous addition and continuation of digital transformations through the biological transformation of industry value adding. Initial approaches and key research topics have been identified within the scope of this study.

3.2.2 Man continues to determine value adding

Technological change will radically change the role humans play in production. This does not mean that in future our factories will be deserted. What is does mean is that automation technology, artificial intelligence and assistance systems will require profound changes to be made in relation to traditional job profiles. Employees will be relieved of routine tasks therefore freeing up capacities for creative, cognitively demanding and creative tasks. New collaboration and competence partnerships will lead to a symbiotic relationship between man and machine in which the potential of human flexibility and the efficiency of the machine can be maximized. The motor, intellectual, associative, sensory and emotional abilities of man, and his flexibility and diversity in skills will be complemented by the abilities of machines to efficiently and precisely perform defined tasks. An interdisciplinary and trans-disciplinary discourse needs to take place to unite these two worlds through social acceptance. The understanding of man's role will change and move away from being the source of costs to being the generator of value and guarantor of flexibility.

3.2.3 Structural models of future value added systems

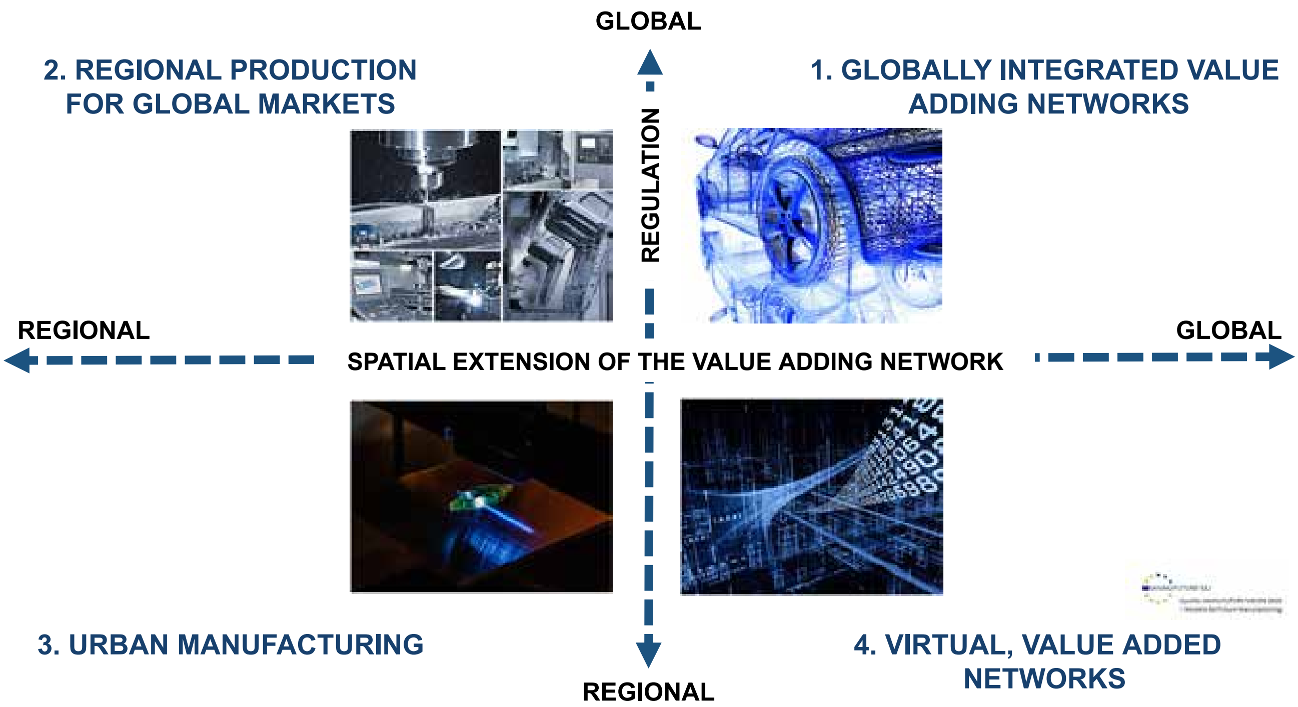
Depending on the market segment and underlying conditions, different structural models will result for future value adding systems. As part of the process of developing Vision 2030, European experts from MANUFUTURE-EU identified and described four core models (Figure 5).

The four core models can be classified in a portfolio spanning the spatial extent of the value chain (from regional to global) and its regulation (also from regional to global). In the case of virtual value added networks, the value adding partners are subject to regional regulation. Since these networks fluctuate strongly, often being created on an order-by-order basis, global regulation will only be weak. These four general value adding structures will co-exist with many intermediate stages and will have very different characteristics depending on the market, customer benefits, product module life-cycles, quantities and many other aspects.

