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acatech TAKES POSITION – NO. 3

> MATERIALS SCIENCE AND ENGINEERING IN GERMANY

RECOMMENDATIONS ON IMAGE BUILDING, TEACHING AND RESEARCH

acatech
DEUTSCHE AKADEMIE DER
TECHNIKWISSENSCHAFTEN

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The Fraunhofer Institute for Production Technology (IPT) was asked, in cooperation with the Institute for Physical Metallurgy and Metal Physics, to prepare, perform and evaluate surveys, to conduct investigative research and to plan the present project report and create its textual design. This project work was led by Dipl.-Ing. Jennifer Kreysa (Fraunhofer Institute for Production Technology IPT). Further participants were Dr.-Ing. Sascha Klappert (Fraunhofer Institute for Production Technology IPT), Dipl.-Ing. Sebastian Nollau (Fraunhofer Institute for Production Technology IPT) and Dipl.-Ing. Rolf Berghammer (Institute for Physical Metallurgy and Metal Physics, RWTH Aachen).

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> Project schedule, syndication and publication

This position paper was prepared during the time period from January to October 2008. The acatech Executive Board syndicated the paper on 21st October, 2008. On 3rd November, 2008, the paper was introduced to the public at the "Tag der Technologie 2008 in Rheinland- Pfalz" in Mainz, Germany.

> PREAMBEL

Materials are the basis of the production industry. Traditionally, Germany has been very strongly positioned in this sector. Despite the great economic significance of classic materials (metals, glass/ceramics and plastics) and new materials (composite materials), public awareness of materials is very low. Consequently, associated degree programmes are pursued by only a small number of students. Research is largely bound to the classic disciplines. As a result, gaps open in the material-to-product chain, which in turn lead to a delayed interdisciplinary transfer and ultimately to a delay in the application of materials in innovation.

To advance its overall goals, such as the promotion of young scientists and engineers and the application of research results to technology, acatech, which is the German Academy of Science and Engineering, works to strengthen materials science and engineering in Germany with the aim of ultimately increasing value added in Germany.

The present paper is the result of an analysis performed by a project group of the Materials topical network of acatech. Its purpose is to alert the public, research funding organisations, policy makers and universities to the current situation of materials science and engineering in Germany, and to demonstrate the need for action.

This analysis originated in nine hypotheses that were developed in a workshop in October, 2007. By means of a written questionnaire and expert interviews, these were either verified or modified, and then developed into positions. From these nine positions (see Section 2.4), acatech derived statements and recommendations for five areas of activity. These are briefly summarised below (Sections 1.1 to 1.5) and are then examined in detail in the subsequent sections.

1 SUMMARY

1.1 MATERIALS: THE DISPARITY BETWEEN SIGNIFICANCE AND IMAGE

Materials and materials technologies – both conventional and new – are the basis for and the motor behind products and product innovations. Some five million people are employed in the major materials-related sectors in Germany, which achieve an annual turnover of almost one trillion euros.

Nevertheless, the public is largely unaware of the significance of materials. Materials are concealed in products, and materials science and engineering does not have a strong public voice. The innovative potential of materials is underestimated.

> acatech recommends

Enhancing the public perception of the significance of materials requires a more concerted public relations effort on the part of science and industry. Materials, their special and sometimes surprising properties, and their relationship to products in daily use and especially to product innovations, must be made visible to the wider public.

To strengthen the identity of materials and to create name recognition for this field, the term "materials science and engineering" should be used as an umbrella term, especially when referring to programmes of study, in research and for research promotion.

1.2 MATERIAL-TO-PRODUCT CHAIN

Complexity and multidisciplinarity are inherent to the materials science and engineering sector. However, it is precisely in this sector that gaps in the material-to-product chain delay the creation of product innovations based on the results of materials research. They also drive up the duration and cost of research and development projects and prevent the development and use of new materials. An in-depth examination of these gaps is needed to smooth the progression from materials research to product innovation.

> acatech recommends

Knowledge transfer at every level of the material-to-product chain should be stimulated through closer networking and cooperation between the participating players. An exchange between the "minds" in this field, particularly of researchers from science and industry, is especially effective.

1.3 TEACHING AND STUDIES

Students have a very low awareness of materials science and engineering studies. This is primarily due to the general public's overall limited awareness of materials. Moreover, existing degree programmes and associated career opportunities are not sufficiently promoted. They lack appeal and fail to focus on the link between materials and their ultimate application in innovative products.

> acatech recommends

To catch the attention of students, materials science and engineering studies must have a clear profile that stresses their impact on future innovations. Career opportunities should be emphasised.

The materials sciences and engineering faculties at universities should design "material-to-product" degree programmes. This is didactically useful, encourages an interdisciplinary mindset and is attractive to students. Apart from a solid basic education in materials science and engineering, students should promptly be exposed to processing technologies, process engineering and product manufacturing.

The curriculum must be updated continuously to reflect the latest requirements. The related activities of the newly founded Studientag Materialwissenschaft und Werkstofftechnik should be supported.

1.4 RESEARCH

The research chain from material to product is broken in many places, beginning with poor communication between materials scientists and engineers, even at the educational level. The lack of effective collaboration leads to considerable delays in the use of materials to create innovative products and, conversely, in the realisation of product ideas using suitable materials. In addition, the German research landscape in materials science and engineering is strongly fractured due to evolved decentralisation and the subdivision of research according to faculty and materials class.

> acatech recommends

Materials scientists and engineers must work together more closely. The Bundesvereinigung MatWerk was recently founded as a platform for networking. Its activities should be supported.

Research projects should have an interdisciplinary design, without neglecting the niche areas of specialists in the field.

The development of strategies and roadmaps as coordinating instruments should be promoted both at the national and European level. These can also serve as a guideline at the project level, involving various development stages and development partners.

1.5 RESEARCH PROMOTION

While the advancement of basic research appears to be quite efficient, there is a need for improvement in the promotion of applied research and the development of collaboration between basic and applied research.

> acatech recommends

The funding organisations should design their funding programmes as flexibly as possible. They should also coordinate these more effectively with each other to ensure continuous support from basic research to product development.

When focusing on specific topics, the funding organisations should place equal emphasis on traditional materials as on the so-called high-tech materials. Finally, they should develop new financing concepts for research in materials science and engineering, especially in the industry-related prototype and pilot phases.

2 INTRODUCTION

2.1 CURRENT SITUATION OF MATERIALS SCIENCE AND ENGINEERING: THE NEED FOR DIRECTIONAL ADJUSTMENTS

The fact that the German Academy for Science and Engineering has found it necessary to turn its attention to an issue as fundamental as "materials" is an indication of the potential of materials science and engineering research and demonstrates the key role that material science and engineering plays in the production-oriented industry sectors in Germany. On the other hand, it is also an indicator of the need for specific directional adjustments that require an integrated approach with the co-operation of research institutes, research sponsors, businesses, associations and policy makers. The purpose of this paper is to analyse the conditions necessary for the success of materials science and engineering and to make recommendations for specific measures that can be implemented to strengthen the position of materials science and engineering.

Use of the standardised name of "materials science and engineering" to refer to the research and development of materials has only come about in recent years. This designation underscores the inseparability of two fields that in the past have often undergone a parallel development. Materials science refers to the scientific study of materials creation, material structure and material properties. Materials engineering is the engineering-related development of materials and processing methods and builds on knowledge from materials science.[1] Moreover, for the first time, all research activities dealing with the diverse range of materials and materials classes[2] are now integrated under this unified term. Nevertheless, cooperation between the representatives of the various materials classes as well as between various points along the materials development chain is still weak. This often has the effect of delaying the implementation of research results into practical applications and thus hampers economic growth. The standardised term represents an important first step in bundling resources and thus accelerating the development and use of materials. However, materials science and engineering is a particularly interdisciplinary and heterogeneous scientific field. The difficulties arising from this are evident: low transparency, poor coordination and the lack of a coherent voice. This paper describes approaches to overcome these difficulties and will thus contribute to the definition of the scope of materials sciences and engineering.

Rather than examining the issues concerning individual disciplines or materials classes, this paper focuses on the challenges that all of materials science and engineering is facing. These challenges are largely influenced by a fundamental problem common to all materials: Although materials are the basis of almost all goods and products in daily and industrial use, they stand in the shadows of the final products they constitute and rank low in public awareness. The resulting problem of conveying the relevance of materials to the development of today's and tomorrow's products propagates itself into many areas: a lack of demand by students for degree programmes in materials, low efficiency in the application of scientific discoveries to marketable products, and a failure to perceive the materials-based scientific disciplines as being fundamentally intertwined.

An important goal of this initiative is to eliminate the discrepancy between how materials are perceived and their actual significance by improving the level of awareness for all materials, especially in terms of the wide variety of sectors in which they play a role, the ways in which they can be applied, their relevance to product development and their enormous development potential. Therefore, the aim is to specifically create a counterbalance to the current focus on catchwords such as "nano" and "bio materials" as can be observed in public discourse and among sponsoring organisations. These materials, which often have not been sufficiently defined, are frequently given priority by public research funding over traditional materials that are far more significant for industrial use. This is the case even though the innovative potential of traditional materials is considerably higher, both in the short -term and often in the long-term.[3]

The material-to-product chain is the theme that lies at the heart of the analysis examining the challenges facing materials science and engineering and of the development of solutions. The chain is comprised of the numerous steps in the value chain on the often lengthy route from materials research and materials engineering to product development and product manufacturing. It connects science and industry and requires an interplay between the various disciplines and authorities.

1 See Höcker 2008, p.9.
2 These include materials classes such as iron/steel, nonferrous metals, plastics, ceramics, glass, construction materials, natural fibres, micro fibres and nanomaterials, biomaterials, semiconductors, composite and hybrid materials.
3 See Höcker 2008, p.9.

