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> ORGANIC ELECTRONICS IN GERMANY

ASSESSMENT AND RECOMMENDATIONS FOR FURTHER DEVELOPMENT

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This project was performed in the period of January to December 2010. The acatech board syndicated the paper on 8 February 2011.

PREFACE

Organic electronics are still a young area of technology that comprises applications as diverse as illuminants, photovoltaics, printed electronics and batteries. Replacing inorganic by organic materials, in particular conversion of light to electrical current (photovoltaics) and electrical current to light (light diodes), are promising basic economic and ecological benefits as well as benefits regarding application options and design, e.g. for large-area lighting, flexible displays and generation of energy. However, a competitive, efficient and low cost implementation still requires considerable research efforts regarding theoretical understanding, efficient materials and controlled process technology, i.e. the entire value-added chain.

A medium to long-term global market volume of several hundred billion Euros is forecast for organic electronics. International competition for success in development and implementation into marketable products is accordingly high. This is reflected on the one hand in the considerable expenses for research funding, and on the other hand in the strong commitment of the global economy.

In Germany, research and development in the area of organic electronics has been promoted significantly and specifically over the past years. A strong contributor to this was the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung; BMBF) in the scope of the high-tech strategy in two innovation alliances and a leading-edge cluster, providing € 200 million from public sources, as compared to € 800 million from the industry. Additionally, the German Research Association (Deutsche Forschungsgemeinschaft) promotes organic electronics in two focal point projects. The funding on a federal level is complemented by many state-specific funding measures. Finally, specific programmes in the scope of the 7th framework programme of the European Union are aligned with organic electronics.

This situation led to Germany's overall position in the race for innovations in the area of organic electronics being quite good as compared to the large competitors of the U.S. and Asia, even though it is not entirely leading. To maintain this position in future or to strengthen it and to ensure implementation of research and development results into marketable products in Germany, however, a number of training, science organisation and science policy efforts are necessary in addition to considerable financial expenses. In particular, timely further development of organic electronics in Germany requires the definition of target products that are binding for all actors.

It is no coincidence that acatech is publishing a statement on nanoelectronics as future key technology of the information and communications technology in Germany at the same time[1]. The increasing relocation of the production sites closer to future target markets in Asia is viewed with concern, and concerted action in industrial policy and research funding is requested.

The present position paper is to be seen as an initial study that is to provide the Federation and states, universities, research organisations and companies with an orientation aid for coordinated action using the acatech recommendations. The objective is combining the activities of the promoters, economy, researchers and developers, to prevent large-scale double developments, and to in particular cause researchers and developers to focus on the guidelines and to counter split-up of the activities to release additional forces from synergies.

Organic electronics may be able to open up an entirely new world that can be hardly forecast in detail at this point. It should be worthwhile to participate in the first lines of creation of this new world.

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1 acatech 2011.

EXECUTIVE SUMMARY

Organic electronics are a future technology that promises a market volume of several hundred billion Euros. Lighting, displays, photovoltaics, printed electronics, sensors and batteries are actual or planned areas of application. The competition in development of marketable products is accordingly large, in particular in Asia and the U.S. In Germany, research and development work in the area of organic electronics have been promoted specifically over the past few years, so that the German position in global competition is still rather good overall. To maintain this position in future, and to improve it if possible, actors must develop general binding priorities regarding application objectives in addition to receipt of funding. The present paper develops guidelines in the form of acatech recommendations that are to lead to further coordination of the efforts and thus to strengthening Germany in the area of organic electronics.

Thus, the paper is targeted at politics, funding and research organisations, as well as at researchers and developers in science and the economy. It is based on the results of a workshop and an expert survey, as well as active contribution of a project group made up of specialists who essentially contributed to making the general initial positions more concrete.

With the support of the Federal Ministry for Education and Research (Bundesministerium für Bildung und Forschung, BMBF) and strong industry involvement, two innovation alliances, the OLED initiative and the Innovation Alliance for Organic Photovoltaics (Innovationsallianz Organische Photovoltaik; OPV), have been founded in Germany in the scope of the high-tech strategy, as well as the leading-edge cluster "Forum Organic Electronics", which focuses on cross-sectional subjects of organic electronics. The German Research Association supports organic electronics in the key areas of organic field-effect transistors (OFET) and organic photovoltaics. Additionally, state-specific and European funding is present.

Germany has opportunities in many areas of organic electronics, e.g., in the area of organic materials, organic light diodes (OLED Lighting), organic photovoltaics (OPV) and the area of organic field-effect transistors (OFET), as well as in the low-price segment of everyday electronics, printed electronics and organic batteries. For successful product development, the entire value-added chain "from material to the product", i.e. from material development to plant technology, device production to product integration and application development, is required with a high demand for iterative procedure, with the production and process-technical developments being particularly important.