Globally integrated value networks

This value adding model represents a further development in today's globally distributed value adding networks. Global companies with a large supplier network, such as the automotive industry, are the representatives of this. In the future, these models will manifest a pronounced real-time integration of the physical and virtual worlds. They will be monitored

Figure 5: Four prototypical structural models of future value added systems



and protected by globally standardised regulations. These networks will be supported by artificial intelligence (AI) systems that monitor potential customer behaviour, identify needs and desires and translate them into product designs, design data and cost-benefit calculations as a decision-making tool for management.

Regional production for global markets – Competence regions

Like the one above, this model relates to global markets. On the manufacturer side, however, regional networks dominate, frequently made up of medium-sized manufacturing companies. By way of example, highly specialised factory equipment suppliers can be named here that are capable of mastering entire, customers-specific process chains with a high level of in-house production. The production facilities are created to be cost and expenditure-optimised according to frugal principles. Professional platforms support the development of products with the customer. Prescribed norms and standards are taken into account here along with the production possibilities available and product-related services. Corresponding to the Regional Smart Specialisation Strategy (RIS3), the regions specialise in delivering specific and successful products and product groups and deliver them around the world.

Urban Manufacturing

The prototypical model of urban or customer-focussed manufacturing has an even stronger regional association than the model described above. Manufacturing takes place regionally for regional customers. Owing to urban growth, this often takes place in cities and is therefore referred to as urban manufacturing, although it also includes manufacturing and production in rural areas. Elements or components can be sourced worldwide here. However, final production takes place close to or even directly at the customer's site. An example of this is the personalised production of premium-value consumer goods in regions for regions as currently seen in the sporting goods industry.

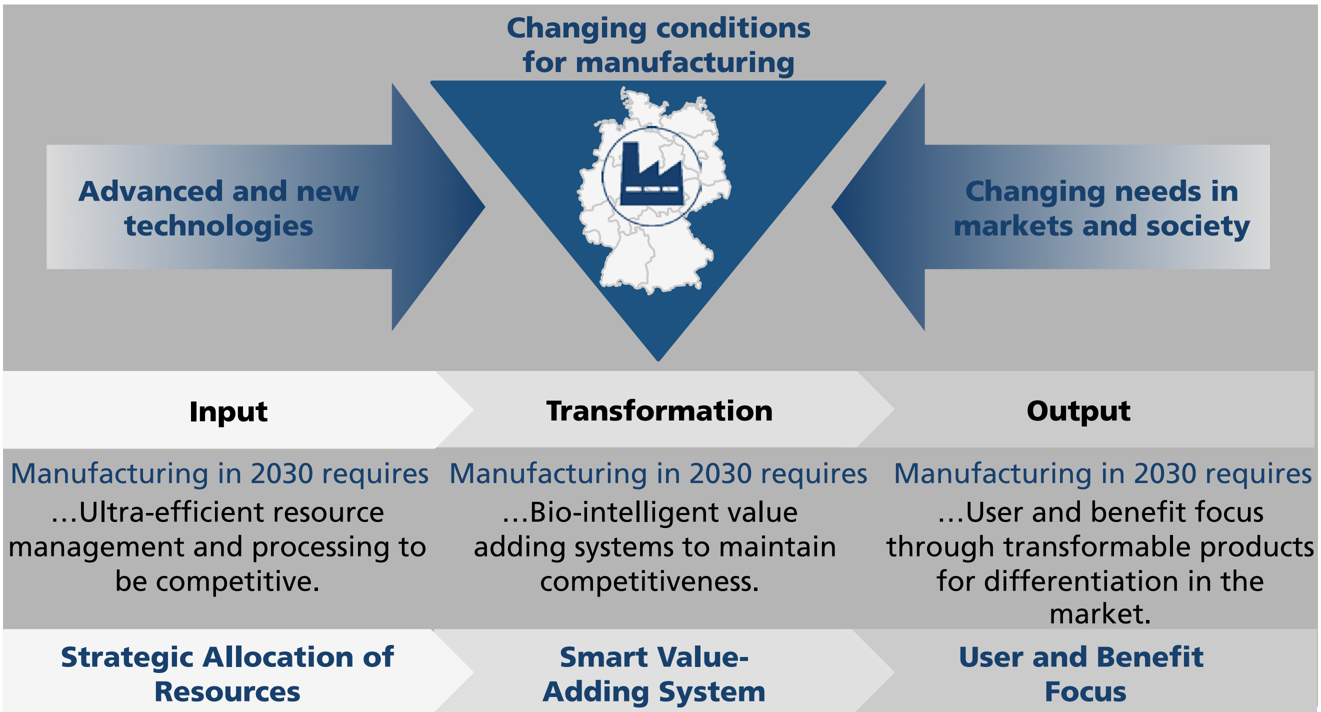
Virtual value added networks

In contrast to centrally controlled value added networks in globally integrated value added networks, virtual value added networks are wholly decentralised. Platform-based, ad-hoc value added networks are formed spontaneously in order to meet a need that is a limited in time and space. Production companies and service providers of all sizes offer their expertise and capacities over these platforms. Professional platforms which are operated by brokers or are provided on an open-source basis support the formation and operation of these ad-hoc value added networks, including legal administration and financial settlement. Numerous successful examples of this can already be found today as platforms on the Internet in various practical segments.

