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FUTURE R&D

Trends and Success Factors in Industrial Research and Development

FRAUNHOFER VERLAG

Frank Wagner, Marco Kayser, Michaela Keßelring

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Foreword

In the years to come, industrial research and development (R&D) must continue to change and adapt in order to successfully offer new products, processes, services, solutions and business models to global markets and international customers.

Since by definition R&D is oriented towards the future, this study is intended to provide R&D managers with support for strategic and operational future orientation.

"Industrial R&D is subject to continuous change, which is accompanied by discontinuities, technological trends and changes in the market environment."[1]

This quote from the foreword to the 2015 trend study still applies today just as it did back then. Current geopolitical and economic turbulences are destabilizing the markets, new technological trends such as the digitization of industries produces new winners and losers. This offers opportunities, especially for small and medium-sized enterprises, which recognize these potentials and can use them for profitable growth.

Fraunhofer's "Agenda 2022"[2] and its "Key Strategic Initiatives" describe comprehensive technical and systematic solutions for the future of Germany as a high-tech nation. Topics such as "Artificial Intelligence" and "Cognitive Systems", which were also mentioned in the survey results, but also research topics such as "Quantum Technology", "Programmable Materials" and "Biological Transformation" become increasingly important and *"have a high relevance for the German and European economy and society"*[3].

Our R&D survey examines trends and goals as well as success and influencing factors in industrial R&D from the perspective of technology-oriented companies. After 2010[4] and 2015 "R&D – Fit for the Future", this is already our third consecutive trend study. Back in the 1990s, the empirical study "R&D today"[5] examined the situation of industrial R&D in Germany at that time. We are delighted to continue the long-term tradition with this publication.

This "third edition" of the R&D study focuses not only on current trends that influence and shape industrial R&D but also sets them in the context of goals, influencing factors as well as success factors. In doing so, we wish to consciously increase the relevance and usefulness for industrial R&D and offer R&D managers up-to-date information and new ideas.

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[1] Wagner, F. (Ed.): FuE – Fit für die Zukunft. Stuttgart: Fraunhofer Verlag, 2015.

[2] Fraunhofer-Gesellschaft e. V. (Ed.): Annual Report 2018. Available online: https://www.fraunhofer.de/en/media-center/publications/fraunhofer-annual-report.html. Access on 15.11.2019.

[3] Fraunhofer-Gesellschaft e. V. (Ed.): Fraunhofer annual meeting and presentation of the Fraunhofer research prizes in the organization's anniversary year. Press release, 8. Mai 2019. Online: https://www.fraunhofer.de/en/press/research-news/2019/may/a-success-story-that-has-lasted-70-years.html. Access on 15.11.2019.

[4] Wagner, F.; Finger, J.: Future Trends and Challenges of R&D – Results of an empirical Study within Manufacturing Industry. Proceedings of the R&D Management Conference. Manchester, 30.06. – 2.07.2010.

[5] Bullinger, H.-J.: F&E-heute – Industrielle Forschung und Entwicklung in der Bundesrepublik Deutschland (IAO-Studie). Munich: GFMT-Verlag, 1990.

The medium-term trends and goals as well as influencing and success factors of industrial R&D in this study are consistent and complementary to the longer-term projections of the "Impulse Paper"[6] of the Fraunhofer Group for Innovation Research. The paper describes five theses on the future of innovation as well as the results of the project "Foresight Fraunhofer"[7] with a focus on applied research of the Fraunhofer-Gesellschaft. Both studies are oriented towards the time horizon of 2030. The five theses of the impulse paper are of significant importance for the future-oriented design of industrial R&D:

1. "In 2030, openness, the ability to learn and cooperation will be the guiding principles of innovation."
2. "In 2030, integrated solutions will be the focus of innovation activities."
3. "In 2030, innovation processes will be fully digitized."
4. "In 2030, knowledge will be open to all – the challenge will be to apply it profitably."
5. "In 2030, Europe will enjoy unique global competitive advantages in terms of data security and sovereignty."

In addition, the results of the Foresight project are very topic-oriented and are briefly described in chapter 5 "Fraunhofer Future Topics".

The present study is essentially divided into three parts: The documentation of the results of the survey, interviews with international experts from industrial R&D who comment on and interpret these results from their point of view as well as a short excerpt from and link to the "Agenda Fraunhofer 2022" and the "Fraunhofer Future Topics".

Based on the study results and the great interest of the participants, we will initiate an industrial network project that will support companies in the interpretation and use of trends and factors as well as in the implementation of individual and company-specific R&D strategies, roadmaps, initiatives and projects. The participants of the network project will also benefit from an exclusive study that will focus on the identification and use of external success factors of an "R&D ecosystem".

As in the years before, we hope that this study will once again provide you with some suggestions, motivation and initial solutions for the design of an efficient and "future-oriented" industrial R&D. Please do not hesitate to contact us if we can support you with "words and deeds".

Stuttgart, November 2019

Frank Wagner

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[6] Fraunhofer Group for Innovation Research (Ed.) (2018): Understanding Change – Shaping the Future. Impulses for the Future of Innovation. Stuttgart. Available online: http://publica.fraunhofer.de/dokumente/N-509887.html. Access on 15.11.2019.

[7] Fraunhofer-Gesellschaft e. V. (Ed.): Foresight Fraunhofer – Future Topics with Relevance to Application-oriented Research. Available online: http://publica.fraunhofer.de/dokumente/N-541003.html. Access on 15.11.2019.

Content

1
Background and aim of the study

New technologies and technological concepts such as artificial intelligence (AI) or the Internet of Things and Services (IoT) promise new potential for application in the manufacturing industry. These companies face the challenge of competing on a global scale and creating new opportunities.

R&D as the innovation driver in manufacturing plays an important role. Its task is to anticipate future technological developments and their relevance for the company and to initiate actions that ensure long-term market success.

"Intelligent risks are based on wide and voracious data gathering checked against gut instinct; while dumb decisions are built from too narrow a base on inputs." [8]

In order to recognize future trends and technologies early on and put them into perspective, it is essential to raise awareness of the challenges that industrial R&D faces. This requires a holistic view of R&D across different dimensions.

In this context, the Fraunhofer Institute for Industrial Engineering IAO conducted an expert survey on current R&D trends in companies. R&D employees and managers in manufacturing companies were surveyed. The aim of the survey was to identify relevant trends, success factors and goals of R&D departments in industrial companies across different industries. In addition, influencing factors were surveyed that are expected to have an impact on R&D over the next ten years.

In total, more than 100 experts from various international companies, primarily from mechanical engineering and automotive industries, took part in the survey. The majority of those surveyed were R&D employees and managers. Also, most the respondents had been with the company for more than eight years.

A summary of the survey results has been published as a scientific paper in advance.[9]

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[8] Daniel Kahneman, Nobel Prize-winning psychologist.

[9] Kayser, M., Wagner, F., Keßelring, M.: F&E-Trendumfrage 2018 – Trends und Erfolgsfaktoren in der industriellen Forschung und Entwicklung. In: wt Werkstattstechnik online 109 (2019), Issue 3, pp.199-202.

2
Results of the survey

The following chapter contains the most important information and results from the R&D trend survey. First, the methodology of the survey is presented and details of the companies involved are given. Subsequently, the results on R&D trends and goals as well as success and influencing factors are evaluated. The most relevant trends are discussed in more detail. The chapter concludes with a summary in which the key findings of the survey are briefly presented.

2.1 Introduction

Initially, around 5 000 R&D experts from various sectors of the manufacturing industry were contacted by e-mail to participate in the survey. Both German and English questionnaires were sent out. Between February and May 2018, responses were submitted either by mail or via an online survey tool[10].

From the questionnaires submitted, 105 were considered for the final evaluation. This equals a response rate of nearly 2 %. Small and medium-sized enterprises (SMEs) were involved to about 34 % in the survey. This number includes all companies employing fewer than 250 employees and with an annual turnover no greater than EUR 50 million.

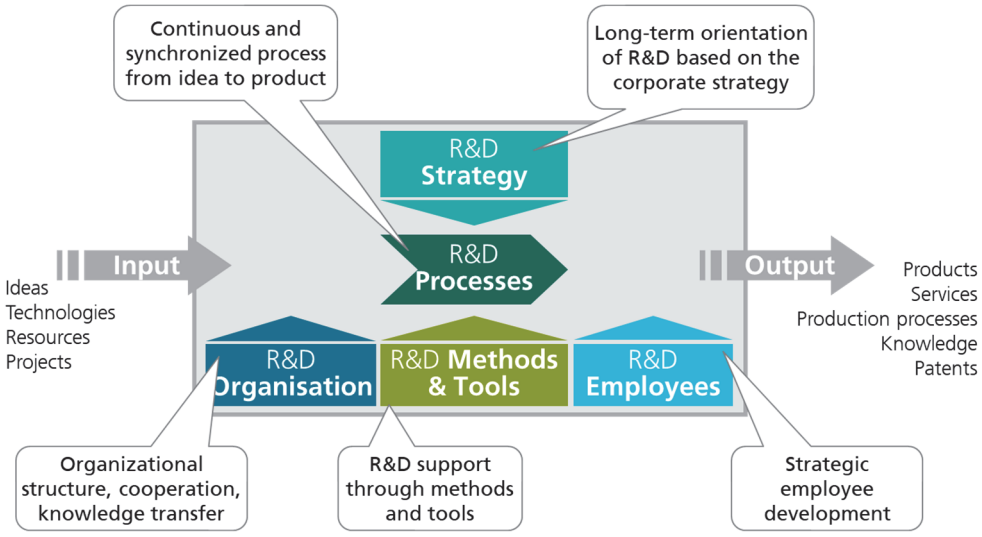
2.1.1 Framework conditions and implementation

The questionnaire that was used for the 2015 study served as the basis for the new survey. Prior to the study it was revised and complemented with additional trends. A total of 38 R&D trends were chosen for the study and structured according to the five areas R&D strategy, organization, processes, methods & tools and employees (Fig. 1).

The respondents were able to assess the relevance of the R&D trends for the next 2–5 years using a 6-point scale with the scores – *None to very low*, *Low*, *Rather low*, *Rather high*, *High* and *Very high*. Participants were able to comment on other relevant trends by entering a text box.

[10] LimeSurvey GmbH: LimeSurvey – An Open Source survey tool. LimeSurvey GmbH, Hamburg. Available online: www.limesurvey.org. Access on 15.11.2019.