These and other core ideas, such as the creation of this paper, are the result of work by the Materials topical network of acatech, whose vision can be formulated as follows:

- "The public is sufficiently aware of the significance of materials."
- "The degree programmes for materials science are interdisciplinary, product-oriented and therefore attractive to students."
- "Research, development and application of new materials in innovative products form a closed chain; this ensures a rapid transfer of information."[4]
- This paper should be viewed as a contribution to the realisation of this vision. It also lays a foundation and creates principles that will guide the activities of the topical network in coming years.

2.2 TARGET GROUPS AND THE ENVIRONMENT

To achieve the intended effect, it is important to address a broad circle of players. These include all involved entities along the value chain, including university and non-university research institutes, industrial R&D facilities, regulatory authorities, testing laboratories and companies that are directly involved in materials-based sectors. This paper is directed at universities, fund providers and associations. As major decision-makers, the federal government, the state governments and European policy makers are also important addressees.

The efficient use of research results in developing marketable products in the area of materials has already been identified as an important field of activity by a number of initiatives. This paper serves to supplement and coalesce these activities, which focus on the promotion of materials science and engineering in Germany either as a central theme or as part of the overall structure of the research landscape.

The initiatives that were taken into consideration in drawing up this paper are listed below.

- The first initiatives listed here are the high-tech strategy along with the first progress report of the federal government. The progress report emphasises the role of materials technologies as interdisciplinary fields that are key in the advancement of growth and for securing Germany's international competitiveness.[5]
- The most highly funded national support programme focusing on materials, "Materials Innovation for Industry and Society – WING", was launched by the Federal Ministry of Education and Research (BMBF) and features a broad spectrum of activity fields.[6] Projects initiated and supported by this programme include: application-oriented material development projects; strategic topics such as a BMBF project, executed by the VDI Technologiezentrum, with the purpose of identifying innovation obstacles in materials research and development[7]; and initiatives with high public visibility such as the "expedition materia" travelling exhibit.[8]
- In addition, priority programmes and support projects of the Deutsche Forschungsgemeinschaft (DFG), such as the "Strategy for Efficiency Increases and Future Orientation in Materials Science and Engineering"[9], demonstrate that materials sciences and engineering should also be given top priority when the objective is to promote basic research.
- This paper is consistent with the objectives of the newly founded Bundesvereinigung MatWerk and with the Studientag Materialwissenschaft und Werkstofftechnik[10].
- The "Materials Innovation" committee is an industry-driven initiative with the declared objective of promoting technology and knowledge transfer between research and industry. This initiative is identical to the "Innovation Strategies and Knowledge Management" initiative of the Federation of German Industries (BDI).[11]
- The major role that new materials play in bringing forth product innovations is also emphasised by the study entitled "Germany as a Centre for Innovation - Quo Vadis" by The Boston Consulting Group.[12]
- Consideration was also given to the work presented by the Research Alliance in the paper entitled "The Emerging Field of Materials Technologies" that appeared in June, 2008.[13]
- The "European White Book on Fundamental Research in Materials Science" by the Max Planck Society should also be named.[14]
- Contextual impulses were also delivered by programmes across the globe. European strategy programmes include, for example, the "Strategic Research" agendas of topically related technology platforms of the 7th Research Framework Programme of the European Union (such as SusChem[15]). Relevant work from countries outside of Europe include the "Materials Science Outlook" of the National Institute for Materials Science (NIMS)[16] of Japan, and initiatives of European neighbours such as those of the British programme, "A Strategy for Materials" (see box). This example shows that the problems of materials science and engineering are not limited to Germany. Disregarding country-related specifics, comparable strategies in other European countries provide valuable impulses for the continuous optimisation of the orientation and structure of materials science and engineering in Germany.

4 Höcker 2008, S. 10.
5 see BMBF 2006, p. 95ff.; BMBF 2007, p. 53 ff.
6 http://www.fz-juelich.de/ptj/werkstofftechnologien.
7 VDI Technologiezentrum 2008.
8 http://www.expedition-materia.de.
9 Roadmapping 2008.
10 http://www.matwerk.de.
11 see BDI 2008, p. 184-186 and p. 196-198.

12 see Boston Consulting Group 2006, p. 59 ff.
13 Forschungsunion 2008.
14 Max-Planck-Gesellschaft 2004.
15 http://www.suschem.org.
16 http://www.nims.go.jp/eng/news/outlook/index.html.

> „A Strategy for Materials"

The paper entitled "A Strategy for Materials" (2006) was created by the "Materials Innovation and Growth Team", a group of high-level representatives from industry, science, trade federations and associations, research sponsors, trade unions and government ministries. The objective was to develop specific measures that would strengthen materials research and the materials industry in Great Britain.

The strategic character of "A Strategy for Materials" can largely be attributed to its pronounced focus on the supply chain (the chain spanning from materials development to materials manufacturing and processing): Instead of working out recommendations for individual materials classes, the team addressed general problem areas affecting the entire field, and developed an overall strategy relevant to all areas of materials science and engineering. By reflecting collectively on the challenges common to the entire field, the field's inherent heterogeneity was confronted at the conceptual level.

A further measure intended to help bring about a gradual unification is the close link between the creation of the strategy paper and the founding of a joint umbrella organisation (MatUK).[17] As the common voice of all materials science and engineering fields, this organisation will play a decisive role in implementing and coordinating the measures introduced in the strategy paper.

The British initiative approaches the problem by examining the low public awareness of the impact that materials themselves, or materials science and engineering in general, have on technological advancements, economic growth and overall prosperity. This is reflected by the under-representation of the field and the industrial sector. The paper primarily associates these issues with the pronounced heterogeneity of the field:

"The diversity of the materials community has previously made it difficult to achieve a collective vision and to respond with a coherent strategy to the major challenges of the day, globalisation, sustainability and the environment." (A Strategy for Materials 2006, p. 5)

17 http://www.matuk.co.uk.

2.3 METHODOLOGY

> Workshop

Preparation of the acatech paper entitled "Materials Science and Engineering in Germany" was initiated at an expert workshop on 17th October, 2007, entitled "Materials as a Motor of Innovation" under the direction of Hartwig Hšcker. Ten experts from differing perspectives of science and industry illustrated the situation of materials science and engineering in Germany, made field-based suggestions for improvement and created the motivation for the basic themes in this paper through their presentations. As a follow-up to the workshop, contributed presentations were published as a volume in the "acatech DISCUSSES" series.[18]

The core ideas of the workshop were subsequently broadened and integrated into the format of this paper.

> Hypotheses

A hypothesis-based methodological approach was used: In the first step, the presentation contents were condensed into nine largely consistent and non-overlapping hypotheses. The defined hypotheses were substantiated through a written survey, followed by expert interviews and research work.

> Written survey and expert interviews

Instead of a broad-based, statistical questionnaire, a concentrated survey, with a national focus, was conducted and qualitatively analysed. This project was assigned to a team from the technology management department of the Fraunhofer Institute for Production Technology IPT.

The survey participants were chosen from the acatech General Assembly and the companies represented in the acatech Senate; in addition, about one-third of the questionnaires were sent to the management of materials-based institutes of the Fraunhofer-Gesellschaft. The participants included representatives from research as well as from industry and from associations of the target and interest groups. The twelve-page questionnaire contained questions on the topical areas of materials (significance and innovative potential), research, teaching and promotion.

The survey, performed in March and April 2008, had a return rate of 32 percent. Accordingly, 71 answered questionnaires were evaluated (73 percent of those answered stemmed from university/research facilities and 27 from industry and associations). The answers from the two groups varied in terms of the number of answered questions and how they were answered. In cases where the return rate was sufficiently high, the evaluations of the subcategories could be compared. As 82 percent of returned questionnaires came from acatech associates, the survey results particularly reflect the point of view of acatech.

Some of the questions led to a distorted picture, which can be attributed to two causes. These causes relate to basic problems associated with this field of science and the industrial sector:

- While the questionnaire was being developed, the lack of a classification structure that would permit an unambiguous assignment of all structural and functional materials, including composite materials, invariably led to inaccuracy.
- Although an effort was made to achieve a balanced representation in selecting survey participants, the analysis of the questions that related to specific materials classes revealed the random structure of the participant pool in terms of the material class with which they were associated. This in itself may be a striking indication of the "fragmentation" of this scientific field and industrial sector, an issue that is a central topic of this paper. Because of these problems, it was decided to forego considerations based on the materials class.

Survey results relating to specific topics were examined more closely in interviews with experts of the acatech group and beyond.

18 Höcker 2008.

> Research

In addition to the qualitative discourse, the results were aligned with numerous relevant initiatives, activities and strategy work from within Germany and abroad.

> Project group

The project group discussed and confirmed the results of the surveys and transformed the initial hypotheses into nine positions. Ultimately, these led to a set of recommendations.

2.4 POSITIONS

The methodology described was used to transform the nine original hypotheses into "acatech positions". While they served as a guide on which the project work was based, they also represent a milestone for this work.

> Positions on significance and innovation potential

Position 1
Materials and materials technologies are important yet hidden innovation drivers.

Position 2
Both so-called high-tech materials and traditional materials have considerable innovation potential.

Position 3

"Gaps" in the value chain extending from materials research and development to product manufacturing delay materials-driven innovation.

> Positions on teaching and studies

Position 4
To meet the demand for graduates of materials science and engineering studies in Germany, student awareness of these studies must be increased, the degree programmes must be more clearly structured, and their appeal must be enhanced and communicated to the public, particularly by conveying the association between materials and products.

Position 5
The core task of degree programmes in materials science and engineering is to develop in students the conceptual capability of solving problems, in other words to build up a broad base of knowledge and skills in materials science and engineering.

> Positions on research and promotion

Position 6
To preserve Germany's international positioning at the forefront of materials science and engineering, independent fundamental research in materials science and application-based materials engineering structured on industry needs must both be strong.

Position 7
To enhance the image and efficiency of materials science and engineering in Germany, it is important for all materials classes to make a targeted and joint effort to achieve an integrated approach.

Position 8
The funding programmes must strive to increase the effectiveness and speed with which research results are applied to innovative products in Germany.

Position 9
Flexible support models that stimulate effective cooperation between research institutes and companies are necessary to promote materials-driven innovation.