4. VISIONS FOR PRODUCTION 2030

The identification of research needs is based on the basic framework for the classical value added process (input, transformation, output). The fundamental questions of industrial manufacturing can be discussed within this framework. Three strategic pillars have been identified here from a customer perspective – Benefit Centring (output – requirements of the products of the future), Smart Value Adding Systems (transformation – requirements of future value adding), and Production Factor Allocation (input – requirements of resource management). Each of these is punctuated by a proposition and a planned, strategic objective for Production 2030 (Figure 6).

Figure 6: Three strategic pillars along the transformation process path



User and Benefit Focus

In manufacturing in 2030, differentiation no longer takes place via static products, but via the benefits generated by living products

4.1 Vision: User and Benifit Focus

Requirements of the products of the future

Changes in the needs and demands of users shift the relationship model for business-to-user (B2U) into the focus of product and service design. It addresses the actual user and his user behaviour and not the potential buyer. This concept therefore goes beyond the management approach to customer focus. Professionally marketing low-cost products and services alone will no longer suffice to ensure competitiveness. Rather, a personalised benefit needs to be offered. Traditional generic strategies, differentiation and cost leadership are replaced by the strategy of benefit leadership. By synchronising existing technology potentials, real customer needs need to be translated into the functional design of new products. The following requirements of products and services are decisive here:

- **Personalisation** - individually tailored to the user - provision of the service offering.
- **Service focus (Anything-as-a-service – XaaS)** - A diverse range of services can be added to products to expand them. Services only need to be paid for when they are used.
- **Access and availability** - Access to products and services is guaranteed anytime, anywhere, with immediate availability.
- **Transparency and simplicity** - The density of information is tailored to the user and is easy for him to compare with other offers. Usability and interaction are designed to be intuitive.
- **Control and security** - Data security is guaranteed at all times and the user has control over his own data.
- **Sustainability** - Corporate responsibility, in the sense of environmentally conscious material and energy-efficient product and service design, is guaranteed throughout the entire product life-cycle.
- **Freedom of choice and flexibility**- There are no involuntary lock-in effects. The user can switch between products at any time, without suffering any personal disadvantage.

This requires the specific configuration of these requirements to be identified. New product development methods, design guidelines for the development and implementation of business models, and miniaturisation solutions for functional integration into products pose major challenges in the future.

Vision: »Living« products –
Adaptability to the functional needs of the user

»Living« products emerge as the planned vision. The interaction of hardware, software, services and in many cases bioware is constituent for this. Product functions need to dynamically and increasingly adapt independently in future to changing requirements throughout the entire product life-cycle. Products need to be designed so that their components make them transformable. Owing to their openness to innovation, transformability and cognitive-intelligent adaptability with regard to the functional needs of the user, these products of the future can referred to as »living«. This label can also be considered apt since the products of the future can actually carry »life« in them. For example, by integrating bioware, i.e. living bio-organisms.