Fig. 1
Methodology of the survey[11]

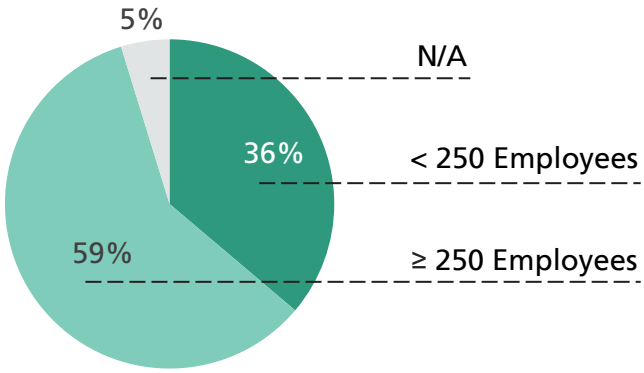


2.1.2 Information on the companies involved

In order to classify the companies surveyed, both their size as well as their annual turnover were evaluated in the questionnaire. Thereby it was possible to determine to what percentage SMEs and larger companies participated in the study.

The majority of the companies surveyed employ 250 or more employees (approximately 60 %). About one third of the companies had fewer than 250 employees. Fig. 2 shows the distribution of the surveyed companies according to the number of employees.

Fig. 2
Number of employees in the companies involved



The analysis of the annual turnover of the companies shows that more than half of the participants achieve an annual turnover of more than EUR 50 million. Approximately 40 % of the companies have an annual turnover that is about or below this number. Fig. 3 illustrates the distribution between the companies involved.

[11] Wagner, F. (Ed.): FuE – Fit für die Zukunft. Stuttgart: Fraunhofer Verlag, 2015.

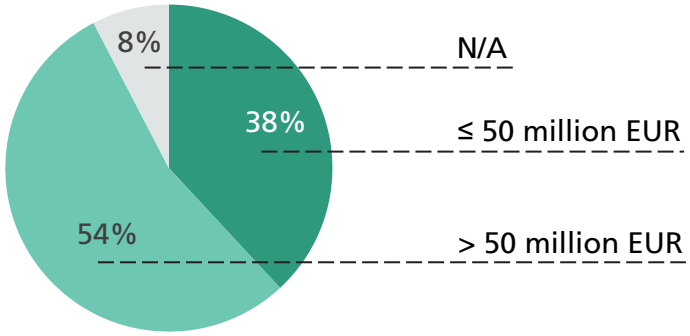


Fig. 3
Annual turnover of the companies involved

When comparing both indicators "number of employees" and "annual turnover", the participation rate of SMEs is about 34 %. This number includes all companies employing less than 250 people and with an annual turnover no greater than EUR 50 million.

In order to determine the companies' industry sectors, the type of solutions (products, services, etc.) offered by the companies were surveyed in the questionnaire. Based on this, a distinction was made between the metal and electrical industries and other sectors. The first group includes all participants from the areas of electronics, medical technology and white goods, the IT industry as well as metal processing and mechanical engineering. "Others" include participants from the construction industry, the wood and furniture industry as well as industry-related services.

For a number of companies there is an overlap across several industry sectors. For that reason, mechanical and plant engineering, the automotive industry and electrical and electronic manufacturers were consolidated. The transition is blurred, especially among suppliers with a diversified product portfolio.

Fig. 4 shows that the majority of the companies surveyed are from the metal processing industry and mechanical engineering. Further branches of the manufacturing industry are represented with a total of approximately 30 %.

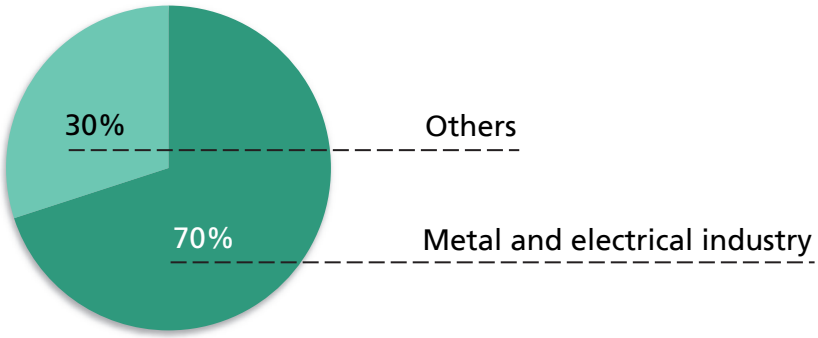


Fig. 4
Industry sectors of the companies involved

2.2 R&D trends, goals and success factors

In the following section, the main results of the trend survey are presented. First, the most relevant trends for R&D are explained. Subsequently, the main goals and success factors in R&D will be described. Finally, relevant factors influencing R&D externally are discussed.

2.2.1 The most relevant trends in R&D

The survey focused on the evaluation of current and future R&D trends in order to draw conclusions about their relevance for the next 2–5 years. The questionnaire allowed respondents to assess the relevance of 38 pre-selected trends from the areas R&D strategy, organization, processes, methods & tools and employees on a 6-point scale with – *None to very low, Rather low, Low, Rather high, High* and *Very high.*

A "Top 2 Box score" (T2B) was used to identify the most relevant R&D trends. In T2B, only the two highest scoring options (*High* and *Very high*) are counted. Fig. 5 shows all trends that were evaluated by more than half of the respondents with either very high or high relevance.

Fig. 5
The most relevant R&D trends according to Top-2-Boxes (as a percentage)

No.	T2B	R&D-Trend
1	78	**Targeted skills development of employees**
2	72	**Development of career paths as a specialist and/ or project manager**
2	72	**Structured monitoring of new trends and technologies**
4	69	**Involvement of customers** (Customer Co-Development, Co-Design)
4	69	**Agile development processes** (Scrum, Design Thinking, Lean Startup, etc.)
6	67	**Creating a unique culture of innovation in R&D**
7	66	**Improving external perception as an attractive employer**
7	66	**Integrated development of products and services**
9	64	**Digitization of all R&D processes** (Workflows, PDM/ PLM systems)
10	63	**Increasing R&D effectiveness** (Better orientation towards strategic goals)
11	62	**Linking R&D stronger with other business units**
12	61	**Modularization and platform concepts**
12	61	**Integrated consideration of business models**
14	59	**Making R&D more flexible** (Internal structures, processes)
15	58	**Lean processes in development** (Lean development)
16	56	**Increasing the consistency and efficiency of all R&D processes**
16	56	**Cooperation with partners within R&D networks**
18	53	**Targeted use of strategic R&D methods** (Roadmapping, etc.)

By using a "Top Box score" (TB), trends were further prioritized. Thereby, only those trends with maximum agreement are taken into account (*Very high*). The trends which more than 30 % of the respondents rated at a very high relevance are shown in Fig. 6.

No.	TB	R&D-Trend
1	36	**Structured monitoring of new trends and technologies**
1	36	**Cooperation with partners within R&D networks**
3	35	**Involvement of customers** (Customer Co-Development, Co-Design)
3	35	**Agile development processes** (Scrum, Design Thinking, Lean Startup, etc.)
3	35	**Increasing R&D effectiveness** (Better orientation towards strategic goals)
6	34	**Targeted skills development of employees**
7	33	**Digitization of all R&D processes** (Workflows, PDM/ PLM systems)

Fig. 6
The most relevant R&D trends according to Top-Boxes (as a percentage)

The seven trends resulting from the TB analysis represent a mix of trends that were ranked relatively high already in the previous study as well as some "newcomers". New trends include *Cooperation with partners within R&D networks*, *Agile development processes* and *Digitization of R&D processes.*

In the following, the seven R&D trends will be discussed in more detail and further information will be provided in the context of R&D management.

Structured monitoring of new trends and technologies

An important competitive factor in times of volatile markets and rapidly changing customer requirements is a formalized and structured technology management. Here, the objective is to identify technological developments at an early stage in order to reduce risks, exploit opportunities and derive measures for strategic R&D planning. Depending on the industry and product life cycles, the time horizon for forecasts is typically up to ten years – in some cases even twenty years or longer. The process of deriving trends and new technologies can be supported by future-oriented research and publications, such as online content from well-known market and technology research organizations (e. g. Frost & Sullivan, Gartner, etc.) as well as several Fraunhofer institutes, including the Fraunhofer IAO. In addition, visits to trade fairs, in-house exhibitions with customers and suppliers, industry networks as well as consulting with external experts can help to generate new knowledge about technological developments and market trends.

In order to formalize knowledge innovative technology management approaches can be applied such as the development and implementation of a technology and trend radar using STEEP[12]. More detailed information on the trends from the radar is documented in so-called trend fact sheets (e. g. technical functionality, illustrations, sketches, experts, contact persons in the company, etc.). Modern software tools can provide additional support here. They allow to streamline the process from data collection to data input (e. g. via the integration of mobile devices) and enhance user interaction through various options for configuration and representation.

A useful overview of the various methods for technology monitoring and assessment is provided in the syncTech publication[13].

[12] STEEP – Analysis of socio-cultural, technological, economic, ecological and political factors.
[13] Warschat, J.; Schimpf, S.; Korell, M. (Ed.): Technologien frühzeitig erkennen, Nutzenpotenziale systematisch bewerten. Stuttgart: Fraunhofer Verlag, 2015.

Traditional approaches to technology monitoring and forecasting such as scenario techniques or trend radar are mainly based on the interpretation of large and poorly structured data. Extracting information is usually done in a manual and time-consuming way (e. g. desktop research, patent analyses, transcribing and evaluating expert interviews, etc.). These aspects make it particularly difficult for SMEs to raise time and financial resources. As a result, it will become increasingly important in the future to make use of new solutions for data collection and evaluation in R&D, such as AI or forms of machine learning.

On the basis of modern software technology and self-learning algorithms, both research and industry have the ability to make trend forecasts more precise and adapt them to their dynamic environment. Self-learning algorithms are based on statistical computer models that are able to recognize data patterns and "learn" from previous events. However, further research is needed to exploit the potential of such anticipatory systems. At first, improved training software for algorithms is needed that serves as a starting point for the "learning" process. It is important to clearly specify the problem that has to be solved by the technology. Therefore, the search area must be defined in such a way that the results of the data analysis allow for a representative statement.

Cooperation with partners within R&D networks

The costs and efforts for industrial R&D as well as the dynamics with which industrial R&D continues to evolve are constantly on the rise. It is therefore becoming more and more important to ensure flexible access to knowledge and capabilities outside of the own organization. Furthermore, investments in radical innovations and the development of key technologies require additional effort and lead to R&D alliances – in some cases even with competitors.

Forms of cooperation range from technology procurement and "ordinary" R&D collaborations to the development of shared R&D facilities, including test environments. In the past, collaborations between partners with similar levels of vertical integration have emerged. In recent years, however, the importance of alliances between manufacturing companies and suppliers, external research institutions and, in particular, start-ups has increased significantly.