3 MATERIALS: THE DISPARITY BETWEEN SIGNIFICANCE AND IMAGE

3.1 MATERIALS AND MATERIALS TECHNOLOGIES IN GERMANY

Materials are the basis of almost all goods and products in daily and industrial use.[19] As the first link in the value chain, materials have a profound effect on the properties, functionality and quality of the final product. Increases in quality and performance and reductions in cost achieved by optimising materials and materials manufacturing are transmitted to the product or system level. This creates the basis for product innovations.

Developments in materials engineering[20] lead to more efficient manufacturing, processing and recovery methods in a diverse range of applications. Germany's innovative strength and dynamics therefore depend largely on the performance of materials and materials technologies.[21] However, it is hardly feasible to quantitatively compare the contribution that materials and materials technologies make to innovation with that of other factors such as production or design. The monumental contribution made by materials is nevertheless emphasised in current studies. It is estimated that around 70 percent of all technical innovations depend directly or indirectly on materials.[22]

Considering future challenges like resource scarcity and an increasing world population, it is essential to extend the assessment of innovations to include the question of sustainability. Materials technology can potentially increase the efficiency of the use of materials and resources[23], therefore contributing to the discovery of solutions to these challenges.

> Materials technologies as key technologies and growth drivers in Germany

In almost all industry sectors involved in production, materials technologies form the basis of or the motor behind product and process innovations with global market potential. The primary materials-based industries in Germany, including the automotive, mechanical engineering, chemical, power, electrical and electronics, and metal production and processing industries, achieve a total annual turnover of almost one trillion euros and employ around five million people. Total material costs of the entire German economy (including the building sector) total around 570 billion euros; this represents between 40 and 50 percent of the gross production costs and is rising.[24]

Beyond this estimate, no detailed assessments are available that examine the value contribution that materials make in Germany and that, in doing so, take into consideration material diversity and the value added throughout the life cycle of a product or system, from its creation, processing and marketing to its ultimate use. An examination of this type would form a reliable basis on which to draw well-founded conclusions about the economic relevance of materials, to point out the immense significance of materials, and to define and justify key areas for research and support.

3.2 INNOVATIVE POTENTIAL OF MATERIALS

Innovation potentials can be evaluated from different angles: Often the term "potential" is understood to refer to the expected turnover while taking into account costs and implementation probability. Particularly in the context of materials, and especially when only very small quantities of a special material are needed in a high-tech product, the innovation financing at the product or system level is not necessarily apportioned to the materials level in a way that is commensurate with the costs incurred at that level. For this reason, there is a need for expanding the understanding of the term "potential" beyond the economic or turnover-driven definition.

A prioritisation of the innovation potential of individual materials or materials classes appears to be neither feasible or purposeful. In all materials classes, technological advancements that lead to market successes are possible – and this applies equally to traditional and new materials. It applies to structural and functional materials as well as to standard (commodities) and special materials (specialties). In accordance with the general tendency toward developing system technologies, the materials sector is increasingly focusing on integrating materials developments innovatively into material or product composites so that the specific properties of the individual material come to bear and result in unique features at the system level. It is important that development work within the individual materials classes be coordinated and oriented toward market-related needs.

> Dominant mechanism in materials-driven innovation

Innovation mechanisms have undergone gradual change: The traditional approach, which was to search for applications for newly developed materials (push principle), has given way to the selection of the most suitable choice among a variety of possible materials or the development of specific materials as demanded by customer needs (pull principle).[25] This pattern was substantiated by the survey conducted in the course of this project. In materials science and engineering, there appears to be a promising balance between the two principles: materials technologies are developed on a demand-driven basis, and the new materials or materials technologies are then implemented in further application fields.

3.3 LOW AWARENESS OF THE SIGNIFICANCE OF MATERIALS

Public awareness and visibility[26] of materials in Germany in no way corresponds to their actual significance.[27] Materials are insufficiently included in syllabi and the "voice" of materials science and engineering in industry and policy-making is too weak. This is problematic for such diverse concerns as research funding and students' study and career choices. Many experts are of the opinion that this underestimation is exacerbated in two primary ways: The lack of knowledge about materials leads to incorrect assessments such as of the environmental compatibility or toxicity of materials. Moreover, fashionable terms such as "nano" and "bio" generally distort the image of materials and materials technologies when they are divorced from any practical applicability.

> acatech recommends

– Expansion of public relations work
To heighten public awareness of the potential of materials, the relevance of materials technologies and their contribution to technological progress, public relations and information campaigns should be consistently pursued and expanded at all levels of science and industry.

Initiatives such as PlasticsEurope[28], techportal[29] and the Stahl-Informationszentrum[30] have demonstrated over the last few years that it is possible to have inspiring and effective public discourse and how to allay concerns. Following the example of "Intel Inside", materials manufacturers will be able to devise original approaches to give materials their own identity.[31] Of course, it will require a high degree of persistence to bring about the necessary change in public awareness.

– Strengthening the identity of materials
To strengthen the identity of materials, the term "materials science and engineering" should be used as an umbrella term to gain name recognition, especially when referring to degree programmes, in research and for research promotion.

Strengthening the common identity of this sector and scientific field is also a matter of targeted work by trade associations. This is one of the goals of the Bundesvereinigung MatWerk, which aims to give this fragmented scientific field a unified identity (see box).[32]

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[19] See Höcker 2008, p. 9; Rühle et al. 2001, p. 11; BMBF 2006, p. 95; BDI 2008, p. 184-186.
[20] Materials technology is considered to be the study of the creation of materials and their processing into semi-finished and finished products, and the study of important treatment methods for obtaining certain properties (see Ruge and Wohlfahrt 2007).
[21] See Bremer/Scheibner 2007, p. 16.
[22] See BMBF 2006, p. 95.
[23] Special development opportunities created by the recycling of materials should be mentioned in this regard; see BMBF 2006, p. 95 ff.
[24] See, for example, the Boston Consulting Group 2006, p. 59 ff.; BMBF 2006, p. 95; Höcker 2008, p. 9 f.

[25] See BMBF 2006, p. 95.
[26] Design, brand and functionality are often the most prominent features in the mind of the customer. Frequently, customers fail to recognise that it is the materials or materials technologies that have a profound effect on the product design and that these lend the product its specific and unique characteristics. In other words: The public only rarely recognises that the product and materials are inextricably intertwined and therefore underestimates the importance of the materials (see Hšcker 2008, p. 9).
[27] See Hšcker 2008, p. 9 f.
[28] http://www.plasticseurope.org.
[29] http://www.techportal.de.
[30] http://www.stahl-info.de.
[31] See Heiker 2008, p. 14.
[32] See Gottstein 2008, p. 42.

> **The Bundesvereinigung MatWerk**

The "Bundesvereinigung Materialwissenschaft und Werkstofftechnik – BV MatWerk" was founded on 22nd October, 2007, as a union of science and engineering associations and federations active in the field of materials science and engineering.[33] The basic mission of BV MatWerk is to honour the vital role that materials science and engineering plays in industry and society in Germany by better coordinating the many activities in this area. This objective continues to be the driving force behind the activities of this new umbrella organisation.

As an integrative initiative, BV MatWerk pursues the goal of linking common interests of materials science and engineering and promoting cooperation among trade associations. In coordination with its member organisations, BW MatWerk is active in the following fields:

– Identification of research needs in a dialogue between industry and society,
– Coordination of scientific processes,
– Promotion of young scientists,
– Support of international cooperation.[34]

33 Vgl. Portella 2008, S. 22.
34 Vgl. http://www.matwerk.de/BVMatWerk/Leitbild.aspx.

4 MATERIAL-TO-PRODUCT CHAIN

4.1 MATERIALS RESEARCH TO PRODUCT INNOVATION

The material-to-product chain involves all stages of materials development and of the value chain that are needed to transfer knowledge from materials science into materials-based product innovations. It thus builds a bridge between the "materials" and "product" systems, but also represents a link between science and industry.

It is clear that both the design and structure of these chains are subject to numerous influences, above all those arising from the material, its application, the industry sector and the development project. This is reflected in the wide variety of different descriptive approaches in relevant sources, and the variety in the underlying interpretations by particular groups of experts.[35] The differences relate to the applicable system limits (for example, with respect to the sphere of influence of materials and production engineering), which in addition are shaped by the point of view of the observer.

The approach that underlies the preparation of this paper is in line the stages of knowledge flow: the researching of material synthesis and material structures; the exploration of material properties; materials engineering (including material creation, forming, joining and coating methods); and product development and production (including product design, product development, production and assembly technologies).[36] The creation of product innovations thus relies on the interaction between a diverse group of professionals (chemists, physicists, material researchers, materials engineers, materials manufacturers, production engineers, product designers, etc.). This approach shows the heterogeneity of the participating knowledge holders, disciplines and areas of expertise as well as the required interdisciplinarity.

However, the knowledge flow approach cannot be separated from a different approach that concentrates more closely on the physical value creation stages. These encompass all of the steps along the following chain: the gaining of raw materials; various creation and synthesis processes; analysis, characterisation and approval; processing and combination steps; system or product integration and field testing. The life cycle approach even extends this chain to include reclamation and disposal. Overarching processes such as standardisation and simulation accompany all of these steps. Above all, this value-oriented perspective emphasises the diversity of the required process steps.