This is countered by the strengths of the main competitors, which lie in device development and on the product side (USA) as well as in plant technology, device development and on the product side (Asia). Regarding areas of application, in particular Asia is leading in the area of OLED displays and the U.S. are strong particularly in the area of OPV and partially in the area of OFET. Considerable transfer efforts take place in the U.S. and in particular in Asia, which is already the home of the companies that are predominant in the consumer electronics industry. In Germany, considerable effort is therefore required to not only assume a scientific leadership position in specifically selected areas, but to also drive research and development work to a point where implementation into marketable products by the industry is possible.

The present paper is to be considered as an initial study for actors to use the acatech recommendations to draw the required technical and subject-specific conclusions for concerted action. Strengthening research, development and implementation in the area of organic electronics requires close cooperation of the knowledge carriers from basic research to applied research, material and device development to product development under special consideration of the production and process-technical development and inclusion of quality assurance and development of standards. Every gap delays the transfer process.

> **acatech recommends**

to consider not only empiric further development, but also research aligned with basic understanding of organic electronics in addition to be very important. Joint research between institutes of the Max-Planck Society (MPG), Leibniz Society and the universities on the one hand and the institutes of the Fraunhofer Society (FhG) and the industry on the other hand should be promoted to improve the target figures (efficiency, service life, costs) for concrete target products of organic electronics. Ideally, this research should be combined "under a single roof" with extensive infrastructure (e.g. joint institute of the MPG and FhG) in direct proximity to relevant industry and where researchers from basic research to application research, from plant technology to production and process technology meet for a limited time from case to case (up to 5 years).

> **acatech recommends**

to pay special attention to research challenges concurring with a scale-up of materials, devices, as well as production and process technology and to support development and use of open pilot plants with suitable business models under consideration of national and European situations to secure implementation in marketable organic electronics products by the industry in Germany.

Organic electronics as a partial area of material science and material technology are a cross-sectional technology that requires not only intense specialist knowledge, but also interdisciplinary understanding and system thinking from the chemists, physicists, engineers and electrical engineers involved. The training opportunities for specialists and generalists, and thus teaching and promotion of young researchers are not currently meeting the expected demand, in particular in the light of the threatening lack of young researchers in the MINT (Mathematik, Informatik, Naturwissenschaft und Technik) subjects and the migration of researchers and specialists to other countries.

> **acatech recommends**

to increase the attractiveness of studying organic electronics, to integrate organic electronics into present courses of studies in the present centres (where the required framework conditions are present, otherwise establishing a master course of studies in organic electronics), to support cross-faculty work, to facilitate the recognition of studies at other faculties, and to develop interdisciplinary teaching and research staff. To raise the students' interest, the degree of familiarity of the new research area should be increased and the industry should participate in presentation of career opportunities.

The current position of Germany in the leading field is due to the early and intense promotion of organic electronics. Every gap in the chain "from material to product" is an obstacle for implementation of the research and development results.

> **acatech recommends**

to ensure the continuity of funding throughout all stages of the development and value-added chains, bundling funding and further improving coordination between the Federation and the states. Alternative funding and financing models – e.g. in the scope of Public Private Partnerships – should be developed to enhance project-independent sustainable research efforts.

> **acatech recommends**

to continue funding the innovation alliances "Organic Light Diodes" and "Organic Photovoltaics" with their complementary focuses while also creating suitable space for innovative ideas, e.g. in the area of organic batteries and printed electronics. Due to the high economic potential and synergy effects, however, further development of organic displays should also be driven in Germany.

> acatech recommends

to develop present funding offers for start-ups and spin-offs and to align the amount of the funds with the respective technologies, to use a transfer platform to mediate contact with venture capitalists and that politics, sponsors and centres pay increased attention to publicity work for organic electronics to increase the founding motivation in the area of organic electronics.

To maintain and improve the efficiency of investments in research and development, and thus the still-good position of Germany in the area of organic electronics, as well as the opportunities to become not only the leading market but also the leading provider at least in selected areas, further efforts must be made by all parties involved.

> acatech recommends

the founding of a strategy group from the circle of actors (research and industry), in particular to make binding decisions on the priority of developments regarding the target or reference products and to determine the manner and demand of pilot plants, and to procure them in a joint effort. Additionally, beside organic light diodes and organic photovoltaics, organic displays should be considered as well.

Regular exchange between researchers and companies is required for quick implementation of research and development results in products and identification of research demand on questions that pose obstacles in implementation.

> acatech recommends

to design the network of actors in organic electronics to be flexible, open and sustainable and to integrate potential users, in particular small and medium-sized companies with potential for new application options of organic electronics (e.g. the printing industry) at an early point.

> acatech recommends

the organisation of regular status-quo events for the actors from the centres, the remaining focuses with special competences and the projects to strengthen cooperation with and between the centres, discussion of problems, progress and possible implementation and coordination of solutions or further procedures. Such meetings should be organised by the executing agency.