The choice of the form of cooperation and the partners depends heavily on the objective that is pursued with the partnership. The objectives of companies engaged in R&D cooperation are typically access to resources and domain knowledge, expansion of existing capabilities, minimization of risk and faster development cycles.

Besides the benefits of cooperation, it can also involve various risks. Challenges such as intercultural differences as well as inefficiencies caused by improperly defined property and exploitation rights are relevant aspects to be considered. This applies both to the know-how introduced into the cooperation by the respective partners as well as to the knowledge generated during the collaborative R&D activities. Here it is essential to establish a legal framework in the initial phase of the joint venture.

As global collaboration increases, so does the proportion of people and teams that need to work together across different locations and time zones. This requires both effective project management and IT support through web meetings and virtual collaborative R&D tools.

Various tools and systems are currently being developed and offered to support virtual collaboration (e. g. Smartsheet). The benefit of these solutions is that users can edit data objects simultaneously online without losing information. File changes and access are stored in different versions and can be tracked by other users.

Involvement of customers into the development process

Successful companies with continuous growth have a fundamental understanding of the needs of their customers, involve them strongly in the process of problem solving and inspire them with innovative solutions based on articulated and non-articulated needs. Hence, an R&D process that focuses on customer feedback is of elementary importance. This can be achieved through focus groups, customer surveys, lead user workshops as well as online surveys. Online developer platforms and user conferences allow potential end users to become directly involved in the development process.

However, obtaining customer feedback using traditional methods is very time-consuming and often does not provide accurate information. Focus groups, for example, are resource-intensive and the results can be highly subjective. Customer surveys also come at a considerable financial expense and it is often difficult to obtain statistically relevant results. In addition, both methods rely heavily on the skills of the interviewer. Online surveys usually require a considerable amount of time for preparation, distribution, data collection and evaluation.

Trending are participative methods and approaches such as design thinking or co-creation for systematically obtaining customer feedback. While the former is oriented towards the observation of user behaviour, for example by means of "netnography", the latter involves the end users directly into the design and development process. This creates synergies and saves costs for market research activities. As an example of this, company-initiated idea and design contests are used, in which users can submit their ideas. Together with the originator of the idea, the most successful proposals will then be implemented as prototypes. In addition it is possible to involve customers and suppliers more closely in the development process by engaging in on-site activities such as the development of integrated digital solutions or IT services.

More and more start-ups emerge that deal with customer-oriented data mining solutions. The solutions provided are mostly compatible across a wide range of industries. One of the challenges is to clean data sets from irrelevant data and correctly interpret statistical events. It is for example necessary to verify whether data used for evaluation originates from a "person" or was generated by computers. The semantics and emotions transported in the statements of individuals also still pose a challenge for AI.

In this context, a group of scientists at the Fraunhofer IAO in Stuttgart is currently working on neuro-ergonomic topics to improve technical design. In the process, researchers measure brain activity to draw conclusions about customers' feelings when using different technologies. The findings are then used to improve the usability of technical devices.[14]

Agile development processes

Agile development processes are often the focus of attention when it comes to managing dynamic business environments and rapidly changing customer demands. Agility in R&D means moving away from linear and long-term R&D program planning towards a more iterative and adaptive approach. This new approach to planning enables project teams to operate successfully in complex and dynamic environments and to initiate innovative solutions.

Instead of inflexible line structures and tightly structured work packages, agile teams perform so-called "sprints" in clearly defined time windows. At the end of each sprint, the team evaluates the progress made and plans a subsequent iteration loop. Agile development requires clearly defined roles and high levels of initiative and responsibility among employees and teams. Further nonlinear development concepts are Scrum, Design Thinking, Lean Startup and Kanban. Some of these methods can even be combined (see Gartner[15]).

The practicability of agile concepts varies widely between the different business areas. In software development where this concept originates from, agile methods are typically easier to implement than in R&D where complex physical products are prevalent. In addition, hierarchical structures and thinking as well as low flexibility in the organization prevent agile concepts from being successfully implemented. Agile thinking and interacting goes hand in hand with a cultural change in the organization. Processes and decision-making mechanisms that used to be static in nature must become more flexible and employees and managers must be trained in agile working principles. Subsequently, first projects can be rolled out in which the participants obtain the opportunity to apply and gradually improve their newly acquired methodological competence.

Increasing R&D effectiveness

"One can run highly efficiently into the wrong direction" – R&D effectiveness therefore plays an important role for strategic R&D. In the past, companies have made great efforts to streamline their R&D processes to become more flexible. Especially in technology-intensive companies, however, it is essential to constantly question whether R&D is currently "doing the right things".

The development and communication of an R&D strategy initially serves as the basis for increased R&D effectiveness. It should be based on the corporate strategy and include the R&D activities necessary to achieve strategic goals. Furthermore, future market and technology development should be taken into account in order to adequately address both opportunities and risks in the R&D

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[14] Available online: https://www.iao.fraunhofer.de/lang-en/collaboration/labs-equipment/1250-neurolab-laboratory-for-neuroscience.html. Access on 15.11.2019.

[15] Available online: https://www.gartner.com/en/documents/3200917. Access on 15.11.2019.

strategy. In this regard, strategic planning tools such as roadmapping or portfolios can provide the necessary support.

As SMEs have limited R&D resources, one particular challenge is strategic orientation and effectiveness. Often the responsibility for long-term planning as well as the assessment of future technological developments lies solely in the hands of a single person, e. g. the managing director or owner. Thus the decision-making is primarily based on personal belief rather than on a critical reflection of the situation from a wider group of people.

In order to make informed decisions and thus ensure long-term success of the company it is necessary to define strategic goals for R&D, provide guidelines for the selection of R&D projects and define responsibilities for observing relevant fields of technology. This results in a mutual understanding of long-term goals and the competencies and resources required to achieve them.

Targeted skills development of employees

Competences are cognitive skills and capabilities of people to solve problems or cope with variable situations.[16] In other words, competence is a combination of "knowledge" and the ability to apply this knowledge in a problem-solving way. This is a major challenge for skill development of employees as the training of specific abilities requires targeted actions. In this context, targeted skill development means the combination of different measures to influence the skills of individual employees and teams.

Stronger demand for the development of employee competences in R&D are the result of increasing global competition and digitization. For many German companies the high degree of innovation of their products is the most critical success factor – that is the problem-solving capabilities of their R&D employees. For example, the automotive industry and its suppliers face the challenge of evolving their traditional R&D capabilities such as design and engine development towards alternative powertrains, autonomous systems and new mobility services. As a result, the demand for specialists in the fields of mechatronics, electrical engineering, sensors and software development is increasing.

There are many possibilities in competence management to meet new requirements such as targeted employee training, team-building activities, mentoring and professional coaching. New concepts for skills development make use of web-based and interactive learning concepts. Through virtual interaction between the learning community on the one hand and knowledge providers on the other, new skills can be developed in a more flexible and scalable way. Online learning platforms and individual learning modules, for example, have become increasingly popular. Employees can build up competences independently based on individually designed development plans.

[16] Weinert, F.E. (Ed.) Leistungsmessungen in Schulen. Weinheim: Beltz (2001) pp. 17-31.

Digitization of all R&D processes

Digital continuity in R&D processes is an essential success factor for efficient and target-oriented R&D. The objective is to ensure that all data associated with the product is maintained by a single R&D platform and that all relevant stakeholders have access to it. This includes data from development, testing and production but also data that is generated during the product lifetime.[17]

Ongoing digitalization offers new opportunities to digitally represent complex processes and large amounts of data that are generated during product development. In this way, complex projects can be broken down into subtasks with lower complexity. They can then be implemented as part of a uniform, team-oriented and structured process. Ideally, the entire product life cycle is considered – from conception to operation and in some cases even to end-of-life. Therefore, it is vital for companies to maintain an IT infrastructure that is able to handle data across various modular systems and track adaptations of product specifications.

Support is provided by end-to-end, bidirectional product data management (PDM). Hereby, the use of simulation tools enables product functions to be validated quickly and cost-effectively. This involves a digital representation of the physical product (digital twin) which contains data from the engineering process as well as real-time data from usage. In the coming years, great potential for improvement of these systems is expected through the use of AI which allows to detect patterns or anomalies in large multi-variate data sets.

Another important aspect is the level of digital competence of R&D employees. The introduction of new digital working practices and supporting IT tools requires the early involvement of employees. Ideally, the affected employees are already involved in the process design and definition of workflows in order to promote both digital and consistent work routines. Thereby, technical problems can be approached holistically and system-oriented solutions can be developed.

Summary

The seven R&D trends that were rated as the most relevant by the participants provide a balanced representation of the five R&D areas as presented in Chapter 2.1.1. R&D methods & tools are particularly prominent this time (*Structured monitoring of new trends and technologies*, *Involvement of customers into the development processes* and *Digitization of all R&D processes*).

From the trends identified, *Cooperation with partners within R&D networks*, *Agile development processes* and *Digitization of all R&D processes* made it into the "top 10" for the first time. These topics were also discussed in great detail among our R&D experts in the interviews (see Chapter 3). Furthermore, there is a large number of consulting services on the market for agile training and the digitization of R&D and business processes. Stronger external orientation of R&D is currently trending in manufacturing and provided the motivation for initiating an R&D network project at the Fraunhofer IAO.

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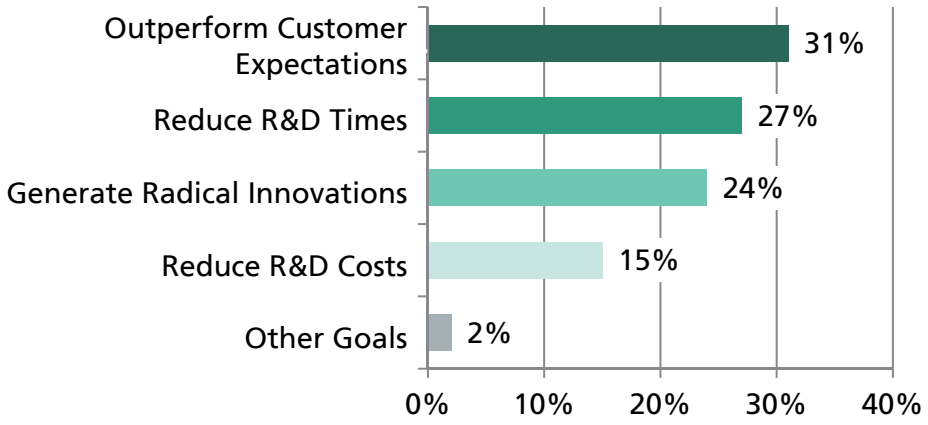
[17] McLean, M.; Davis, B.H. (Ed.): Time and Bits: Managing Digital Continuity. Getty Research Institute, 1999.