Development projects that encompass the entire chain from material to product are thus subject not only to the influences specified above, but typically are also shaped by the heterogeneity of the participating knowledge holders and the extreme diversity of the processing steps. Hence, development projects that are either driven by new materials or that require materials development generally exhibit the following characteristics:

> **High complexity and interdisciplinarity**

The material-to-product chain is shaped not only by numerous process steps but also by a high and increasing degree of mutual interactions[37]. These occur along the entire chain, both in the direction of value added (such as in the transfer of knowledge, results and goods) and in the opposite direction (such as the communication of needs to upstream process steps). Both the outcome and the driver of this complexity is a high level of process interdisciplinarity; of importance is not only the interplay between the various branches of study within materials science and engineering, but also with related disciplines such as production engineering. Every segment of the process chain changes a material's microstructure and thus the spectrum of material properties, depending on the applied process technology. Thus, the combination of materials engineering and production technology not only determines the properties of the final product or system, but also dictates certain process parameters such as the processing time or resource consumption.[38]

> **Low vertical integration depth**

In many cases, material and product development and product manufacturing do not form a closed process chain. This is in part due to „missing" value creation stages, which can be partially attributed to the migration of value creation stages to other countries; especially raw materials are obtained from abroad almost without exception. In addition, the various stages of the value chain are usually handled by different manufacturers. In this respect, the current situation in Germany differs somewhat from

35 See, for example, Kopp 2008, p. 25 ff.; Gottstein 2008, p. 45; Winnacker 2008, p. 48; Forschungsunion 2008, p. 8 f.; VDI Technologiezentrum 2008, p. 42 ff.; BMBF-WING 2004, p. 5.
36 See Hšcker 2008, p. 9.
37 For example, to determine material and marginal parameters, research institutes are increasingly being integrated into industrial development processes.
38 See Kopp 2008, p. 25 ff.; Gottstein 2008, p. 45.

that in other countries like the USA or Japan.[39] From a financial perspective, this disconnectedness is decidedly disadvantageous for materials development and manufacturing: In many cases, the materials manufacturer, despite high R&D costs, receives only a small share of the ultimate value added of the component or system since, particularly for functional materials, the market only requires small material quantities.

> Long-term nature of materials development

The time it takes to develop new materials typically exceeds that of product development and process development. Therefore, the development of materials that meet specific requirements for use in special products or systems often requires a lengthy research-oriented lead time without any guarantee of success, making development project planning very difficult.

> "Scale-up"

A typical challenge of all materials development processes is the so-called scale-up. This term, also used in process engineering, for example, refers to the transformation of manufacturing processes from the laboratory or model level to the application scale. Continuous, cost-optimised scalability is often not feasible when dealing with materials. For example, material properties can change during the transition from the test melt to the component. High-cost apparatus and assemblies, as are often needed for materials development and creation, are often not scalable, meaning that their use only pays off beyond what is usually a large critical quantity.[40]

4.2 CURRENT GAPS IN THE MATERIAL-TO-PRODUCT CHAIN

The above description of the characteristics of development projects already suggests that there are a number of factors that delay the creation of product innovations from materials research results. They also drive up the duration and cost of R&D projects and even prevent the development and use of new materials.[41]

Most of these obstacles can be attributed to the difficulties in communication, interaction and cooperation between the process participants from different areas of expertise. Therefore, the obstacles can be directly linked back to the complexity and interdisciplinarity inherent to the process.

Technology transfer is impeded by hurdles related to intellectual property (a fear of the loss of knowledge, for example), but is also hampered by organisational hurdles (such as a lack of useful contacts in materials science and engineering). However, the greatest obstacles can be attributed to communication and technical issues. This problem manifested itself in the survey results as shown in the following examples:

- From a product and marketing point of view, there is a lack of product orientation in the early phases of the chain. The presentation of material ideas (marketing activities) would be one possibility to remedy this. From the materials research point of view, on the other hand, requirements from a systems perspective are not formulated with the necessary clarity and precision. Some materials researchers even complained of a low level of interest on the part of industry for research results and consider this to be the reason why many product developers are only aware of a small subset of the available materials and material properties.[42]
- Conversely, from the point of view of production, experts in materials research often lack knowledge about how material properties are influenced by production processes. Materials researchers and engineers, on the other hand, see a need for improving materials-related knowledge in product development.

In terms of the (forward) transfer of results from materials research, technical obstacles such as incompatible data formats

[39] See Winnacker 2008, p. 48 f.; BMBF-WING 2004, p. 5.
[40] See Kopp 2008, p. 25.
[41] The "gaps" named below were identified primarily on the basis of the survey and the interviews that were conducted as part of the investigation for this position paper. They were also compared to the cross-sector results of the research study entitled "Innovation Barriers in the Field of Materials Research and Development", conducted on behalf of the BMBF (VDI Technologiezentrum 2008).
[42] See Höcker 2008, p. 89.

hinder a smooth knowledge transfer. Most prominent, however, is a lack of awareness of the time and effort that need to be put into the scale-up stage. This is primarily exhibited by a lack of funds and support sources for the prototype phase, in which the scale-up stage is most frequently carried out.

Moreover, the total process duration needed for the implementation of new materials in products is often underestimated. This arises because materials with tailored properties, which already have long development times, must additionally undergo acceptance, testing and approval procedures. Apart from the development of the material itself, almost all development projects also involve additional materials technologies. These include the integration of newly developed individual materials into material composites or the examination of the impact of processing on material properties. Time-related problems arise from the duration of materials development in relation to product development. This makes planning and synchronisation difficult, prevents the development of new materials and sometimes even results in a return to old, familiar materials.[43]

Apart from the problems of interdisciplinary cooperation, the communication of requirements at the system or customer level to materials science and engineering is considered to be in great need of improvement. The lack of familiarity with customer requirements is a question of communication; it is also, however, a consequence of the fact that final customers generally have a low awareness of the significance of materials and do not formulate specific material requirements. The lack of technical and academic experts in the field, the high level of investments needed and the associated economic risks are additional factors that have an impact on speed and efficiency along the entire chain from material to product. According to an analysis by the VDI Technologiezentrum, these are among the most important innovation obstacles across industry sectors.[44]

4.3 MEANS TO CLOSING THE GAPS IN THE MATERIAL-TO-PRODUCT CHAIN

In practice, process delays in materials development and implementation are generally not caused by single obstacles. Therefore, a set of multiple measures is usually necessary to effectively bring about process optimisations.[45] This section contains recommendations that have a direct impact on interdisciplinary cooperation. Additional pertinent recommendations can be found in the sections on teaching, research and research promotion. Here it is possible to pinpoint specific causes for the gaps in the material-to-product chain.

> acatech recommends

– Intensification of cooperation and networking
Knowledge transfer along the entire material-to-product chain should be promoted through closer networking and cooperation. This should take place at different levels (for example, at the product level, among people and between associations) and in different forms (for example, long-lasting networks for knowledge exchange and temporary topical and project-oriented structures).

This requirement also applies to technology-driven R&D platforms for (horizontal) interdisciplinary topics and above all for vertical, application-driven networking (for example, through product-focused development alliances).[46] Long-term cooperation between universities and companies, such as in public-private partnerships, is considered to have great potential, especially when these involve projects designed to train young scientists and engineers.[47]

[43] See VDI Technologiezentrum 2008.
[44] See VDI Technologiezentrum 2008.
[45] The analysis conducted by the VDI Technologiezentrum shows that there are many obstacles that are unique to materials science and engineering. It also shows, however, that the relevance of individual obstacles depends on the particular sector. For sector-specific measures in the automotive sector, traffic, chemistry/materials and medical technology/health, please refer to the analysis of the VDI Technologiezentrum (VDI Technologiezentrum 2008).
[46] See Forschungsunion 2008, p. 19.
[47] See Kopp 2008, p. 38.

– Knowledge transfer between science and industry
Knowledge transfer between science and industry primarily occurs between the experts in the field. This should be taken into consideration in materials science and engineering as well. The opportunities for a direct exchange of knowledge and experience between researchers at universities and in industrial R&D departments should be enhanced and expanded by new promotional tools.[48]

– Integrated planning of products and (materials) technologies
The integrated planning of products and (materials) technologies should be intensified.

The goal is to coordinate and even synchronise the development of products and (materials) technologies through the use of systematic planning instruments and aids (such as roadmaps). The necessity for this arises above all from the great disparity between the time needed to develop products on the one hand and materials or materials technologies on the other. In addition, synergy effects should be better utilised.[49] Roadmaps can be used within a company or (as a largely solution-independent communication medium) they can promote and support the exchange between different organisations in the innovation process (such as between materials developers and system manufacturers).

[48] In addition to the promotion of partnerships (for example, by means of so-called transfer projects of the DFG), the promotion of spin-offs should also be utilised; see Kleiner 2006.
[49] Synergy effects such as these can be achieved by joining and aligning product-related innovations (needs-based materials developments) and materials-related capabilities that have already been realised (or are anticipated).

5 TEACHING AND STUDIES

5.1 TEACHING MATERIALS SCIENCE AND ENGINEERING IN GERMANY

Academic studies in materials science and engineering in Germany are exceptionally heterogeneous, which is attributable to the history of degree programmes in this field. The existing courses of study were developed from purely materials-oriented programmes and from natural science and engineering studies. Because of the growing significance of materials and the mounting requirements in industry for graduates with materials-related know-how, content relating to materials science and engineering is increasingly being integrated in the curricula of natural and engineering sciences. Ultimately, this has led to specialised degree programmes, such as for inorganic nonmetallic materials or plastics engineering. They were developed from branches of study as diverse as metallurgy, materials science in mechanical engineering and solid-state physics. The parallel development of "pure" materials sciences studies on the one hand and engineering and natural science studies on the other, with their different orientations and requirements, brought forth a heterogeneous variety of degree programmes with materials science content.[50] The results for education in materials sciences and engineering in Germany are a broad and cryptic array of studies, a limited coordination of topics among different curricula and a lack of visibility of the study programmes and of materials science and engineering as a whole.[51] As a result, materials science and engineering studies were previously not included in rankings due to the lack of a common name and presence.

As with most engineering science degree courses, materials sciences and engineering studies are characterised by a high number of semesters, high drop-out rates, a low percentage of female students and, most importantly, student numbers that are far too low: Of the 295,091 first-year students in Germany who began studying in the winter semester of 2006/2007, only 1 percent (2,862) decided to pursue a degree programme explicitly dealing with materials science or materials engineering.[52] Although recent years have shown signs of a positive trend, with the number of first-year students in materials science and engineering increasing slowly but steadily, the number of graduates continues to be very low. This has an inhibiting effect on research output, industry and the economy.