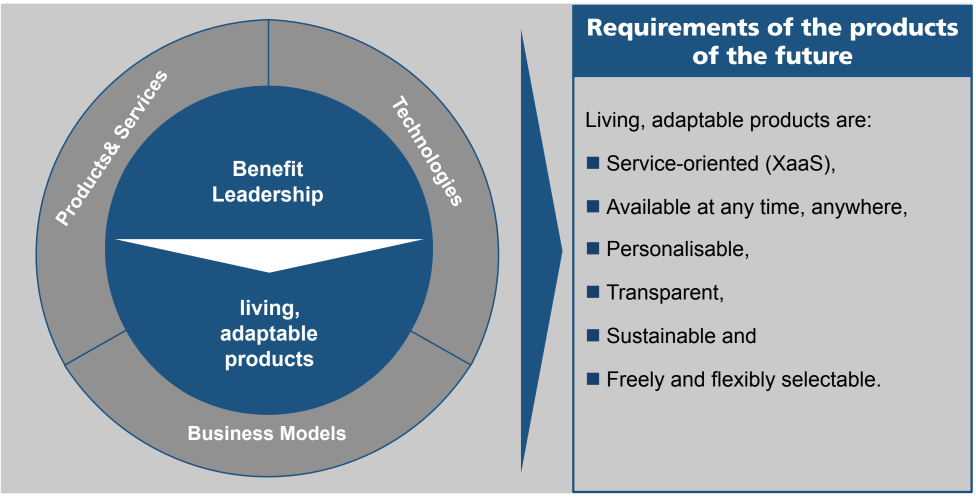


Figure 7: User and Benifit Focus – Requirements of the products of the future

4.2 Vision: Smart Value Adding Systems

Requirements of the value adding of the future

The sustainable and efficient processing of scarce resources subject to the requirements of resource efficiency can only be achieved through an intelligent value adding system. This demonstrates the intelligence in orchestrating the resources available. Until now, ambiguities in value adding have determined the value adding architecture, for example, the contradictory dependencies between the degree of flexibility and efficiency, or striving for the maximum utilisation of assets, while maintaining the constant availability of assets. In future, these traditional conflicts of value adding will be resolved by a needs-based adaptation of the design and composition of the value adding architecture. This is flanked and supported by the digital and biological transformation. The aim here is to dissolve rigid value chains through an intelligent, networked complete system – from the machine to the market structure. Adaptable and living structures are necessary for this, which have a high degree of autonomy and can make decisions and perform optimisations autonomously. Bio-integration can generate new efficiency potentials, for example, by shortening value adding chains in technical systems. In combination with the optimal integration of man and his capabilities, the overall system is empowered to reach new heights (Figure 8).

Vision: bio-intelligent value adding systems – ad hoc and autonomous adaptation of the value adding architecture into the optimal solution for the value adding task

In bio-intelligent value adding systems, the scope available for digital transformation is used and raised to a new level by applying biological principles and procedures. The vision of the future continues to address the fundamental and sustainable development of the socio-technical system. In addition to technological challenges, social challenges (e.g. the future integration of humans, the ethical challenge of machine autonomy or biotechnology) will also play a major role.

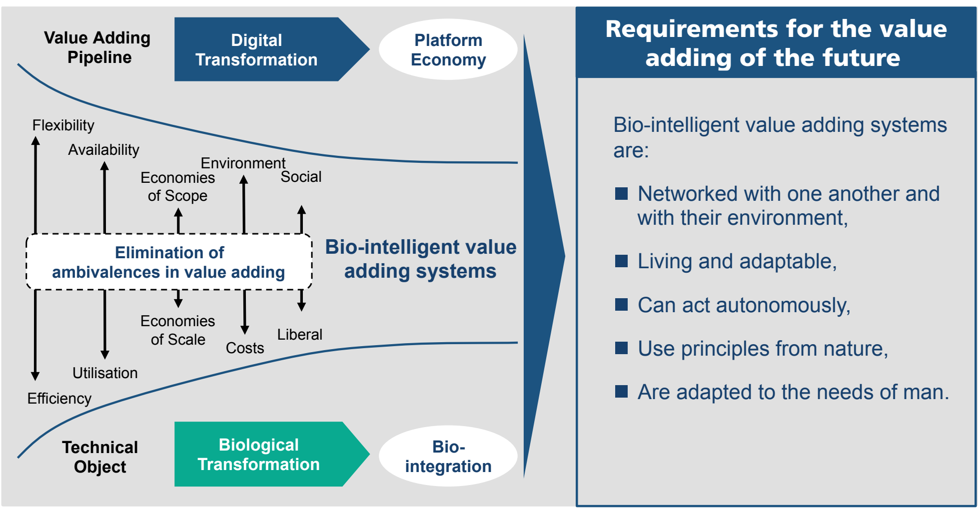


Figure 8: Smart Value adding systems - Requirements for value adding systems of the future

Strategic Allocation of Resources

In manufacturing in 2030, the ultra-efficient management of factors of production determine value adding efficiency

4.3 Vision: Stratgic allocation of ressources

Requirements of resource management

Competition for energy, material, human and monetary resources is becoming more and more intense. New competition for knowledge-relevant resources, such as data, information, ideas or creativity, is also emerging as a basis for innovation. At the same time, creative knowledge work or empathy-based services will compete with artificial intelligence in the future. This results in the need to expand the concept for resources. In addition to classical factors of production, complexity has to be added as a resource. This rises from the diversity, complexity and dynamics of the individual, partially closely meshed production factors and the environment. In conjunction with technological advances in key technologies, it is also important to develop new concepts and technologies for efficiently processing resources. A change in perspective from the consumption of resources to the use or generation of resources has taken place for this purpose, with the aim of managing resources ultra-efficiently.

Vision: ultra-efficient resource management – sustainable and resource-optimised service provision

In the case of ultra-efficient resource management, the allocation and maximum exploitation of the potential uses of the input factors are as much a focus as the development of new organisational and learning concepts (Figure 9). The increase in complexity has to be managed and used as a competitive advantage and not necessarily reduced. New agile leadership and organisational models need to be established to dissolve the inertia of existing hierarchies. Appropriate methods are needed to identify and retain talent and continuously develop the skills of employees. The effective and efficient use of existing resources increasingly needs to be placed in the focus of companies and research. New, sustainable energy and material concepts need to be developed. In this context, it is important to develop and research new materials with new properties, sustainable substitutes for critical raw materials and related production technologies and processes.