2.2.2 Goals in R&D

When asked which the most important R&D goals are, outperforming customer expectations was the main goal to almost one third of the respondents. Reducing R&D times as well as R&D costs were ranked with 27 % and 15 %, respectively. For about one in four participants their main goal in R&D is to generate new and radical innovations. Only few R&D experts do not pursue any of these R&D objectives. Multiple answers were allowed in the survey. Fig. 7 provides an overview of the results for the most important R&D objectives.

Fig. 7
Most relevant goals in R&D



The results show that in addition to optimizing traditional target parameters such as time, cost and quality, the focus of R&D activities increasingly shifts towards generating new and radical innovations.

This type of innovation refers to a completely new technology or idea that emerges from the interdisciplinary interaction of different areas and solves problems in a completely new way. It primarily occurs when experimental activities take place and new unproven methods are used to develop prototypes and solve problems.[18]

According to the experts, in R&D practice there exists a so-called "mix of goals" in which the following objectives are targeted:

- Filling the roadmaps of current businesses
- Disrupting current markets
- Creating new markets next to existing ones
- Creating new ones with breakthrough technology.

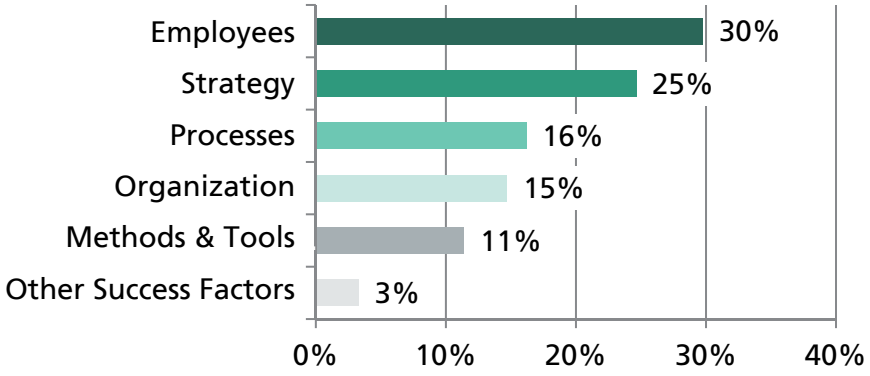
[18] Bundesministerium für Bildung und Forschung/ Federal Ministry of Education and Research (BMBF) (Ed.): Research and innovation that benefit the people: The High-Tech Strategy 2025. Available online: https://www.bmbf.de/en/the-new-high-tech-strategy-2322.html. Access on 15.11.2019.

2.2.3 Success factors in R&D

Success factors typically have a causal relationship to the success of companies. In most cases, these factors can be directly impacted by organizations (e. g. product quality, innovation capability). In contrast, influencing factors impact businesses externally (e. g. political or economic factors, social trends). These factors should be closely monitored and considered during decision-making.

The participants were asked which of the areas – R&D strategy, organization, processes, employees and methods & tools - they consider most important for successful R&D. Multiple answers were allowed in the survey. Fig. 8 illustrates the results and lists the most relevant R&D success factors in descending order.

Fig. 8
Most relevant success factors in R&D



The results clearly reflect that a coordinated R&D strategy and employees capable of practically implementing that strategy are among the most relevant success factors. It is therefore not surprising that most free text entries confirmed these two factors. In the area of R&D strategy, the respondents were advocating stronger customer orientation, the development of new business models and increased R&D cooperation. The willingness to support change and being enthusiastic about new work tasks were repeatedly mentioned for employees.

2.2.4 Influencing factors

Influencing factors define external factors that have a direct or indirect influence on the company's success. These factors can cover a wide range of sectors such as social, technological, economic, ecological and political (e. g. demographic development, interest rate policy, etc.).

Participants of the study were asked to name the most relevant factors influencing R&D within the next ten years in a free text. The respondents had the opportunity to give multiple answers. Fig. 9 shows the five most frequently mentioned influencing factors.

The results show that access to skilled workers remains the major challenge for manufacturing companies. SMEs in particular often have a low visibility on the job market and therefore receive only a small number of qualified applications. Joint projects between SMEs and research institutions or universities can provide a valuable strategy for SMEs to gain access to young talents early on.

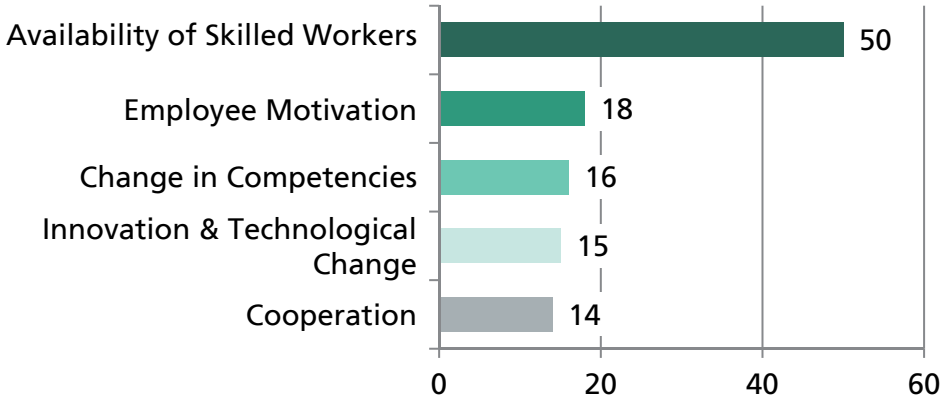


Fig. 9
Most relevant influencing factors on R&D

Having an innovative corporate culture and a CEO who lives these values on a day-to-day basis provides the groundwork for passionate and productive employees. Also, the perception of the company's innovativeness from the outside has a direct impact on the access to talent. Companies that are perceived as highly innovative environments, such as SpaceX, Tesla or Google, can pick from a large pool of applicants and attract the most talented people.

2.3 Summary

In the previous sections, the most relevant R&D trends and goals as well as success and influencing factors were presented. In the following, the key findings of the study will be summarized briefly.

Developing the skills of employees in a targeted manner is one of the most relevant factors in R&D. From a strategic perspective, collaboration with external partners within R&D networks or so-called innovation ecosystems is of high importance. In order to adapt to changing customer requirements and dynamic markets, agile development processes provide the necessary flexibility. Involving customers into the development process minimizes risks and saves costs. Future R&D will also require more digitized R&D processes such as virtual simulation models. The effectiveness of strategic R&D can be improved by synchronizing R&D goals with the overall strategic corporate goals and also by carefully monitoring new trends and technologies via a structured process.

Besides optimizing target parameters – time, cost and quality - the new focus of R&D is on generating new and radical innovations. However, for R&D departments this presents both a very desirable goal but also one that is extremely difficult to plan and predict.

A coordinated R&D strategy and employees that are capable of practically implementing this strategy are among the most relevant success factors. Access to specialists who are compatible to new competency profiles as well as an innovative environment that positively affects employee motivation are among the factors that enable competitiveness.

Competent and well-motivated employees are therefore not only a cost factor, but more importantly, one of the key elements in successful industrial R&D.

3
Case studies

In order to anticipate future developments and technological trends, R&D departments of manufacturing companies follow different approaches. During interviews, R&D experts from a number of globally operating companies give their opinion on the plausibility of the results of the study and report exciting insights from R&D practice.

3.1 Technology & Innovation Management at Siemens

Dr. Norbert Lütke-Entrup is **Head of Technology & Innovation Management** at **Siemens AG**.

Dr. Lütke-Entrup supports the research activities of Siemens as Head of Corporate Technology by identifying so-called "Company Core Technologies" and their implementation in corporate networks. In total, there exist 14 networks in areas such as Data Analysis & AI, Cyber Security or Additive Manufacturing processes. Dr. Lütke-Entrup is also responsible for business support for standardization and technical regulation as well as the engagement of Siemens with innovation policy makers.

Fraunhofer IAO: *What is your opinion on the R&D trends identified?*

Dr. Norbert Lütke-Entrup: The weighting of the various trends is debatable. One major trend is the increased use of digital technologies in the R&D environment. For example, complex technical systems are no longer developed without being simulated comprehensively. Materials are also being developed more and more "in silico" rather than "in vitro". Data analysis and big data approaches are also becoming increasingly important for R&D. Engineers are thus increasingly expected to confidently master these and other digital tools.

However, since innovation cycles become increasingly shorter and product development processes become less fragmented and sequential, successful R&D employees require more than only technical skills. They are expected to have a basic understanding of business strategy – including the ability to think in terms of new business models and to commercially exploit new technologies. Part of this is also to outline new business ideas or understand and communicate possible effects of new technologies on the corporate strategy as well.

Since it is rare for a single R&D employee to have such a broad range of competences, working in interdisciplinary teams is becoming increasingly relevant. Rather than simply implementing roadmaps from the management, R&D employees are enabled to actively participate in the development of business, innovation and subsequent market implementation.

Agile development processes will be increasingly used. Strategic planning of projects is done less and less over a long period of time (e. g. several years). Nowadays, targets are defined in an increasingly agile way and more frequently during the course of the year. Development projects are implemented in so-called "sprints" that typically only take a few weeks. After each "sprint", the results will be evaluated and follow-up activities will be defined. Agile is not limited to software development, but can also be applied to the development of hardware components.

External networks help to identify new trends and technologies more than an internal, structured monitoring process. Therefore, the company has to be well networked to receive the right impetus. For example, at all times Siemens is involved in more than 100 pre-competitive collaborative research projects. In addition, the company gains close insight into start-up companies worldwide through its in-house venture capital unit "Next47". However, there is no systematic mapping of all identified trends in the form of a radar, but instead the focus lies on the rapid exploration of individual trends.

Expert careers are sufficiently established at Siemens. These enable technically brilliant employees to progress in their careers without necessarily having to switch to a management position.

The involvement of customers into development processes plays an important role. This is not always easy because the "Tone from the top" is also a critical factor here. For this form of cooperation, often referred to as "co-creation", there exists a growing number of reference projects. This is especially the case for the digital sector, where Siemens is developing digital applications and solutions in "Mindsphere Application Centers" together with customers on site.

Cooperation in R&D networks, for example with research partners such as universities and research organizations, is highly important and should be ranked further up.

IAO: *What are your overall R&D goals?*

Lütke-Entrup: Innovation is not only about meeting customer expectations, but mainly about triggering and satisfying new customer needs. For the company, it is the primary goal to develop a digital portfolio of technologies, applications and business models in order to offer customers completely new opportunities for value creation. Guaranteeing the availability of high-speed trains as part of a performance contracting is an example for this. Monitoring of trains is performed, supported by data analysis, to ensure that any imminent malfunctions are detected well in advance and are prevented from happening. In this way, a traditional service is evolving into a completely new type of value creation with technology as the key driver. A modern R&D department should focus on identifying and promoting such development paths.