The two main challenges, namely the inhomogeneous array of degree programmes and the lack of young scientists and engineers, have also been recognised abroad. Corrective measures have already been developed and implemented. In the USA, for example, degree programmes with a comparatively strong identity have been established under the term "materials science and engineering".[53] In Great Britain, a successful initiative to streamline the diverse degree programmes and to promote young scientists and engineers was started with the UK Centre for Materials Education (UKCME). Certain aspects of this programme can serve as a model for initiatives in Germany.[54]

The "Studientag Materialwissenschaft und Werkstofftechnik" was developed in Germany as the central entity to confront these challenges. This corresponds to the council of faculties of other disciplines. To strengthen the common identity of this scientific field and to improve public awareness of the degree programmes, it was decided to introduce the joined term "materials science and engineering". The term is intended to embrace the full breadth of the field and in this way help the public to understand as well as positively assess this field of study.[55]

An examination of the state of education in this field should not, of course, be limited to university programmes; apprenticed trades and vocational training must also be taken into account. To date, a lack of current curricula and staffing in both domains, especially in regards to interdisciplinary educational topics, has led to great time losses during the transfer of know-how gained in research and development to everyday industrial practice.[56]

[50] See Gottstein 2008, p. 39 f.
[51] See the Studientag Materialwissenschaft und Werkstofftechnik website, http://www.matwerk.de.
[52] Due to the lack of a listing of available degree programmes in materials science and engineering, the analysis of the number of first-year students is based on the following studies: materials science, glass technology/ceramics, wood/fibre technology, plastics engineering, metallurgy, textile and clothing technology, microelectronics and microsystem technology; see Statistisches Bundesamt Deutschland, http://www.destatis.de.
[53] See Gottstein 2008, p. 40.
[54] See the UK Centre for Materials Education (UKCME) website, http://www.materials.ac.uk.
[55] See Gottstein 2008, p. 42.
[56] See Forschungsunion 2008, p. 25.

5.2 MEANS TO ALLEVIATING THE SHORTAGE OF YOUNG PROFESSIONALS IN MATERIALS SCIENCE AND ENGINEERING

The low number of students and the resulting lack of young scientists and engineers in materials science and engineering were identified as a core problem by both industry and science. The causes are, for one thing, a failure to inform potential students (see also Section 3.3). In addition, as was described above, it is due to the heterogeneity and poor transparency of the array of materials science and engineering degree programmes. Finally, the poor integration of relevant content from materials science and engineering into other degree programmes is yet another cause for this dearth.

> Providing information to potential students

To increase the demand for university places in the field of materials science and engineering, corrective measures need to be taken to improve student awareness of degree programmes and to increase the amount of information available on curricula and career opportunities.[57] Awareness and knowledge can only be improved by intensifying information and public relations work, both for materials in general and for the associated degree programmes in particular.

To develop a comprehensive occupational image, to sustain and strengthen this image, and to coordinate initiatives and measures for attracting potential students, it is vital for universities, industry and associations to work closely together. This is the only way to sufficiently differentiate this field from competing courses of study.[58] Public interest and especially that of potential students should be generated at the school level through the integration of materials science into the syllabus and additionally through activities with a broad impact such as the BMBF Science Year programme.[59]

As the Technische Universität Bergakademie Freiberg has shown in the project entitled "Marketing Concept for Increasing the Appeal of an Engineering Degree", sponsored by the DFG, the image of the degree programme and career is a key deciding factor for students choosing a course of study.[60] The authors of the white book primarily ascribe the limited popularity of natural and engineering sciences among first-year students to comparatively low earning potential and to limited social recognition of scientists (compared to that of physicians or attorneys, for example).[61] Most potential students are unaware that numerous exceedingly attractive career opportunities are open to graduates with degrees in materials science and engineering.

> Streamlining the array of degree programmes

Streamlining the array of degree programmes available should provide a clearer course structure and give students a better variety of possibilities from which to choose. A core curriculum of required courses should be defined for the materials science and engineering studies. Beyond this, the course structure and the special areas of concentration should be aligned with the focus of the respective university.

The Studientag has already taken the first steps in unifying the course offerings in materials science and engineering in Germany. Its mission, in cooperation with the public, policy makers, research organisations and industry, as well as with national and international institutions, is to align the education offered at universities with the knowledge and skills required from graduates by science and industry. Another objective is to create a clear course structure and to further develop the academic profiles of the individual degree programmes by defining the minimum academic requirements and by making recommendations regarding basic curriculum issues. In the initial phase, the Studientag is analysing and documenting the existing degree programmes in materials science and engineering at German universities and aims to help shape the profile of the materials science and engineering discipline.[62]

[57] See Max-Planck-Gesellschaft 2004, p. 14.
[58] See Enke et al. 2007, p. 34 ff.
[59] See BMBF-WING 2004, p. 13.
[60] See Enke et al. 2007.
[61] See Max-Planck-Gesellschaft 2004, p. 276.
[62] See the Studientag Materialwissenschaft und Werkstofftechnik website, http://www.matwerk.de.

> acatech recommends

– Structuring and information
Improvements in the structure of study programmes should be linked with student consultations to ensure that students can fully benefit from the existing course offerings and are able to configure their studies to optimally match their personal wishes and capabilities. Students should be made aware of their career options and perspectives to enable them to plan accordingly.[63] Even potential students should be informed about career opportunities and misconceptions should be resolved (such as those regarding poor earning potential and low social recognition). Efforts to provide such information to students and potential students must be intensified to meet these needs.

5.3 APPROACHES TO ENSURING A HIGH LEVEL OF EDUCATION

Despite the relatively low number of students, the academic standards at German universities in materials science and engineering rank highly in an international comparison. This is demonstrated by the relatively high number of foreign students in Germany choosing degree programmes in materials science and engineering.[64]

It is necessary to continuously adjust and improve the curriculum and didactic methods to sustain these high academic standards.

> acatech recommends

– Product orientation of degree programmes
One important measure that can be taken to assure an excellent education is to gear materials science and engineering degree programmes to include a strong sense of the ultimate product. In this way, the concept of the material-to-product chain would be integrated at the educational level. Special emphasis should be placed on how the various stages of the process chain have an impact on material properties.

The didactic objective here is to communicate to students that the process chain can also be reversed, namely conclusions on material requirements an be derived from products. This highlights the necessity to create a clear definition of material requirements.[65]

– Strengthening the interdisciplinary approach to thinking and working
Interdisciplinary thinking and working should be reinforced at the educational level. Coursework in individual disciplines should be expanded to include interdisciplinary content, which will help improve communication and interaction along the entire process chain. This does not mean that a broader education should be provided at the cost of specific knowledge, but simply that exposure to the perspective of other sectors and disciplines is beneficial.[66]
Because materials science and engineering is of central importance to the material-to-product chain, materials scientists and engineers are increasingly taking on tasks that presuppose effective communication and cooperation across multiple disciplines. For this reason, the capability of working effectively across multiple disciplines must be developed at the educational level. This can be achieved by one of the following three ways:

- A strategy already in use at numerous universities is the establishment of interdisciplinary independent degree programmes that cross faculty boundaries. A promising continuation of this approach, which is also being advocated by the Studientag Materialwissenschaft und Werkstofftechnik, is the introduction of master's programmes for degrees in materials engineering, materials chemistry and materials physics. These make it possible for graduates with a bachelor's degree from an associated discipline to adjust their career direction toward materials science and engineering.
- An alternative strategy endorsed by many experts in the field is a stronger integration of materials science and engineering topics into other, existing degree programmes. An effort should be made to integrate topics from materials science and engineering into all fields that deal with product creation and development. These include product design,

[63] See Max-Planck-Gesellschaft 2004, p. 14.
[64] See Kopp 2008, p. 37.
[65] See Hšcker 2008, p. 90.
[66] See Kopp 2008, p. 26; Gottstein 2008, p. 45; Weber 2008, p. 57.

production engineering and mechanical engineering, and application-oriented fields such as automotive engineering, aerospace, mechatronics, biotechnology and medical technology. The methods of integration range from single, focused seminars and courses to the creation of separate subject minors for associated degree programmes. These measures would ensure, above all, that tomorrow's engineers learn to work with tomorrow's materials. In addition, despite the low number of students in the field, a broader dissemination of materials science knowledge would be achieved in core areas.[67]
- The diversity of the curriculum in materials science and engineering should be retained in any case: either as a separate degree programme or as a minor alongside, for example, a mechanical engineering, civil engineering or physics major. This will go hand in hand with the streamlining of course offerings when the degree programmes and subject minors are standardised throughout Germany.
- The third alternative route for building interdisciplinary skills in students is to increasingly integrate content from associated disciplines into the existing degree programmes of materials science and engineering. In light of today's "overloaded" syllabi, the likelihood of being able to implement this measure appears rather low.[68]

The call for greater interdisciplinarity in materials science and engineering must be treated with caution as the obvious advantages may come at the cost of a solid basic education. For students to learn how to handle a wide spectrum of tasks, they must receive a broad basic education of sufficient depth combined with instruction that fosters the ability to think conceptually, to recognise interdependencies and connections, and to develop solutions to problems.[69] A suitable core curriculum could encompass the teaching of a broad basic education in all materials classes and an in-depth knowledge in at least one materials group. A modern academic programme must be supplemented by additional coursework such as project, knowledge and innovation management (methodology), business management basics and languages.

– Needs-based orientation of the curriculum
The curricula of continued education and training offered at the non-university level likewise needs to be continuously adjusted to meet current needs. This should be performed at all educational institutions, and should be based on periodic analyses examining a variety of sectors and topics.[70] The Studientag Materialwissenschaft und Werkstofftechnik is predestined to handle this task and should be supported in its activities.