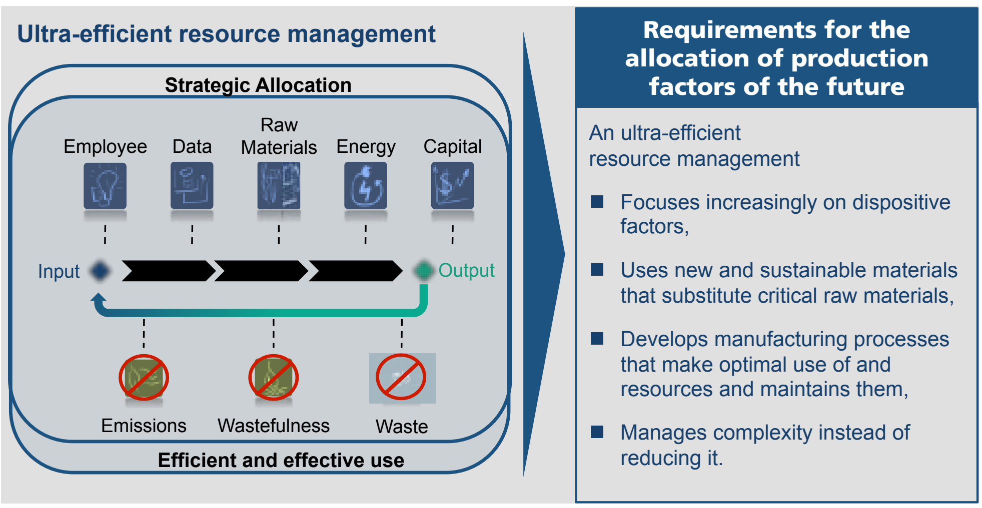


Figure 9: Allocation of production factors – Requirements of resource management

5. RECOMMENDATIONS FOR FUTURE RESEARCH PRIORITIES

In line with the vision of »production technology as an integrator of multidisciplinary and systemic approaches«, the orchestration of the individual topics identified is crucial to the success of the industry. Nevertheless, individual topics have a key role to play especially in achieving the objectives of the three strategic pillars. In the following, we emphasise the highly relevant research fields that have emerged from the iterative prioritisation and discussion process.

Further explanations of the research fields, including the research topics that have been identified and classified, can be found in the unabridged version, of this document under www.ipa.fraunhofer.de/studien (in German only).

5.1 Priority research fields for the development of living products

In order to achieve the planned vision of achieving living products, the three research fields addressing the adaptability of products, functional materials and surfaces and business ecosystem engineering need to be emphasised in particular.

Adaptable design of products transformability by design

The adaptable design of products enables product designs to adapt to future requirements. In the sense of a living product, in order to be able to adapt to changed general conditions over the entire life-cycle of a product, the design of future requirements already needs to take place during the development stage. The research topics identified in the research field help to convert existing systems or technologies (what are called legacy systems) into (bio)-intelligent systems on the fly. Customisations and improvements to the products can therefore be performed decentrally during operation or use (unabridged version, Sec. 4.1.1, Research Field 3).

Adaptable design of products

Inventory systems can be upgraded and made into (bio-)intelligent systems. Hardware, software and bioware are also designed for future requirements. Customisations can be performed decentrally during operation.

Key research topics:

- Development of new automation architectures – open and real-time operating system
    - Openness (Open X)
    - Customisability in real time and during runtime
    - Functional safety in open systems
- Migration concepts for existing systems

Figure 10: Adaptable design of products

Functional materials and surfaces

Thanks to nano-modified structures, functional materials and surfaces make it possible to design products that are more robust, lighter and more energy-efficient right up to energy-autonomous products, and offer enormous potential for the spatial concentration of functions and features. The research topics help to facilitate integrated and highly concentrated functionalities in materials and surfaces here and therefore the realisation of smart miniaturisation solutions (unabridged version, Sec. 4.1.2, Research Field 7).

Functional materials and interfaces	*Integrated functionality in materials and surfaces as an enabler of smart miniaturisation solutions.*

Key research topics:

Development of smart and functional materials

- Identification of and possible applications for intelligent material properties (e.g. magnetostrictive materials)
- Development of
  - Programmable materials
  - Self-healing surfaces
  - Innovative functional fabrics and material combinations

Development of methods for direct functionalisation

- Production and assembly processes for functional integration into materials and surfaces
- Coating techniques with higher resolution and accuracy for the functionalisation of structural elements

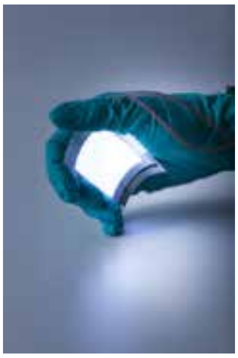


Figure 11: Functional materials and surfaces

Design and implementation of business ecosystems business ecosystem engineering

The intensification of horizontal cooperations is decisive for the targeted fulfilment of customer needs. For example, it is important to investigate the technical, legal and organisational aspects of business ecosystems and develop systems for their description and design. The goal is to involve the user in all stages of the value adding process. In Production 2030, all manufacturing companies either work in volatile business ecosystems (without an involuntary lock-in effect), or in stable business ecosystems, that do not unintentionally decouple them from access to their customers. (unabridged version, Sec. 4.1.3, Research Area 10).