However, for R&D departments targeting radical innovations is only of limited use. Even if we are able to identify radical innovations in time and demonstrate their potential accordingly, market implementation remains a strategic decision.

Especially if the innovation cannibalizes existing business. This type of innovation is primarily of concern to the management. We, as an R&D department, can only provide technical advice. But if necessary, we are responsible for the implementation at a later stage.

Another aspect of R&D goals is agility. Today, a linear process where a product is developed and introduced to market according to predefined specification is no longer feasible. The reason is, that by this time essential product requirements might be outdated. Development "in foresight" is therefore becoming increasingly important, and processes and methods in R&D must provide sufficient freedom to operate. Therefore, the continued development of agile structures and processes is another relevant goal in R&D.

IAO: *What do you consider the most relevant success factors in R&D?*

Lütke-Entrup: The ranking of success factors is in line to what we experience. Ultimately, skilled employees are needed, both strategy and R&D must be synchronized, and processes must be geared towards agility, time-to-market, etc.

IAO: *Which influencing factors have the greatest impact on R&D?*

Lütke-Entrup: The influencing factors can best be summarized under the collective term "Future of Work". Nowadays, young employees have a desire to work differently than their parents. They have a very strong motivation to realize their own ideas instead of implementing specifications according to plan. They not only expect the freedom to operate from their employer, but also its support. They also demand a certain degree of flexibility in their own work and appropriate equipment with suitable devices to enable forms of mobile work. The way of communication is strongly influenced by WhatsApp and Facebook. Overall, the young generation has a stronger desire to get involved with their own ideas and to be engaged in a modern working environment. Companies have no other choice than to deal with these expectations.

3.2 Research Management at Testo

Dr. Axel Gomeringer is **Head of Division - Research** at **Testo SE & Co. KGaA**.

Based in the Black Forest, the company offers high quality test and measurement equipment for heating, ventilation, air-conditioning, and refrigeration. With around 3 000 employees worldwide, Testo SE & Co. KGaA works on innovative and smart solutions. These include cloud-based measurement data monitoring systems or devices that can be operated via smart phone, such as the Smart Probes.

Fraunhofer IAO: *What is your opinion on the R&D trends identified?*

Dr. Axel Gomeringer: The results presented in the study largely reflect corporate practice. In practice, however, these are not perceived as "trends", but rather as general challenges. We are intensively involved with the topics of competence development and specialist careers. In addition to the human aspect within the company, we see great potential in customer involvement in R&D processes. This raises the question of the distribution of roles and responsibilities in the company. Product managers and researchers must cooperate more closely with each other. Tight collaboration requires knowledge and information exchange not only within but also between departments. Product managers, who are traditionally closer to the customer, should be aware of new technological developments and discuss them with the customer. The same applies to R&D managers working on new technologies. In this regard, it can be helpful to involve product managers at early stages of research projects in order to consider the customer benefit right from the start.

IAO: *In your opinion, are the R&D trends complete?*

Gomeringer: When it comes to resource allocation, there is the question of prioritizing activities. Market relevance is crucial not only at the early research stage but especially at the time of the product launch. Here, many different factors play an important role. Interaction between product and business development, between technical and visual design as well as ensuring that the product meets the market requirements are among these factors. It must further be assessed whether the new technology can achieve competitive advantages in the market and whether the advantage is significant enough to justify R&D spending. Putting effort on things that ultimately end up providing insufficient market potential does not make a lot of sense. R&D must pay off.

IAO: *How do you integrate trends into R&D practice?*

Gomeringer: As part of an established process within the company we identify research topics and new technologies through scouting activities, scanning on conferences, and cooperation with universities and research institutes. Insights

gathered through this process are subsequently mapped onto our trend radar. The radar provides the basis for initiating follow-up scouting projects. Afterwards, we take a closer look at the topics, carefully analyze and finally summarize them in a report. On this basis, we generate plausible results and are able to make informed decisions about new technology projects.

IAO: *What other trends appear on your radar?*

Gomeringer: R&D will continue to focus on digitization. Digital processes are rapidly evolving and will increasingly penetrate R&D processes. From a market perspective, sustainability plays an important role. This is a great opportunity for Testo's measuring instruments group. Particle measurement technology and technology for measuring exhaust gas emissions are already an integral part of the sustainability debate today.

3.3 Innovation Management at Evonik

Dr. Daniel Witthaut is **Head of Corporate Innovation Strategy** at **Evonik Industries AG**.

Evonik is one of the leading companies in specialty chemicals. As Head of Corporate Innovation Strategy, Dr. Witthaut is responsible for supporting the Evonik Executive Board in guiding and steering the Group's innovation activities.

Fraunhofer IAO: *What are the objectives of your R&D?*

Dr. Daniel Witthaut: The objectives of our innovation activities are twofold. On the one hand we aim to maintain our very strong competitive position and on the other hand we strive to generate additional sales and profit growth through innovations. Radical innovations or as we call them internally, "transformative innovations", are of particular importance if we are to surpass market growth. Transformative innovation projects happen in fields with a high degree of uncertainty and are therefore particularly challenging. In an effort to improve the way these innovation projects are managed and to increase their chances of success, we recently set up a program called "Create Innovation". The goal of this program is to either increase the success rates of projects with a high degree of uncertainty or to cancel them early. Here, the focus lies on learning how to cope with uncertainties – which means learning to act in a flexible and quick manner.

IAO: *Do you consider transformative innovation as your main R&D goal?*

Witthaut: No. The main goal is to maintain our competitive advantage. To do so, incremental innovation remains relevant. Around 70 % of innovations are still incremental. However, growth requires radical innovations. To put it more simple, incremental innovation can help maintain competitiveness over time, but in order to outperform the market, considerable resources must be allocated to activities that have the potential to result in transformative innovations.

IAO: *What is your opinion on the R&D trends in the survey?*

Witthaut: The innovation culture in R&D is very important. Despite it being an essential success factor in R&D, innovation culture is not yet very well established in many companies. For example, the "German Chemical Industry Association" has found that often the biggest obstacle to innovation is a lack of innovation culture within the company. This includes risk aversion, an absence of a learning culture, dealing with mistakes, and also overcoming failures. At Evonik, we have a number of initiatives to ensure a nurturing innovation culture. An example is our annual "Innovation Entrepreneurship-Award". Here, we in-

vest time and money in the advancement of our employees' ideas and concepts. We also honor employees who are on the verge of introducing their product, process or business model ideas to market. Evonik further involves customers into R&D processes and monitors trends and technologies in a structured manner. Concerning targeted skill development Evonik offers an expert career path to R&D employees, running in parallel to the management career path.

IAO: *What other trends play a role, especially in your industry?*

Witthaut: Increasing complexity, volatility and speed are shaping the world. In consequence the challenges, especially in terms of sustainability grow. From this perspective, I see that transformative innovations emerge in particular from so-called innovation ecosystems. By innovation ecosystems, we understand multilateral cooperation with technology providers, customers, suppliers and other experts along the value chain. As a result, risk of failure can be reduced and speed increases. I believe innovation ecosystems are a trend with increasing importance for the chemical industry and beyond. Finally and as part of innovation ecosystems as well as on a general note, collaboration with start-ups gains importance.

IAO: *Which trend do you think will be most important in the future?*

Witthaut: For me personally, employee development is the most important aspect. Working in innovation ecosystems or cooperating with start-ups, can only be realized if we involve our employees in all relevant change processes.

3.4 Research & Innovation Management at NCC AB

Prof. adj. Dr. Christina Claeson-Jonsson, is **Head of Research & Innovation** at **NCC AB**.

NCC is one of Scandinavia's leading construction and real estate development companies with a turnover of almost SEK 57 billion and 16 300 employees. NCC is engaged in the development of commercial real estate and the construction of housing, offices, industrial facilities, public buildings, civil engineering and other infrastructure. In addition to her work at NCC, Prof. adj. Dr. Christina Claeson-Jonsson is an adjunct professor at the renowned Chalmers University of Technology.

Fraunhofer IAO: *Do you consider the outcome of the study plausible?*

Prof. adj. Dr. Christina Claeson-Jonsson: I agree with the results. In some cases the ranking does not fully correspond to what we have in the construction industry but I think you have captured the most relevant trends. In particular, I appreciate that the human factor plays a central role. It is important for companies to recognize that the shortage of skilled workers must first and foremost be countered internally through targeted skill development. The focus shifts to the development of internal resources.

IAO: *How do you increase the competence base, also on an interdisciplinary level?*

Claeson-Jonsson: There is need for more collaboration. This includes subcontractors, universities, material suppliers and even our competitors in some cases (e.g. in health and safety). In Sweden there exists a private fund for research and development for contractors to which they pay a certain amount as a result of a union agreement. At the moment, we are involved in several cooperation projects with competitors in order to increase the competence base for the whole sector. In the public sector, clients are a little bit reluctant to demand a certain type of quality solution if only one supplier can meet this request. This is because it is their job to get the most value for the money. If we can increase the competence level overall in the sector, including us, public clients will eventually ask for higher competences. Later, we as a company, can use these skills as a competitive factor. For us that is very important. We do that within the construction sector where we cooperate with companies in order to raise the overall competence of the sector, and within the area health and safety, however, health and safety is something we do not compete on because we say you should never compete on health and safety, instead we try to share experience and we do a lot of collaborative work together.

In construction, safety on site is a huge issue, as construction is a rather dangerous profession. Therefore, we need to increase safety on site. And this is why we need to design our sites to use selected technologies when possible without violating union rules or any associated legal restriction.

IAO: *What is the main driver in optimizing safety on the sites?*

Claeson-Jonsson: I think we need to use technology better, we need to change behavior, and we need to change the processes. So it is the awareness and the way you handle risk. You should never put a person in danger when you try to optimize costs.

At this point, I think, that the human machine interface such as Augmented and Virtual Reality (AR and VR) becomes increasingly important. The majority of our customers comes from industries apart from the construction business. They often find it difficult to read technical drawings and to imagine the realization of technical designs. This frequently leads to diverging expectation between customers and developers. By using AR and VR, technical drawings can be visualized in a vivid way, thus lowering barriers and improving the coordination process. This makes planning processes more efficient and minimizes uncertainties. We also use VR technologies for safety training. By visualizing the construction sites employees can familiarize themselves with the special features of a construction site before entering the first time. This makes it possible to raise awareness of potential sources of danger and to train appropriate risk prevention measures.