A good education not only requires high quality content but also relies on a highly qualified teaching staff. The appointment of excellent teachers is central to the optimisation of education in materials science and engineering in Germany. Only the best lecturers, with a sufficient amount of experience in the manufacture and application of materials, will successfully impart an understanding of the entire material-to-product chain to students and expose them to different thought patterns. This contradicts the unwritten policy that universities generally to not require practical experience from their faculty. It is the only way that students can learn to merge the problem-oriented thinking of natural scientists with the solution-oriented approach of engineers, an important skill in an interdisciplinary field such as materials science and engineering.[71] To attract skilled teachers, German universities must build faculties and institutes that are internationally superior in the field of materials science and engineering.[72] They should offer basic courses not only in fundamental areas such as mathematics, physics and chemistry, but also courses that are field-specific to materials science and engineering. This will fuel student enthusiasm for the field while simultaneously developing expertise in materials science.

[67] See Winnacker 2008, p. 51 f.
[68] See Winnacker 2008, p. 52.
[69] See Gottstein 2008, p. 42 ff.
[70] See Forschungsunion 2008, p. 11.
[71] See Gottstein 2008, p. 45; Höcker 2008, p. 89 f.
[72] See Max-Planck-Gesellschaft 2004, p.14.

6 RESEARCH

6.1 RESEARCH IN MATERIALS SCIENCE AND ENGINEERING IN GERMANY

Germany has attained a leadership position in materials science and engineering on the international arena, particularly in the area of basic research. This is rather remarkable since pertinent studies have shown that Germany's federal and industrial R&D expenditures, both in absolute terms and relative to the gross domestic product, are far below those of other leading research nations such as the USA and Japan. An overview is provided by the European White Book of the Max Planck Society. The White Book demonstrates that a broad and well-founded theoretical knowledge base is absolutely indispensable. Not only is this a prerequisite for the success of research and development in application- and product-related areas, but it also has a major impact on the efficiency and sustainability of the application of research results.[73] To ensure the continued endurance of solid foundation for innovation in Germany, it is important to enhance the performance of basic research at universities and research institutes in the long-term. This recommendation is reinforced by the German Council of Science and Humanities in its proposals for the interaction between science and industry.[74]

> Interface-related losses

Although researchers have successfully defended the German leadership position on a number of fronts for numerous decades, the exceedingly hesitant application of scientific discoveries to products has repeatedly resulted in the loss of Germany's leading edge to international competitors. Numerous examples of this in the last decades and in the more recent past illustrate the persistent problems in materials science. These setbacks are not only characterised by long material development times and unused patents, but actually extend to the loss of value creation stages in Germany and the building of new sectors abroad on the basis of German research results.[75] Moreover, they point to the need for a knowledge transfer between sectors.[76] This is primarily the task of applied and product-oriented research, although the trend toward a gradual transition between basic research and applied research makes it difficult to precisely assign roles.[77] A characteristic of applied research, as a phase in the research and innovation process, is that it requires interaction between the driving actors in science and industry.[78] It is these interfaces that are the primary source of the various efficiency deficits in the material-to-product chain (see Section 4).

Especially application-oriented research must be mindful of the various phases along the path from material to product to reduce interface-related losses. In contrast to basic research, applied research requires a process and product orientation that is more closely aligned with industry requirements and societal or market needs. Creating a better focus to increase efficiency is recommended both in the study entitled "Germany as a Centre for Innovation - Quo Vadis" by The Boston Consulting Group and in the concept of the High-Tech Strategy for Germany launched by the federal government (17 fields of innovation).[79] These papers can serve as guidelines for the internal alignment of applied research within materials science and engineering. In order to meet the steadily increasing market dynamics with tailored materials solutions, it is important not only to optimise efficiency but also to increase flexibility. In addition, because of the trend toward the development of cross-cutting or system technologies, interdisciplinary research efforts will be key to the position of Germany in the international research arena of materials science and engineering. In this respect, a more earnest cooperation will be necessary among process technologists, production engineers, product designers, product developers, measurement technicians, etc. – in short, with all disciplines that interact along the material-to-product chain.

> Fragmentation

The fundamentally favourable research conditions in Germany are often not fully utilised in materials science and engineering due to the evolved decentralisation and the subdivision of research according to faculty and materials class. The parallel de-

[73] See, for example, Max-Planck-Gesellschaft 2004, p. 11.
[74] See Wissenschaftsrat 2007, p. 87 ff.
[75] Examples are LCD display technology or light emitting devices (see Boston Consulting Group 2006, p. 60) and application of the giant magnetoresistance (GMR) effect (see Heiker 2008, p. 17).
[76] See, for example, Wissenschaftsrat 2007, p. 29; Boston Consulting Group 2006, p. 59; Forschungsunion 2008, p. 10; Hšcker 2008, p. 6.
[77] See Wissenschaftsrat 2007, p. 87.
[78] See, for example, Wissenschaftsrat 2007, p. 12 ff.
[79] See BMBF 2006, p. 27.

velopment of materials science research as part of the natural science faculties on the one hand, and materials engineering as part of the engineering sciences on the other, has not yet been overcome. It still hampers the development of materials with optimal properties.[80] In addition, research activities in the area of materials science and engineering in Germany are still influenced by fragmentation due to the traditional division between metals, plastics, glass/ceramics, etc. Within the individual materials classes, cooperation is usually vigorous and shapes the self-image of that field.[81] While Germany has leading experts in certain materials classes and key topics, fragmentation prevents the concentration of forces and hinders the utilisation of the potentials for system-oriented innovation, which is becoming increasingly significant.

The impact of this topical fragmentation corresponds to the organisational fragmentation described by the authors of the June 2008 Research Alliance strategy paper entitled "The Emerging Field of Materials Technologies": "The strong fragmentation of the world of materials and individual topics is reflected in the current organisational landscape with its vast number of platforms, networks, clusters, centres of expertise, professional networks, etc., some of which are regionally based while others are nationwide. This, too, leads to the fragmentation of energies and to the individualisation of interests, but above all to a lack of clarity for users and research sponsors. It impedes [...] profiling in the European and international field, i.e, at the competitive level."[82]

> Young scientists and engineers are becoming scarce

In addition, the growing lack of young scientists and engineers in Germany is a challenge for materials science and engineering. This problem has primarily resulted from the lack of demand for degree programmes in materials science and engineering. The number of students choosing a course of study in this area falls far short of the need for graduates, despite good course offerings.[83] After completing a university education, attractive research opportunities for science graduates are plentiful; however, these positions cannot always compete with the conditions and perspectives of employment in research institutes outside of Germany or in industry. The experts questioned in the present study also pointed out that the situation is particularly dire in a number of basic research fields, avoided by most students due to the extremely involved research effort or research risk inherent to the field (for example, prototype materials and process development) or due to a lack of knowledge (such as regarding simulation or modelling).

6.2 RELEVANT KEY RESEARCH TOPICS IN MATERIALS SCIENCE AND ENGINEERING

In respect of the analysis of current key areas of research and expertise in Germany, the goal of the preliminary work for this paper was to take stock of the relevant developments and marginal conditions. The collected data would then serve as a basis for formulating interdisciplinary guidelines for the future orientation of research in materials science and engineering. The following is basically a list of ideas that arose out of the work performed by the acatech topical network and that was further consolidated by additional expert opinions. These key topics are not specific to individual materials classes but rather apply to issues common to the entire field.Zergliederung

> Key topic: "System expertise"

Another key topic for research and education should be the build-up of system expertise since future success will rely not only on an understanding of individual materials, but also of system composites of diverse materials within final products, with an emphasis on the entire material lifecycle.[84]

System expertise means being able to identify complex interdependencies (such as between material composition, production and processing and the final product's functional properties) and to make these manageable through the use of structuring instruments. The creation of so-called "building block systems" for the use of additives in materials development is an example of this type of solution approach that is intended to systematise and simplify the problems of needs-based materials development for the user. To develop and apply system expertise, scientists and engineers must be able to think and work in a highly networked manner that extends beyond the boundaries of traditional scientific disciplines.

> Key topic: "Simulation"

As described above, burgeoning developments like multiscale materials simulation and advanced materials simulation are prime examples of the demand for more system expertise in general. In many technical areas, computer-aided simulation was introduced years ago and is now state-of-the-art. This is not the case in materials development.[85] With computer-aided support, new simulation approaches and techniques should make it possible to track material properties through the various phases of the material lifecycle – from development, creation and processing to a prediction of the expected component properties.

Successes in gaining a better basic understanding of the relationships between material structures and properties over the last several decades have given rise to the hope that it will be possible to develop models for the properties and processes within solid bodies at the atomic, microscopic, mesoscopic and macroscopic levels. These could form the basis for simulation chains – both across different scales and along the material lifecycle. The objective is to achieve a deeper understanding of the properties and property correlations between the individual material levels. In addition, a financially-motivated objective is to replace the traditional costly and time-intensive methods (trial & error) used in the empirical search for and testing of new materials.[86] In this connection, the method referred to as "inverse simulation" is of great importance. In the context of materials and materials technologies, this means creating a closed simulation chain in reverse, i.e. moving from the desired product properties to the material and process levels. If successful, this approach would offer product developers the decided advantage of obtaining tailored materials solutions, including technical and industry-related information, with considerably less effort.

By linking the generally atomistic approach of the natural sciences with the macroscopic thinking of the engineering sciences, the "multiscale materials simulation" is of course interdisciplinary in nature. Particularly noteworthy is the special platform character of the comprehensive multiscale simulation that can meet a challenge of materials science and engineering common to the various sectors and materials classes of this field.[87] In the medium- to long-term, the aim should be to link the various simulation approaches and instruments, which are currently largely independent. This would result in continuous simulation chains that link multiple process chains. Of course, the simulation may not take off on a course of its own; its relevance must be experimentally verified.