Business ecosystem engineering	*All manufacturing companies work either in volatile business ecosystems (no involuntary lock-in effect) or in stable business ecosystems (BES) that do not unintentionally decouple them from access to their customers.*

Key research topics:

- Methodologies for the strategic design of BES (e.g. segment-related or cross-industry)
- Empirical investigation of the long-term, economic and economic impact of BES
- Methodologies for planning, operating and optimising BES
- Evaluation of new modes of cooperation (open source, open community or cooperative models)

Figure 12: Design and implementation of business ecosystems

5.2 Priority research fields for the development of smart, value adding systems

Requirements in the areas of networking, agilisation, automation, biologisation and humanisation need be implemented until a standard of systems can be achieved in production that is autonomous, decentralised and adaptable on an ad hoc basis. Many technologies and concepts on the path to the platform economy (platform-based value adding) and bio-integration are not or not yet fully researched and require the considerable use of resources on the part of industry, research and politics. The following research fields will be decisive in achieving the planned vision.

Platform-based value adding

Digital platforms create more efficient and transparent markets. They offer companies new ways to cooperate with customers and industry partners. Especially small and medium-sized companies benefit from improved global visibility for their own company and possible cooperation partners in the market. The services offered on the platform, such as payment or logistics infrastructures, also offer added value. Research and industry need to jointly develop new platform, operator and participation concepts in order to be able to use the potential of this technology in a focussed manner. Questions concerning the design of cooperation systems or systems for improving incentives and acceptance also need to be answered with regard to the implementation of interoperability, (unabridged version, Sec. 4.2.1, Research Field 14).

Platform-based value adding

New business models, opportunities for cooperation, efficiency potential and increasing the speed of innovation through cross-platform networking.

Key research topics:

Creation of infrastructure (platforms, operator participation concepts)
- Concepts for ideal platform design
  (large, central vs. small, decentral; open vs. closed, anonymity vs. transparency)
- Development of safety and process concepts
- Evaluation of the opportunities and risks of joint data pools

Realisation of interoperability
- Development of platform-based innovation and cooperation systems
- Methods for automatically negotiating delivery terms, eligibility requireme
  and payment terms
- Modelling and formalisation of competences

Requirement:
- Legal safety and clarification of data sovereignty
- Resilience by design throughout the whole life cycle
- Trustable and stable infrastructure

Figure 13: Platform-based value adding

Transforming cyber-physical production systems (CPPS)

The production of personalised products and shorter product life-cycles requires a high level of adaptability and speed, with maximum availability of all the components and just-in-time stock levels. As a result, value adding systems are subject to constant changes in input and output variables and general conditions. This requires the permanent adaptation of the entire production system. For instance, in order to economically structure the conversion or reuse costs of manufacturing systems and be able to adapt the system simultaneously at a market-driven speed, fabric elements need to be modular. The resulting flexible architectures, e.g. based on plug-and-produce concepts, make the economic configurability and scalability of systems possible. This forms the basis for production systems that change independently and permanently on an ad-hoc basis to match changing tasks and environments and adapt to resource and material markets (unabridged version, Sec. 4.2.2, Research Area 15).

Transforming CPPS

Production systems that change independently and permanently on an ad-hoc basis to match changing tasks and environments and adapt to resource and material markets.

Key research topics:

Development of transforming means of production
- Identification and design of flexible architectures
- Plug &Produce concepts

Concepts for dynamic quality assurance
- Zero-defect concepts for single quantities
- Quality management concepts for transformable systems

Design of convertible production systems
- Design approaches and migration strategies for
  - Multi-use fabrics
  - Re-use of manufacturing systems
  - Scalable production systems

Concepts and implementation of fluid logistics systems
- Free navigation in space
- Real-time navigation - localisation and control

Figure 14: Transforming cyber-physical production systems (CPPS)

Artificial cognitive intelligence

Artificial cognitive intelligence forms the technological and elementary basis for increasing productivity. As an academic discipline, artificial intelligence has existed as a subject since the mid-1950s. Selflearning image processing systems, intelligent robots and independent production planning tools have only become more and more real due to the leaps in technology made in the last few decades. Nevertheless, production research and industry are still in their infancy in this field of research. The planned vision to be aimed for here is one where cyber-physical systems learn what type of behaviours and plans lead to success and then implement them autonomously (unabridged version, Sec. 4.2.3, Research Area 21).

Artificial cognitive intelligence

Cyber-physical systems learn which behaviours and plans lead to success and implement them autonomously.