IAO: *What do you consider the greatest success factors in the construction industry?*

Claeson-Jonsson: Digitization is probably one of the biggest areas of potential. While many other industries are embracing digitization, for the construction industry it remains a struggle. Typical influences such as debris, dust and climatic influences put special demands on the use of mobile devices, equipment and user interfaces which decreases the applicability of some technologies. However, we employ drones for tunnel construction, for observing the status quo of large construction sites as well as to support the risk assessment for a construction site. In some cases, so-called "enabling technologies" such as robots or 3D printing processes are already implemented.

IAO: *What challenges do you deal with at the moment?*

Claeson-Jonsson: In order to succeed we have to attract motivated people from different backgrounds and genders and generate an environment in which the motivation sustains. When talking about gender diversity, we still see few women in the construction business. Not only that, at least 50 % of the customers are women, but we have to intensify our efforts in attracting female workers. We see a decisive competitive advantage in making the construction industry more diverse. This does not exclusively apply for women but for workers of all races and ethnicities. In order to do so, we must provide flexible working models to all our employees. As an example, the Nordic countries allow parental leave for parents regardless of their gender, and we see that fathers stay home while the mothers work. As a company, we have to ensure that we support alternative work modes. By establishing an attractive working environment and to have a diverse mix of employees ultimately benefits the company, as it provides the best environment for innovation and the future.

3.5 Managing Electrical Drives in Asia-Pacific

This interview reflects the answers of **Dr. Norman Roth, Regional President Asia Pacific** for the **Electrical Drives Division** of the **Bosch Group**.

The Bosch Group is a leading global supplier of technology and services. Its operations are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology. As a leading IoT company, Bosch offers innovative solutions for smart homes, smart cities, connected mobility, and connected manufacturing.

Electrical Drives is part of the business sector Mobility Solutions. It offers a wide range of innovative and energy-efficient electromechanical components and systems. They include motors and drive systems for convenience features such as window lifters, seat adjustment, and sunroofs, powerful servomotors for electric steering, ABS, ESP®, and other applications in the engine compartment, and front and rear wiper systems including wiper blades. There is also a comprehensive range of products for engine thermal management, including engine cooling modules, pumps, valves for cooling systems, and air-conditioning fan components. Drives and systems for new mobility solutions such as e-bikes and e-scooters complete the portfolio.

In his position as regional president of the Asia-Pacific region of the Electrical Drives division, Dr. Norman Roth has responsibility for the management and sales of around ten locations in India, Korea, Japan, Thailand (ASEAN) and China.

Fraunhofer IAO: *Do you think the results of the survey are plausible?*

Dr. Norman Roth: The results certainly include the most important trends, goals, influencing and success factors. Since the study was not designed for one particular industry sector only, the results remain fairly universal. If this had been the case, the responses would have been more sector-specific.

Within the Asia-Pacific region, the trends demonstrated slightly differ: In Japan, for example, the competence level is relatively high. Countries such as Thailand, Vietnam or Western China, on the other hand, show a distinct lack of competence. These countries need to catch up. The same applies to the fulfilment of customer expectations and shorter development times. In China, it is crucial to enter a market with a good product as early as possible, while Japanese automotive manufacturers have to respond to one of the most demanding customer segment when it comes to technology. Here, excellence is key. India's automotive market, in contrast, has the lowest prices worldwide, i.e. development costs have to be as low as possible.

Another interesting aspect is the topic of cooperation. Traditional supplier-customer relationships, as we know them from the past, will no longer exist in the near future. Autonomous driving, electrification, and connectivity extremely complex fields, which are already embedded in a complete ecosystem. Often these domains are already embedded in a complete ecosystem.

Today we are already in a situation where a partner can be customer, supplier, and competitor simultaneously. In consequence, one can easily imagine that there will be an increasing demand for intelligent cooperation models. As it is not always easy to collaborate with a partner who is both customer and competitor, compliance will grow in importance.

IAO: *What is your recipe for successful cooperation models?*

Roth: This topic can certainly be discussed extensively and there is no short answer. So no, I don't have a recipe, but allow me to provide some guidance:

1. First of all, a so-called "strategic fit" must be ensured. The question of what each partner can contribute in a cooperation must be carefully discussed and well understood.

2. Based on my experience, it is important that the basic corporate philosophy, mission, and vision fit well together. For example: A long-term operating company like Bosch could quickly find itself in a conflict of interest with a partner focusing on short-term profit maximization.

3. The form of cooperation must be clearly defined. There exist many different cooperation models ranging from acquisitions, joint ventures to simple (strategic) partnerships. The form of cooperation should be chosen carefully in accordance with the framework conditions and requirements of the partnerships.

4. In my opinion, one of the most underestimated issues is the legal aspect of partnership models. Topics like product liability and compliance have become increasingly important and therefore cooperation agreements have to be defined very carefully. Even small inaccuracies in contracts can lead to considerable frustration and costs.

IAO: *Do you agree with the statement that standardization is an effective tool for reducing complexity?*

Roth: Here I would like to refer to the so-called Stacey Matrix. The Stacey Matrix visualizes appropriate management actions in complex systems, based on the level of agreement and the degree of certainty. Here the level of agreement is defined by pre-set requirements and the degree of certainty refers to the certitude of technologies, tools, and methods. R&D tasks can be well standardized in those areas, where requirements are fully accepted and the required technologies, tools, and methods are perfectly clear. In areas with dynamic requirements and high uncertainty (such as the consumer goods industry), more agile and less standardized approaches make sense. All in all, I think that we should standardize processes, methods, and tools much more in R&D activities.

IAO: *What do you think are the trends of the future?*

Roth: IoT, connectivity, electrification, autonomous driving, and individualization of products and services are among the big trends in our industry. The use of data is also of great importance. In the Asia-Pacific region, you often hear people say "Data is the New Oil". AI is one of the most frequently discussed topics at industry conferences and symposiums. Our plants increasingly demonstrate pilot applications and Bosch places great emphasis on the whole topic. However, we have yet to see widespread application, but it will certainly come.

The digital transformation associated with Industry 4.0 applications is well on its way to becoming the industrial norm at Bosch. All our plants in Asia-Pacific are working intensively on this topic. From my understanding the use of "digital twins", i.e. virtual images of factories, additive manufacturing, and big data analytics qualify as Industry 4.0 applications. At the same time, we are also developing smart products that can be controlled electronically using various software. Obviously, IT security plays a major role here.

IAO: *What is your opinion on the success factors identified?*

Roth: From a practical angle, I agree on the success factors, such as employees, strategy, and processes. Our employees form the basis of our strategy map, and I believe that this will remain the case in the future. The "war for talent" is in full swing, i.e. we believe that we need the best team to be the best on the market. Strategy is also crucial. It is important to bear in mind the big picture and to be aware of the unique selling propositions of our products or services. And of course it is also important to continuously improve them. From a strategic point of view, the markets must again be differentiated by region. In China, the strategic planning horizon is rather short and adjustments are required frequently. Here, we are living certainly more in a "VUCA" world than, for example, in Central Europe. In Germany and Japan our planning horizon ranges from medium- to long-term and South Korea is somewhere in between.

IAO: *What is your opinion on our R&D trends?*

Roth: As I have mentioned before, the study includes the most relevant trends. In my industry I see IoT, connectivity, electrification, autonomous driving, and individualization as the most important trends. Presumably, the involvement of customers into the development process in B2B has to be ranked higher than demonstrated in the study. In order to avoid R&D teams to put great energy into re-engineering solutions that already exist, requirements need to be carefully analyzed together with the customer, from early on. This applies especially to very complex projects.

I would also rank agile development processes higher. Especially in large corporations and in areas with high uncertainty with regard to technology/ methods and changing requirements (see note on Stacey Matrix above), this is very important. Processes must be adapted to market dynamics. One promising approach is to institutionalize short improvement cycles. To me, this means following up on the idea of agile development by doing short, highly frequent sprints and simultaneously developing various technical alternatives. As a team, you can then agree on the best alternative.

3.6 R&D Management at Danfoss A/S

Fabio Klein is **Head of Research and Development** at **Danfoss A/S – Commercial Compressor Business**.

Danfoss is one of the leading companies in the field of heating/ cooling technology, control and drive systems, gas compressors and frequency converters, with headquarters in Denmark. Mr. Klein is responsible for global R&D of scroll/ piston compressors and condensing units with teams located in France, China, US, Germany, Brazil and India.

Fraunhofer IAO: *Do you feel that the identified trends reflect the situation your company is in?*

Fabio Klein: Yes, I agree with the results. Up to this point, I have taken part in various surveys, but this is the first time that the role of the people has been so clearly positioned as the top priority. Of course, the importance of the employees is always a point of discussion, but it is the first time I see a study indicating it so clearly.

I enjoy seeing that the "war for talent" is a central finding. Developing our own talents instead of just recruiting them is increasingly important to us. I regularly ask myself the question: How do I manage to put together the right mix of employee skills, both from a technical and a business point of view?

IAO: *Which influencing factors do you consider critical in order to succeed in the "war for talent"?*

Klein: Increasing product lifecycles are challenging our reaction capability. Until recently, technology roadmaps were set up with a time horizon of ten years. At present, the market changes at a faster pace, which challenges us to think in shorter planning cycles. Real-world predictions that exceed a timeframe of five years are hardly feasible. Consequently, we need employees that work with foresight and are able to flexibly adapt to new situations. It is difficult to find specialists with such skills on the job market, especially since companies try to protect their highly skilled employees.

IAO: *How do you deal with the qualification of your workforce?*

Klein: We have internal projects for the targeted development of highly qualified employees. This is part of our talent management. Here we develop training plans tailored to the individual. In this course of action, we strengthen the profile of our talents, challenge, recognize and support them while providing our employees a platform to gain visibility in and outside the company.

IAO: *Would you consider regional differences between the professionals?*

Klein: When I think about "regional differences" I take into consideration two perspectives: Cultural and co-location. Cultural differences are very positive, once it brings great diversity of thoughts into the work. Whenever it is possible, the physical co-location is implemented, once it rapidly helps the creation of bonds in between project participants and it is a key aspect for fast decisions. However, I acknowledge that the real globalization we have nowadays – project members based on different countries - do not diminish the effectiveness of any tasks. Virtual co-location is here to stay and we have many tools to make it happen!

IAO: *Talking about technologies – which are the technologies that your company considers relevant?*

Klein: All of your trends are important. However, the market we are in is a rather conservative one, still allowing a lot of space for these technologies to come in. The current market is still very focused on energy efficiency, cost, reliability and refrigerants transition (eco-friendly). We monitor the market very closely and we work hard (including with external partners) to accelerate the new technologies' implementation.

IAO: *Do you incorporate external resources such as start-ups for example?*

Klein: We do have some activities with external partners, and I would like to intensify this course of action. Considering how fast new technologies are being developed, establishing new collaborations in the market is crucial for keeping the pace with different technology scenarios and addressing the various markets demands in a fashionable way. It is no more possible to keep running the developments only with internal resources.