> Key topic: "Composite materials and material composites"

Composite materials and material composites are good examples that illustrate the necessity to overcome the boundaries between materials classes.[88] A small sample suffices to indicate the breadth of the field: metal-, ceramic-, glass- or polymer-based hybrid materials, lightweight materials, biomaterials, coatings and adhesives. They all share the characteristic that contrasting qualities of individual materials are combined in a specific way to obtain unique features at the system level. Modern demands require for materials that satisfy heterogeneous specifications that go beyond functionality (e.g. in terms of safety, costs and recycleability). Often, mixed and system structures are the only solution.[89] Research work in the area of composite materials and material composites is therefore a highly interdisciplinary field that deals with a multitude of materials and materials classes. It also continues to require research in the field of individual materials, i.e. involving both new and "traditional" materials. Central

[80] See Hšcker 2008, p. 9.
[81] See Forschungsunion 2008, p. 10; Max-Planck-Gesellschaft 2004, p. 299.
[82] Forschungsunion 2008, p. 10.
[83] See, for example, BMBF 2006, p. 96.
[84] See Heinricht 2008, p. 61.
[85] Köhler 2008.
[86] See BMBF-WING 2004, p. 32; Brandt et al. 2007, p. 10.
[87] See Forschungsunion 2008, p. 19.
[88] The Deutsche Gesellschaft fŸr Materialkunde e.V. (DGM) regularly holds symposia on this topic, which points to Germany's leadership position in this field and to the anticipated growth in this sector.
[89] See Forschungsunion 2008, p. 16.

research questions relate to interfacial effects and mechanisms both at the microscopic and visible macroscopic level. During the development and implementation phase, unsolved questions primarily involve system design, materials manufacturing, phase bonding, materials behaviour during use, and matters regarding standardisation and disposal. While market success of composite materials has generally fallen short of expectations due primarily to production-related difficulties, the anticipated potential in the area of material composites/multi-material systems is quite high.[90]

6.3 APPROACHES TO INCREASING RESEARCH EFFICIENCY IN MATERIALS SCIENCE AND ENGINEERING IN GERMANY

Notwithstanding the need for action to improve knowledge transfer, a key to product and application successes lies in basic research.[91] Examples such as modelling and simulation technology illustrate that the greatest contributions to efficiency improvements may arise from research in materials science and engineering.[92]

In addition to commensurate funding levels and programmes, this will provide a much needed boost to the people working in this field, in more ways than just from the perspective of an efficient knowledge transfer. Of primary importance is the increased appeal of Germany as a research centre for highly qualified scientists from within Germany and abroad and the improved and enhanced education of young researchers.

The project sponsored by the DFG entitled "Strategy for Efficiency Increases and Future Orientation in Materials Science and Engineering" is a promising initiative for improved focusing and coordination in research. The aim of this endeavour is to draw up, for the first time, a comprehensive "roadmap" for materials science and engineering in Germany that will integrate a large number of different sector roadmaps and strategy papers.[93]

By defining strategies for applications and providing a largely solution-independent communication and planning basis, roadmaps of this type illustrate paths for promoting a common direction for research activities, for identifying "white areas" on the research map and for realising new application and synergy potentials.

> acatech recommends

– Strategies and roadmaps
The development of strategies and roadmaps should be promoted both at the national and European level because these roadmaps will only be valid, current and applicable if they are created with broad-based participation and active support from within the sector. These strategies and roadmaps should also be used as coordinating instruments at the project level to steer research and development work that spans multiple developmental phases and partners in the required direction. System solutions in particular, which are characterised by numerous and highly networked development activities, currently lack strategic roadmaps with clear focus.[94]

– Coordination and networking
The disadvantages of the geographic fragmentation of the German research landscape should be counteracted by improving coordination. The goal is to achieve tighter networking within materials science and engineering, including research. Even less comprehensive network structures – such as those that are used for a goal- or topic-oriented cooperation among research institutes and companies – can bring about considerable improvements in efficiency.[95]

The Bundesvereinigung MatWerk was founded as an organisation at the association level with the mission of actively promoting exchange between individual associations and strengthening the research network at the sector level (see Section 3.3).

[90] This is underscored by the prominent position that this topic area holds in the strategy paper of the Research Alliance.
[91] See also the website of the EU Technology Platform for Sustainable Chemistry, http://www.suschem.org.
[92] Modelling and simulation technologies play an active role at numerous locations in the process chain, not only accelerating "scale-up" but often actually making it possible to find solutions.
[93] Roadmapping 2008.
[94] See Forschungsunion 2008 p. 10; Max-Planck-Gesellschaft 2004, p. 289.
[95] See Forschungsunion 2008, p. 19.
[96] See the website of Surface Technology Center Rheinbreitbach, http://www.tzo-gmbh.de.

A number of positive examples[96] indicate that geographic proximity between experts has a favourable impact on the efficiency of the product creation process and value chain. Consequently, the formation of regional centres for key topics has already become the focus of numerous funding programmes such as the Special Research Program of the DFG, Centers of Expertise, the Innovation Clusters of the Fraunhofer-Gesellschaft and Leading Edge Clusters (see below). Aside from geographic advantages, these networks are also beneficial by acting as fixed points of contact for certain topical areas. This helps counteract the lack of clarity regarding responsibilities and key topics in materials science and engineering.

Numerous additional measures can be implemented to bring about further improvements in the basic conditions necessary for the rapid and broad application of research results.

– Provision of existing infrastructure
Existing research infrastructure should be made readily available to small and medium-sized companies and to research institutes with limited resources (such as prototype laboratories); among other advantages, this would lead to an improved utilisation of often costly systems.[97]

Although the impact of measures such as these is often rather limited when viewed individually, the sum total of implemented single measures can result in considerable efficiency increases when viewed as a whole.

First and foremost, the joint image of materials science and engineering research in Germany can be strengthened on the international stage by achieving excellent integrative research results. However, enhancing the image of this sector and scientific field as a whole is also a question of targeted public relations work (see Section 3.3).

[97] See A Strategy for Materials 2006, p. 6.

7 RESEARCH PROMOTION

7.1 CURRENT RESEARCH PROMOTION IN GERMANY

As a field that has considerable leverage in products and systems, materials science and engineering has been in the past, and will be in the future, fertile ground for research promotion. In some cases, even comparatively small funding amounts can result in significant leverage – as the numerous technical and economic successes of publicly supported projects have shown.[98] In addition, materials science and engineering is the basis for innovation in virtually all important sectors of industry. Therefore, the level of promotion should be adjusted to equal that of sectors such as biotechnology or IT.[99]

The German funding landscape consists of topically-open funding of basic research by the German Research Foundation (DFG) and topically restricted funding of applied research by the BMBF, the BMWi via AiF and others.[100] Apart from these national support organisations, support programmes funded by the European Union also exist.

> Problems with the promotion of application-oriented research

Unlike the promotion of basic research by the DFG, which many experts questioned in this study considered to be on target, the promotion of applied research and the interface between basic research and applied research shows potential for improvement.

To be able to funnel resources properly, it is essential to link funding to particular areas of application-oriented research. Various key topics that reflect important societal developments, customer requirements, potential user benefits or the attractiveness of the markets have already been defined. These include, for example, mobility, health, the environmentally compatible supply of energy, and information and communication.[101] In light of the proximity of these key topics to the final product, it is immediately possible to prioritise key areas for funding due to the high number of materials and materials technologies.

From the point of view of materials science and engineering, this can result in topical "gaps" in the funding of application-oriented research, which can hamper or even prevent promotion of important subareas. However, adjusting the promotion landscape to the needs of materials science and engineering is impeded by a number of conditions. Due to long lead times in materials research, many material developments do not pay off, or only do so after a very long time. Therefore, the long-term promotion of research should not be based on short-term profits and employment figures, and policy makers should not expect the materials to be fully applied in the component and system industry in the early phases of materials development.[102] To avoid an unfair advantage for individual companies, funding and favourable subsidy rates are often focused on pre-competitive research while application-oriented research receives less funding. However, this often causes a break in the material-to-product chain.

Another major challenge to material research promotion is the imbalance between the research effort and the value added share received by the manufacturer in the material-to-product chain: A materials manufacturer usually only receives a small share of what is later often a high value added for the component or system, although the manufacturer bore the brunt of the R&D costs.[103] For this reason, it is frequently difficult to convince funding organisations of the prospective success of project suggestions.

7.2 APPROACHES TO IMPROVING RESEARCH PROMOTION

With respect to the need for targeted adjustments in applied research promotion and meeting the specific challenges encountered in materials science and engineering, the following approaches can be identified on the basis of the results of the questionnaire and expert interviews:

[98] See BMBF-WING 2004, p. 6.
[99] See Max-Planck-Gesellschaft 2004, p. 308
[100] See Kopp 2008, p. 28.
[101] See BMBF-WING 2004, p. 20
[102] See Winnacker 2008, p. 50.
[103] See BMBF-WING 2004, p. 5.

> acatech recommends

– Coordination of funding programmes
The various funding programmes should be more closely intercoordinated to ensure that all stages of development, including the prototype phase, can obtain funding and financing where necessary.

– Continuous promotion from basic research to product development:
To prevent the failure of developments that have nearly reached completion, promotional measures must be available at all stages of the value chain.[104] In materials-based developments, the phases composing the "scale-up" stage (see Section 4.1) need particularly strong support. Materials science knowledge will only enter into materials-based innovations if all phases are adequately promoted. Often this means very long promotional periods, which can be supported by means of staggered funding. Another route by which technology transfer occurs is via spin-offs, and these should therefore be promoted as well.

In the chain spanning the idea, proof of principle, proof of concept, prototype creation and product development, the current focus of promotion is on the stages from the idea to proof of concept. According to experts, the subsequent phases are not adequately promoted, especially in materials science and engineering, because of the risk of them acting as a subsidy. Moreover, the time needed to convert new materials systems and technologies into marketable products usually exceeds the grant periods of funding programmes. Another reason for the lack of funding in the final phases is that the significance of the technologies that accompany materials development, or even make it possible – such as manufacturing processes or measuring equipment – is often underestimated.[105] In materials science and engineering, it is precisely in the phases from prototype creation to product development that high but often still risky investments need to made.[106] Companies have great difficulty finding venture capitalists willing to finance the scale-up phase.

– Consideration of the innovation mechanism
When promoting innovations, the call for proposals should not emphasise topics that favour the pull principle (see Section 3.2). Rather, there should be a balance between the innovation mechanisms. This would ensure that even those materials developments that are not directly linked to applications would have a greater potential of success. Strategies, which can be derived from megatrends and anticipated requirements, and roadmaps can be used to find the best direction for development work and bring about efficiency increases.