Key research topics:

Transfer and development of production knowledge in analytical mathematical rules

- Artificial Neural Networks (ANN), Deep learning for production applications
- Software and multi-agent systems
- Self-optimising and self-learning

Development of demonstrators and application examples for the industry

- Digital assistants
- Augmented reality and virtual reality

Requirements:

- Creation of legal frameworks
- Accessibility of real data bases for research
- Big Data, analytics, simulation bases
- Powerful hardware or high computing power

Figure 15: Artificial Intelligence

Application of bio-based processes and intelligence

Insights into the dynamic interactions between entities in a biological system and the behaviour of the system as a whole are transferred to production research. Methods from biological cybernetics, i.e. the control and regulation processes in organisms and ecosystems, can be used to design living, autonomous and networked value adding systems. The transfer of natural phenomena to technology is nothing new per se. Self-replicating, cellular machines had already been conceived in the sixties, but have not been realised yet. The use of biotechnological processes in industry offers considerable potential for resource conservation and efficiency enhancement. The possibilities for applying biotechnology and systems biology to production technology and organisation are manifold and range from bio-based network design to bionic construction methods, eco-efficient circulation systems and autonomous logistics, to the use of the swarm intelligence principle (unabridged version, Sec. 4.2.4, Research Area 24).

Application of bio -based processes and intelligence

Bio-intelligent production is based on understanding and applying nature's principles and systems.

Key research topics:

Transfer of biological organisation and control mechanisms to production

- Transfer of control processes and operations from organisms and ecosystems to value adding systems (bio-intelligent cybernetics)
- Bionic principles for hardware design (architectures, structures, functions, interfaces)
- Development of methodologies for the organisation of value adding systems collective intelligence

Development of bio-technical intelligence

- Bio-intelligent, evolutionary algorithms
- Bio-intelligent machine -learning

Requirements:

- New formats for development and research
  (Institutes; start-ups; international, bilateral research collaborations;
  Establishment of interdisciplinary specialist groups at the DFG)

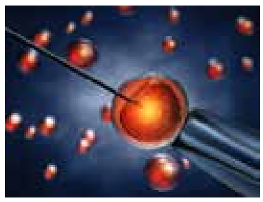


Figure 16: Application of bio-based processes and intelligence

Cognitive interaction of socio-technical production systems

In addition to physical interaction, the cognitive interaction between man and machine needs to be developed further. Complex and challenging processes involving analysis and time-consuming routine tasks will be taken over by machines in future and will free up people's capacities. The role of humans will be to evaluate information using their experience, transferability and creativity, and to make decisions. To this end, for instance, application fields and modes of interaction for augmented and virtual reality tools and usability, i.e. the intuitive interaction between humans and machines, need to be further developed and practicable solutions for production developed. In all business processes, man needs to be supported by intelligent systems in his decisions and work. Digital technology will provide him with all the information relevant to making decisions in a personalised way, thus expanding his perceived reality and increasing his cognitive abilities (unabridged version, Sec. 4.2.5, Research Field 27).

Cognitive Interaction	*In all business processes, man will be supported by intelligent systems in his decisions and work. Digital technology provides him with all decision-relevant information in a personalised way, thus expanding his perceived reality and increasing his cognitive abilities.*

Key research topics:

- Development of approaches to consumerisation and gamification for production
- Interaction modalities for augmented-reality tools
- Continued development of the usability: Intuitive user interfaces, intuitive programming and configuration
- Methods for interpreting non-standardised usage patterns
- Development of robust methods for capturing and processing natural interaction: looks, gestures, language
- Development of methods for supporting context-related decision-making and providing information (personalised augmented operator)

Figure 17: Cognitive interaction of socio-technical production systems

5.3 Priority research fields for achieving ultra-efficient resource management

The allocation and maximum exploitation of the potential uses of materials and energy, and the development of new, organisational and learning concepts and employment profiles for production in the future are central to ultra-efficient resource management. During prioritisation, two research fields of particular relevance were identified as follows.

New concepts for learning and continuing learning

Future tasks in planning and executive activities place new demands on skills and abilities. Complexity, abstraction and problem-solving requirements represent key competencies in the future. Lifelong learning becomes a prerequisite for mastering ever-changing intelligent systems. Virtual and augmented reality open up new possibilities for integrating learning and qualification tools into the workplace (on-the-job training / near-the-job training). New methods and (mobile) learning technologies enable work-integrated, needs-based and personalised learning. This supports employees in their lifelong learning and the continuous development of their skills (unabridged version, Sec. 4.3.1, Research Area 32).

New concepts for learning and continued learning

New methods and (mobile) learning technologies enable work-integrated, needs-based and personalised training and support workers in their lifelong learning and the continuous development of their skills.

Key research topics:

- Enhancement and transfer of existing e-learning approaches to the production environment
- Development of intergenerational activity and learning concepts
- Learning factories for all topics relating to production in the future (VR/AR; resource efficiency, biologisation, etc.) to develop standards
- Integration of virtual further training/training tools into qualification measures and the working day
- Learning involving cyber-physical systems (CPS as a learning system)

Requirements:

- Interdisciplinary research into engineering, IT and social sciences

Figure 18: New concepts for learning and continued learning

Application-optimised materials engineering

New processes for material testing, production and recycling need to be developed that are even more application-oriented. This requires an even better understanding of the requirements of processes, materials and material properties. The topics to be researched depend strongly on the respective material. In addition to the continuous optimisation of existing tools, for example, to develop the correlation between product properties and process technologies, it is important to learn from nature and develop new methods of construction and drive forward the automated mass production of composites in order to achieve ultra-efficient resource management (unabridged version, Sec. 4.3.2, Research Area 35).