3.7 Research & Development Management at TRUMPF

Dr. Thomas Schneider is the **Managing Director of Development** at **TRUMPF Werkzeugmaschinen GmbH & Co. KG**.

With around 13 400 employees worldwide, the family-owned company is the market and technology leader in machine tools and lasers for industrial manufacturing. In addition, TRUMPF offers software solutions that pave the way to the Smart Factory.

Fraunhofer IAO: *From your experience as Managing Director of Development, which R&D goals would you emphasize?*

Dr. Thomas Schneider: In addition to costs, time, and quality, generating radical innovations is a major challenge in the area of industrial goods and mechanical engineering. Especially in the context of digitization, radical innovations are crucial. In mechanical engineering, development times can take up to 15 years. Thus digital components and interfaces often have to be integrated into on-going development processes. This can be achieved through radical innovations. The implementation, however, is usually bound to the requirement of maintaining "what already exists".

IAO: *What are the challenges of generating radical innovations?*

Schneider: Generating radical innovations in an all along incrementally grown environment requires a shift towards a more innovative mindset. At the same time, however, when you already carry a heavy backpack it is difficult to make big leaps. You cannot simply take off your backpack.

IAO: *How do you manage to reach the right height while jumping?*

Schneider: At TRUMPF, we follow an ambidextrous approach. On the one hand, we drive re-engineering of the existing forward, on the other hand we adopt new topics that have not yet played a role in the company. These are topics such as AI, wireless technologies, 5G or current positioning technologies to track the material flow between the process steps.

IAO: *How do you access ideas that emerge outside the company?*

Schneider: In this regard, cooperation plays an important role. In order to be successful in the long run, you have to employ different sources. Excellent networking and cooperation with start-ups as well as larger companies are always an advantage. Global networks help us to develop new solutions.

IAO: *What is your opinion on our R&D trends?*

Schneider: In addition to the trends that have already been mentioned, the transformation of employees plays an important role. This refers to the employees who have led the company to success over the past 20 years. They need to be motivated and integrated into all the fast-cyclical changes. Especially in the mechanical engineering industry, these employees possess valuable domain knowledge. As a manager I consider these employees as a great opportunity and as part of our future.

IAO: *Which success factor plays the most important role for you?*

Schneider: The key to success is to break down the corporate strategy for the development departments in a way that each employee finds him or herself considered in one way or another. This requires cyclical and transparent illustration of how the activities of each individual contribute to the corporate strategy as a whole.

IAO: *What technology trends do you consider to be particularly important?*

Schneider: First of all, different technologies not only build upon each other, their success is closely interlinked. Against this background, two things need to be emphasized. On the one hand, IT security is an overarching issue, as it is the key to the success of all the technologies listed here. On the other hand, technologies such as AI, connectivity, digital twin, and big data, which we summarize under the term "I4.0", naturally go hand in hand with the qualification of employees. This is a classic challenge for manufacturers, who increasingly converge into the direction of software companies.

3.8 Digital Strategy at REDARC

Mr. Anthony Kittel is the **Owner and Managing Director** of **REDARC Electronics**, an Australian electronics manufacturer based in Lonsdale, South Australia.

REDARC has 40 years of experience in the research, design, development and manufacturing of electronic voltage transformers, inverters, power supplies, battery chargers, battery management and brake force controllers.

Fraunhofer IAO: *What is your opinion on the results of our R&D study?*

Anthony Kittel: In general we have identified the same trends as critical for competing in the upcoming years. Agile development processes are one of the key success factors we are working on at the moment. Here we prioritize the integration of design thinking, lean start-up and especially the scrum mentality in order to reduce product development time. The involvement of customers, co-development and co-design, focus groups. These are all aspects that we are increasingly implementing prior to the product development process.

Structured monitoring of new technologies and trends is done informally within our company. We do indeed acknowledge the importance of a structured monitoring and are sensitive to trends and technologies, especially in terms of electro mobility and automated driving. We have established a research register for identifying and strategically investigating new technologies. If there is one trend to add – this would be the digitalization of R&D processes. In 2015 and 2016, when we had a project with the Fraunhofer IAO, the recommendations for our company were to focus on business model innovation and digitalization.

IAO: *How exactly do you approach digitization?*

Kittel: We are pursuing various initiatives in this regard. As an example, just recently a project was completed to establish digital consistency and real time data processing. In order to do so we launched an Enterprise-Resource-Planning system that centrally links and unites the entirety of our machine data in one system. Next up, we plan the end-to-end digitization of all our business processes – including R&D procedures - with the aim to move forward with paper-less development.

In R&D in particular, we have set up a dedicated team of project managers to take care of R&D processes in a targeted manner. Part of their responsibility is to network R&D with other areas of the company, third party businesses and universities. Our aim is to ensure cross-functional integration of R&D activities. In particular, this means that every department within the company has their representatives in the R&D team.

IAO: *Other than the ones already discussed, do you consider additional trends as relevant?*

Kittel: What is really important for us is the targeted skill development of our employees. In this regard, we are closely cooperating with universities. This means that we match our employees with doctoral students or professors that have similar skill and research profiles. In this way, we enable targeted one-on-one competence development. In addition to, the bilateral exchange, we observe spillover effects that increase the competence level of the entire department. For example, we currently have a PhD student in mathematics working with an R&D expert to develop new algorithms. This improves the overall know-how in the field. Consequently, the ultimate goal is to generate new and innovative products from cooperation. Looking towards the future – skill development is the most important factor.

4
Technology trends from the Fraunhofer 2022 Agenda

As mentioned in the foreword, the Fraunhofer-Gesellschaft has developed its own future-oriented R&D roadmap. The "Fraunhofer 2022 Agenda"[19] currently contains seven "Key Strategic Initiatives" (KSIs). Below, the KSIs with the highest relevance to industry are presented with references to further information.

Programmable materials

"Smart materials with programmable behavior."

Programmable materials are a promising and innovative technology for future industrial applications. Thorsten Pretsch of the Fraunhofer Institute for Applied Polymer Research IAP explains it as follows: *"Programmable materials respond to changes in their environment by adapting in a predetermined way. A programmable material can switch from one state to at least one other state when a stimulus is present. This results in a specific change of a parameter such as color, geometry, hardness, permeability, damping, conductivity, the coefficient of friction or magnetism. Reversibility is an important requirement in the behavior of programmable materials."*[20]

These chameleon-like properties of a material enable innovative products and processes. Thus, desired system properties can be implemented directly into the material. When these materials are designed generatively, the technology is also referred to as "4D printing".

An impulse paper of the Fraunhofer Think Tank from January 2016 describes first innovative application fields: "*Materials that can self-assemble, organize, restructure and repair offer many advantages because they can autonomously adapt to changing conditions and provide efficiency. This enables, for example, surgical threads that contract through the activation of body heat, flat objects that automatically fold into 3D structures, color-changing surfaces for personalized items or pipes that can change independently. In principle, programmable materials are scalable to almost all sizes and can be designed to different combinations and activation sequences".*[21]

Biotechnology and health, defense and security as well as the possibility to personalize and adapt to environmental conditions in the consumer goods industry are, for example, interesting application fields of this technology.

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[19] Fraunhofer-Gesellschaft e. V. (Ed.): Annual Report 2018. Available online: https://www.fraunhofer.de/en/media-center/publications/fraunhofer-annual-report.html. Access on 15.11.2019.

[20] Pretsch, T.: Programmierbare Polymere. Fraunhofer-Symposium Netzwert 2019. Munich, 26.02.2019.

[21] Fraunhofer Think Tank: Karma Chameleon! – Programmierbare Materialien (Impulspapier). Munich, 2016.

Quantum technology

"Quantum technology as the next technological revolution?"

In the publication "Quantum technologies – from basic research to market"[22], published by the Bundesministerium für Bildung und Forschung (BMBF, Federal Ministry for Education and Research), quantum technology is expected to be the next technological disruptor after the digitalization of the industries.

"*In reality, though, our world is not made up from ones and zeros: it is composed of quanta."* This quote from the BMBF publication emphasizes the potential of this technology. The expectations related to quantum technology and its systems include resolving problems where current sensors and digital computers fail repeatedly. The publication structures current-generation quantum technologies into the following four areas:

- Quantum communication
- Quantum sensing and metrology
- Quantum computing and simulation
- Quantum-enhanced imaging procedures.

The study highlights the current state of the art, research focal points in Germany and initial application fields. The KSI which is coordinated by the Fraunhofer Institute for Applied Solid State Physics IAF and the Fraunhofer Institute for Applied Optics and Precision Engineering IOF focuses on the application potential and intends to transfer this *"future key technology from basic research to market"*.

Important application fields are communication and sensors. In particular, quantum communication enables tap-proof communication – even without a trustworthy infrastructure - which opens up initial application fields and customers in the banking and government sectors.[23]

Quantum sensors can even be ranked at a level of technological maturity that is of industrial interest. Current application fields for SQUID sensors (SQUID: Superconducting QUantum Interference Device) for measuring magnetic field changes are, for example, medical technology, geophysics and archaeology.

The Fraunhofer IAO is currently gathering practical industrial experience as a partner in the EU project "INFACT"[24] and is helping to design reference sites for the validation of innovative technologies, including SQUID sensors, for the non-invasive exploration of raw materials.

[22] Bundesministerium für Bildung und Forschung /Federal Ministry of Education and Research (BMBF) (Ed.): Quantum technologies – from basic research to market. A Federal Government Framework Programme. Available online: https://www.bmbf.de/en/information-material.php. Access on 15.11.2019.

[23] Tünnermann, A.: Quantentechnologie – Impulse zum Bereich der Quantenkommunikation (Workshop). Munich, 2018.

[24] INFACT. The future of mineral exploration in the EU. Available online: https://www.infactproject.eu/. Access on 15.11.2019.

Biological transformation

"I think the biggest innovations of the 21st century will be at the intersection of biology and technology. A new area is beginning."

This quote by Steve Jobs from the Fraunhofer White Paper on Biological Transformation[25] emphasizes the innovation potential of this technology trend. As early as 2017, Acatech – German Academy of Science and Engineering already described the "innovation potential of biotechnology"[26].

"Biological Transformation means the increasing application of materials, structures and principles of living nature in technology and management with the goal of sustainable value creation." Biological transformation is interpreted as a *"new approach where nature and technology cooperate and converge"*.[27]

Some innovative fields of application include topics such as bionics, innovative food science, Life Science Engineering (LSE), cell-based biosensors, biopolymers and additives, organisms as producers, biomechatronics, insect biotechnology and cognitive sensor technologies.