– Flexibility in the topics promoted in applied research:
The promotion of applied research should become more flexible in terms of the topics that are supported: Funding should also focus on social topics and on creating a suitable environment for other significant subareas in materials science and engineering. It is important, however, to align research topics with the needs of industrial materials development and not only with current trends.

Applied research must take customer and market requirements into consideration to generate research results that find a place in marketable products (see DPI box). Moreover, the limited research funds demand a focus on topics. These topics are too frequently inspired by the product rather than the concerns relating directly to the materials. Additionally, catchwords like "nano" and "bio" carry too much weight in research promotion.[107] Possibly research projects need to be topically aligned with a certain research programme to be successful. Meanwhile, other areas fall by the wayside, especially in light of the large number of different materials.

– New financing concepts for research in materials science and engineering
To overcome financial obstacles in the development of future materials, new promotion and financing concepts need to be devised. Partnerships in promotion projects or future profit sharing are possible approaches.[108] Materials-related questions should

[104] See BMBF-WING 2004, p. 14
[105] See Forschungsunion 2008, p. 8.
[106] See Kopp 2008, p. 32.
[107] See Boston Consulting Group 2006, p. 60.
[108] See BMBF-WING 2004, p. 5.

> **Alternative promotion models exemplified by the Dutch Polymer Institute (DPI)**

The Technological Top Institutes (TTI) in the Netherlands demonstrate how a flexible promotion model might be designed. The example of the Dutch Polymer Institute (DPI) is used here to highlight special features of these promotion instruments.[109]

Since its founding ten years ago, the DPI has become one of the world's leading centres for basic polymer research. Its partners are large national and international concerns, mostly from the plastics production and processing industry. These partners define research topics that are important them and support the research work of scientists and doctoral candidates in scientific partner institutes, namely in university and non-university research institutes and in R&D facilities within the Netherlands and abroad. Intimate cooperation within the individual research projects between experienced experts from industry and doctoral candidates (at a ratio of nearly 1:1) and between specialists from various technical areas provides the environment for an intensive knowledge transfer and leads to research work of exceptionally high quality.

Since the Dutch Federal Ministry of Economics nearly matches the financial contribution from industry and universities, industry is highly motivated to participate in the DPI. For the federal government, in turn, the model ensures that public funding flows into basic research projects that are relevant to both science and industry. Thanks to streamlined processes and structures, a large portion of the funding is directly dedicated to research work. The consistent application of the "lean & mean" principle is reflected in the virtual institute structure and in rapid application and approval procedures.[110]

However, the promotion model relies to a large extent on federal (and thus national) resources; as of yet it is unclear how the financing model might ultimately be adapted to enable the integration of international partners, considering the trend toward globalisation. In some respects, the short-term orientation of partners from industry collides with the long-term mindset of university partners (for example, regarding the promotion period).[111] Moreover, the promotion model in its current form is unsuitable for integration of SMEs. Finally, the question arises how this approach could be used to better promote application-oriented topics in addition to basic research.

Nevertheless, this promotion concept is exemplary in ways beyond the financing concept: It demonstrates how flexibly research cooperations between science and industry can be designed, as well as how the promotion of materials science and engineering can be concentrated on basic research that addresses relevant industry and market needs while avoiding excessive "rigidity". This is also the only known promotion instrument that brings almost all relevant competitors together at a pre-competitive stage.

be viewed as an integral aspect of product development. In addition, promotion policy should commit to the long-term, explorative nature of materials research and should therefore include the promotion of basic research (see ICAMS box).[112]

> **Other approaches: SMEs, regional networks, tearing down of organisational hurdles**

SMEs (small and medium-sized enterprises) are the foundation of Germany's economic success. Combined, they are the largest employer in Germany and are characterised by great innovative strength. To maintain and expand this economic force in Germany, SMEs are in need of special support by funding organisations.[113] Considering the critical position of SMEs in the value creation network and their key role in the material-to-product chain, the support of SMEs is an essential aspect of a support strategy that extends across the entire value chain. Due to limited resources, SMEs generally do not pursue intensive broad-based R&D. Also, they are limited by inhibitive factors such as high development risks, long development durations, a lack of highly-skilled employees and high investment costs for production technology. The situation of SMEs active in the materials sector is exacerbated by the previously described special difficulties of this discipline. To give SMEs continuous access to know-how and an active technology transfer, they should be closely linked to large corporations, universities and research institutes. This can be achieved by integrating them into networks, centres and collaborative research endeavours.[114] It has long been known that standardised offers, simpler research proposal requirements and better information availability are necessary to strengthen the SME sector in the long-term.[115]

Another effective approach to promoting materials research continuously to the product or system stage is to support regional cooperation among all know-how holders. Current investigations have shown that innovation processes can profit from know-how holders that are in close geographic proximity.[116] Because regional promotion programmes frequently lead to usable results, and because the probability that a cooperation will continue beyond the end of a project is higher in regional networks, these types of programmes should be expanded. One possibility would be to establish regional expertise or technology centres at the heart of a regional know-how cluster, such as those which might emanate from universities or research institutes.

> **Alternative Fördermodelle am Beispiel des Interdisciplinary Centre for Advanced Materials Simulations (ICAMS)**

Mit dem an der Ruhr-Universität Bochum angesiedelten Interdisciplinary Centre for Advanced Materials Simulations (ICAMS) wurde ein Konstrukt geschaffen, das nicht nur inhaltlich, sondern auch organisatorisch sowie hinsichtlich des gewählten Förderinstrumentes neue Wege geht. Das ICAMS geht auf eine gemeinsame Initiative des Max-Planck-Instituts für Eisenforschung, des Initiativkreises Ruhrgebiet und des von der ThyssenKrupp AG geleiteten „Impulskreis Werkstoffinnovation" zurück, die im Jahre 2005 angestoßen wurde und im Juni 2008 in der offiziellen Eröffnung des ICAMS gipfelte.[117]

Das Zentrum für Werkstoffsimulation erhält zunächst eine auf fünf Jahre angelegte Anschubfinanzierung in Höhe von 24,2 Millionen Euro. Ein weiterer wissenschaftlicher Partner ist die RWTH Aachen. Nach dem Public-Private-Partnership-Modell werden Gelder zur Hälfte von einem Industriekonsortium unter Federführung von ThyssenKrupp, dem außerdem Bayer MaterialScience und Bayer Technology Services, Salzgitter Mannesmann Forschung und Bosch angehören, und zur anderen Hälfte vom Land Nordrhein-Westfalen zur Verfügung gestellt.[118] Um interdisziplinäres Arbeiten zu fördern, werden die drei neu geschaffenen Professuren des internationalen Zentrums an der Ruhr-Universität von den Fakultäten für Chemie, Mathematik, Maschinenbau und Physik gemeinsam getragen.

109 http://www.polymers.nl. The comparable Materials Innovation Institute (M2I, see http://www.m2i.nl) concentrates on promoting metal materials.
110 See Lemstra 2008, p. 83.
111 See Lemstra 2008, p. 86.
112 See Winnacker 2008, p. 50.

113 See BMBF-WING 2004, p. 9 ff.
114 See Forschungsunion 2008, p. 24.
115 See BMBF 2006, p. 67; BMBF-WING 2004, p. 9 ff.
116 See, for example, Kopp 2008, p. 28; DIW 2004.
117 See ICAMS, http://www.icams.rub.de/icams.htm.
118 See the Ruhr-UniversitŠt Bochum press release from 6th June, 2008, on the official opening of the ICAMS materials research centre, http:// www.pm.rub.de/pm2008/msg00174.htm.

This idea is increasingly being realised. For example, the state of North Rhine-Westphalia and the Fraunhofer-Gesellschaft founded an innovation cluster named "Integrative Production Technology for Energy-Efficient Turbomachinery – TurPro"[119] and the Bavarian state government initiated the "Cluster New Materials".[120] Another measure that strengthens the innovative power of clusters in science and industry is the Leading Edge Clusters Competition of the BMBF, part of the High-Tech Strategy of the federal government.[121]

To be able to implement the described measures and improve the efficiency of current research promotion, it is important to tear down organisational hurdles. This not only involves the introduction of unbureaucratic procedures for application, approval and controlling, but also greater flexibility in the structure of projects promoted (for example, regarding the promotion time span, or the type and number of partners). While excessive bureaucracy in the promotion process is not specific to materials science and engineering, it was identified as a major obstacle by questioned experts.[122]

[119] See the TurPro website, http://www.fraunhofer.de/institute/innovationscluster/turpro.jsp.
[120] See the website of Cluster New Materials, http://www.cluster-neuewerkstoffe.de.
[121] http://www.spitzencluster.de/de/468.php.
[122] See also the ITAS project, "Wissens- und Technologietransfer in der Materialforschung – Charakteristika und Bedingungen fŸr erfolgreiche Produktinnovation" (InnoMat), http://www.itas.fzk.de/deu/projekt/2006/brae0660.htm.

8 POSSIBILITIES FOR FURTHER ACTIVITIES

In this paper, "Materials Science and Engineering in Germany", acatech, the German Academy of Science and Engineering, describes the current situation of materials science and engineering and identifies approaches to ensure that Germany remains a world leader in this field.

For the near future, the following possibilities can be identified for the continued work by the acatech topical network for Materials Science and Engineering and for following up on this paper:

- To make the public aware of the significance of materials, an in-depth analysis should throw light on the contributions that materials technology makes to the German gross domestic product across all value creation stages.
- With Germany embedded in the European research world and the continuing trend toward market globalisation, the international and particularly the European situation should be analysed. The Materials topical network of acatech is indeed planning to conduct this type of analysis, in parallel with continuous monitoring of strategic activities. In this regard, it is essential to unite forces across national borders to increase the efficiency of the European research landscape in materials science and engineering.
- In conjunction with other players named in this paper, an informed technical analysis should be executed to identify future key research topics throughout the field of materials science and engineering.

The recommendations presented here will be examined and, if necessary, updated at regular intervals to determine whether or not they are being implemented.

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