Application-optimised materials engineering

Materials are developed to optimise the application along the entire value chain.

Key research topics:

Enhancement of materials engineering

- Optimisation of existing tools to extend the correlative understanding of product features and process technologies
- Enhancement of bionic construction methods

Enhancement of material production

- Enhancement of wear-resistant, multi-material systems
- Development of mass-production-compatible, automated composites production
    - Joining technologies, procedures for quality assurance
    - Textile manufacturing processes for the production of composites

Requirements:

- Methods for the simulation and modelling of material properties and behaviour
- Innovation clusters and development cooperations for developing materials and for methods and process engineering

Figure 19: Application-optimised materials engineering

6. RECOMMENDATIONS FOR IMPROVING THE INNOVATION SYSTEM

The importance of production research and technology development for and in industry is undisputed. It provides solutions to societal challenges, such as health, environmental protection, mobility and security, thus making a significant contribution to safeguarding prosperity. To this end, industry and scientific research depend on a stable and well-functioning innovation system, which supports the rapid transfer of new insights and inventions into the markets. Proposals have been put forward in this project to further strengthen research infrastructures and discuss them intensively from the perspective of science and industry. The following presents the priority recommendations for the innovation system. The overall findings are described in detail in the unabridged version of this document (unabridged version, Sec. 5)

Establishing and intensifying multi and trans-disciplinary research

According to the vision »Production technology as an integrator of multidisciplinary and systemic approaches«, the plurality of different technical disciplines are linked by multidisciplinary research clusters and programmes. This requires the implementation of a new school of thought that translates the different research methods, paradigms and conceptual modes (vocabulary) into a uniform meta-level for the disciplines as a pre-condition for working together. The increasing complexity, together with the increasing rate of innovation in all areas, is causing socio-political uncertainties, for example, with regard to increasing digitization and autonomation. Fears and criticisms need be integrated into the discourse on technological developments. Furthermore, in general education, an improved understanding of technology needs to be extracted in order to reduce irrational fears and improve the attractiveness of technical professions. It is important to integrate trans-disciplinary research principles that combine scientific knowledge with practical experience and permit criticism and reflection.

»Research on the living object« – Production research in the factory

Cooperation potentials in research and development are not exhausted. The barriers to cooperation with research institutes mentioned by industry stakeholders relate in particular to missing track records – reference lists concerning investment successes or several sets of certified annual accounts - for leading ideas, the technocratic culture, the partially inactive network with industry and very complex and volatile economic policies. Over and above this, political and contractual decisions often take too long. In addition to reduce these barriers, jointly funded professorships and temporary staff exchanges would also encourage cooperation. In addition to the funding assistance, companies could foster business collaborations that promote collaboration between business and science. Universities and research institutes could provide infrastructure for small and medium-sized enterprises to specifically use as test environments and could also develop and implement the latest methods in collaborative »production clinics«. In order to conduct application-oriented research under real conditions, production research needs to move closer to the production facilities. This is because research institutions are frequently unable to provide the human and technical resources to facilitate research under real conditions, especially in the area of digital transformation.

Tax incentives for funding innovations

Although tax subsidies for research and development in companies are currently being discussed in the political arena, they have not yet been implemented in Germany. Two-thirds of OECD countries and half of EU countries make use of the opportunity to fund research and development through tax subsidies and take advantage of the benefits of tax incentives:[9] for example, the aggregate return on research and development activities is significantly higher than the private rate of return, which results in macroeconomic welfare gains. Thus far, Germany relies exclusively on direct project funding. However, especially for small and medium-sized enterprises, applying for funding for research and development projects is linked with high administrative costs and uncertain outcomes. Extreme uncertainties in planning owing to short-term changes in political funding priorities and volumes also exist. These objections do not argue against direct programmatic project funding, but rather for complementary, broad-based and technology-friendly indirect innovation funding. All evaluation studies certify that tax-funded research is as an extension of private research and development expenditure and thus an economic benefit. Following a positive evaluation, France, the Netherlands, Austria, the United Kingdom and the USA continuing to expand their tax incentives for research and development projects.[10]

9 *EFI 2015*
10 *EFI 2015*

OUTLOOK

We face major challenges in remaining internationally competitive while maintaining our social standards and achieving our climate and environment goals. At the same time, technological progress and our current positioning offer us excellent opportunities to master these challenges.

Together, politics, business, science and civil society need to develop sustainability strategies that are deserving of the name and implement them consistently. To this end, we need to intensify our cooper-ative efforts in all areas and focus national and European research and innovation strategies specifically on future problems. The findings of this study provide a foundation for the successful design of eco-nomic, research and innovation policy and for safeguarding our competitiveness and hence our pros-perity in the long-term.

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