From our discussions with experts in industrial R&D, three current and future application fields seem particularly interesting for this technology trend:

- **Bionics** – This approach addresses technical problems according to the solution principles of nature and biology.[28] "FESTO's Bionic Learning Network"[29] is an industrial application example and presents a wide range of interesting applications in automation technology.

- **Human-Technology Fusion and Bionic Implants** – The consequent improvement of human-machine interfaces leads to a human-technology fusion and bionic implants which enhance or restore the natural abilities of humans. The most popular and most widely used application is the "cochlear implant"[30], which is a hearing prosthesis for individuals suffering from hearing loss.

- **Synthetic Biology** – Combining biology with engineering sciences and information technology enables new potentials and industrial applications such as DNA digital data storage with a very high storage density.

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[25] Fraunhofer-Gesellschaft e. V. (Ed.): Biological Transformation and Bioeconomy (Whitepaper). Available online: https://www.fraunhofer.de/content/dam/zv/en/Publications/Brochures/whitepaper-biological-transformation-and-bioeconomy.pdf. Access on 15.11.2019.

[26] acatech (Ed.): Innovation Potential of Biotechnology (acatech IMPULS), Munich: Herbert Utz Verlag 2017.

[27] Neugebauer, R. (Ed.): Biologische Transformation. Berlin: Springer Vieweg, 2019.

[28] Le, T.; Mayrhofer, H.; Appel, H.; Raps, C.: Game-Changing – Innovation mit Bionik. In Bullinger, H.-J.; Bauer, W.; Rüger, M. (Ed.): Geschäftsmodell-Innovationen richtig umsetzen – Vom Technologiemarkt zum Markterfolg. Stuttgart: Fraunhofer IAO, 2018.

[29] Festo AG & Co. KG. Bionic Learning Network – Inspiration for factory and process automation. Available online: https://www.festo.com/group/en/cms/10156.htm. Access on 15.11.2019.

[30] Cochlear Ltd. Cochlear implants & cochlear implant technology. Available online: https://www.cochlear.com/au/home/understand/hearing-and-hl/hl-treatments/cochlear-implant. Access on 15.11.2019.

The Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) defines this field of research in a current position paper:

"The aim of the synthetic biology approach is to design and manufacture biological systems with new functionalities or a new combination of functionalities for which there is as yet no known equivalent in nature." [31]

This includes the production of synthetic DNA ("Writing DNA") and its application, DNA assembly and genome editing or genome surgery.

The white paper "Die Biointelligente Wertschöpfung" ("Biointelligent Value Creation") [32] by the Competence Centre Biointelligence in Baden-Württemberg describes interaction as the third mode and the vision of "biointelligent value creation" following the inspiration and integration of technology by and with biology.

[31] Deutsche Forschungsgemeinschaft/ German Research Foundation (DFG) (Ed.): Synthetische Biologie/ Synthetic Biology – Standortbestimmung/ Position Paper. Available online: https://www.dfg.de/en/dfg_profile/statutory_bodies/senate/genetic_research/publications/index.html. Access on 15.11.2019.

[32] Kompetenzzentrum Biointelligenz (Ed.): Die biointelligente Wertschöpfung – Whitepaper des Kompetenzzentrums Biointelligenz. Available online: https://www.ipa.fraunhofer.de/de/presse/presseinformationen/Whitepaper-Biointelligenz.html. Access on 15.11.2019.

5
Fraunhofer Future Topics

As the Fraunhofer-Gesellschaft celebrates its 70th anniversary, the current Foresight Process takes a look into the future of applied research:

"The Fraunhofer foresight process identifies future topics from research and technology that could have decidedly positive impacts on economic and societal developments." [33]

As a special characteristic this foresight project combines the knowledge and expertise of all 72 institutes with a very broad scanning of future topics. Further details on the methodology and results can be found in the corresponding study. [34] It describes in detail the influence and relevance of the "spotlight" topics on the various areas of applied research with a forecast for the year 2030.

In the study's executive summary, it becomes apparent how the results of the Fraunhofer Foresight Process are linked with the results of this R&D trend study as well as the Fraunhofer 2022 Agenda:

"The survey results were used as the basis for identifying topics which will bring about ***fundamental changes*** *and therefore require special attention. These topics include* ***deep learning*** *–* ***AI, re-economy*** *and the use and maintenance of* ***biodiversity****. We additionally identified topics that are particularly* ***dynamic in terms of innovation****. Some of these topics, such as* ***biohybrid, water harvesting membranes,*** *and* ***pHealth****, are already highly relevant to applied research today, while others are thus far niche topics that are developing dynamically and could therefore soon encounter broader interest. Many topics from this group are related to microelectronics, such as* ***neuromorphic chips*** *or* ***quantum communication****. The study also identified a further topic group with particular* ***societal relevance****. These topics, some of which are highly controversial, include* ***geoengineering, civic technologies****, and* ***reprogramming of human cells****, for instance."* (The emphasis is taken from the original)

The study identified a total of 51 "spotlights" as possible future topics for applied research. An *"Overview of the 30 spotlights with particular relevance to the future"* as presented in the original study, is shown in Fig. 10. Further details on the "spotlight" topics, their influence on the research areas as well as an explanation of the technical terms can be found in the study.

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[33] Fraunhofer-Gesellschaft e. V. (Ed.): Foresight Fraunhofer – Future topics with relevance to application-oriented research. Available online: http://publica.fraunhofer.de/dokumente/N-552443.html. Access on 15.11.2019.

[34] Ibid.

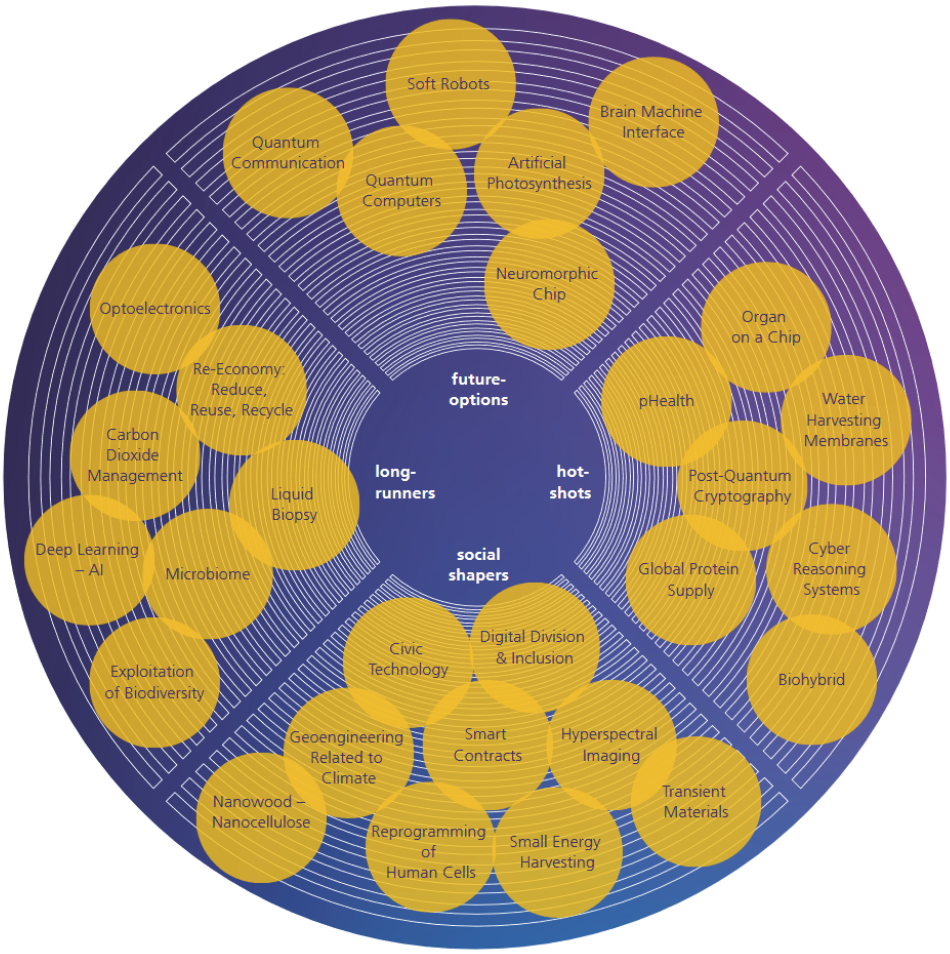

Fig. 10
Overview of the 30 spotlights with particular relevance to the future from the study Foresight Fraunhofer (p. 11)

6
Summary and outlook

Successful industrial R&D relies on a number of relevant success and influencing factors. These factors together with the ability to identify, interpret and benefit from trends at an early stage are important requirements for achieving goals and thus for the future success of R&D and the company. Both from a technological point of view and from the perspective of the market and the environment.

The results of the study show that the "classic triangle of goals" in product development – time, cost and quality - has to be complemented by the generation of new and radical innovations. Among the highest ranked R&D trends are *Structured monitoring of new trends and technologies*, *Cooperation within partners in R&D networks*, *Involvement of customers* as well as *Agile development processes*. Success factors prioritize employees over R&D strategy and processes. This consistent, anthropocentric view of R&D on the human factor is also reflected in the "top 5" influencing factors. These are *Availability of skilled workers*, *Employee motivation*, *Change in competencies* – complemented by *Innovation and technological change*, as well as *Cooperation*.

Knowledge about current R&D trends and goals as well as success and influencing factors supports the process of systematic foresight, definition of R&D strategies as well as development of integrated roadmaps. R&D goals can thus be achieved more effectively. In many industries and industrial sectors a sustainable, effective and efficient R&D is an essential and necessary component of future corporate success.

In the future we will continue to research new questions, tasks, challenges and current trends in the field of industrial R&D. As in the years before we plan to continue this study – possibly with further smaller studies on new and innovative R&D topics.

The latest insights, research and case studies of industrial R&D management can be found on our Fraunhofer IAO website:

https://www.rdm.iao.fraunhofer.de/en.html

7
Many thanks to all participants

This study would not have been possible without the tremendous support of all participants, who were very open and forthcoming in providing us with information, sometimes even on difficult topics. Since we have promised to maintain full anonymity of personal data, the names of the survey participants will not be cited. However, we would like to sincerely thank you at this point.

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Industrial research and development (R&D) must constantly change and adapt in the coming years in order to successfully offer new products, processes, services, solutions and business models to global markets and international customers.

Current geopolitical and economic turbulences destabilize markets, technological trends such as the digital transformation of industries produce new winners and losers. This offers opportunities, especially for small and medium-sized enterprises, which can recognize these potentials and use them for profitable growth.

The study "Future R&D" describes current challenges and provides the latest findings on R&D trends, goals and success factors from the perspective of technology-oriented companies as well as case studies from the business practice of numerous R&D experts.

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