> acatech recommends

not to increase the number of centres in Germany to avoid impairing their visibility and attractiveness for cooperation on scientific and economic, as well as on national and international basis. Public Private Partnership models with key companies of organic electronics should be developed from the centres, not only to finance implementation-oriented developments in the centres, but also to improve combination of science and industry, in particular of companies with a high application potential for organic electronics, and to increase attractiveness of training in the area of organic electronics.

1 INTRODUCTION

1.1 MOTIVATION, OBJECTIVE AND TARGET GROUPS OF THE STATEMENT

The perception that the chemical structure of organic polymers gives them either insulating, semi conducting or – after partial oxidation or reduction – electrically conductive properties smoothed the way for a new research and technology field: organic electronics – development of electronic components based on organic materials. In the 1980s, researchers were able to develop the first functioning organic transistors and, nearly at the same time, the first organic light diodes and solar cells. Since the 1990s, organic electronics have developed rapidly in Germany as well as globally.[2]

Organic electronics promise diverse application options, in particular profiting from the large-scale potential and flexibility of the products. The most prominent ones are organic light diodes (OLED), which are used in lighting systems and displays, organic photovoltaics (OPV) and organic field-effect transistors (OFET), which are already used in printed RFID-tags[3]. Other possible applications are, e.g., in organic batteries, sensor technology, storage electronics and generally in integrated smart systems.

According to the strategic research agency "For Green Electronics from Germany"[4], organic and large-area electronics are forecast to have a global market volume of several hundred billion Euros in the medium and long term, corresponding about to the economic importance of the current conventional silicon-based electronics.[5] The importance of this area of research for Germany is also mirrored in the strong commitment of science and economy. However, it is noted that changes are necessary to stay at the top in future as well. In particular, coordination of the previous efforts of individual actors or actor groups in this area must be considerably improved. The future of organic electronics now more than ever requires an integrated approach involving the science organisations, promoters, companies and associations, as well as politics.

In the recent past, the demand for change has been addressed in many studies and strategy papers on organic electronics. In this context, in particular the white paper "OE-A Roadmap for Organic and Printed Electronics"[6], the strategic research agenda "Towards Green Electronics in Europe"[7], which was developed in the scope of the EU-project OPERA, and its national equivalent "Für Grüne Elektronik aus Deutschland" ("For Green Electronics from Germany") should be mentioned. These papers mark a milestone of national and European activities and form the starting point of this statement.

In this sense, the present paper should be an orientation aid for the Federation and states, as well as for universities, funding originations and companies. The actors' activities in the area of organic electronics should be coordinated or combined. Implementation of the recommendations named in this paper should contribute to securing Germany's strength in the area of organic electronics in future as well and to develop it further.

The present statement therefore is targeted at all actors involved along the value-added chain of organic electronics. First, the target group comprises researchers and developers from science and economy to enter into market- and future-oriented research and development cooperations. Secondly, this paper is targeted at politics and sponsors to continue or develop requirement-compliant funding programmes that enable research success in the key areas while also pro-

2 Cf. Klauk 2007.
3 Radio-frequency identification Tags.
4 VDI-TZ 2009.
5 Cf. VDI-TZ 2009, p.6.
6 OE-A 2009.
7 OPERA 2009.

viding incentives for commercialisation. Thirdly, this statement is targeted at universities and science organisations to take up research focuses and ensure training of qualified young researchers for this highly interdisciplinary technology field. Not least, this statement is an orientation aid for the economy, which requires clear future perspectives for targeted action for investments in this promising technology field.

Organic electronics are a young technology field. Therefore, it still faces mainly research- or science-oriented challenges along the value-added chain – from synthesis of suitable materials to production and process technology. However, this chain must continue without any gaps to create the prerequisites for the fastest possible implementation of the research and development results in marketable products. For this, actors must cooperate throughout the chain of development to increase synergies and determine priorities for leading products and thus for targeted research and development tasks. In this sense, the present paper is an initial study to enable the actors to draw the required technical and subject-related conclusions from the recommendations.

1.2 METHODS

The basis for this paper was created in a start-up workshop that was performed on 18 May 2010, managed by Hartwig Höcker. In this workshop, ten science and industry experts for organic electronics reported on research challenges for the pure research and application, implementation of research results into marketable products and the position of Germany in this research field in international comparison. The lectures illuminated the developments of organic electronics from different perspectives and provided important impulses for this statement.

A hypothesis-based procedure was chosen as a method approach: Based on the contents of the initial workshop, the project group discussed problem areas and condensed them to four fields of activity. Initial positions were generated and then validated, detailed and developed further in expert discussions and investigations in these fields.

In a quality survey in the period from July to September 2010, selected experts on organic electronics and from the adjacent disciplines were interviewed in a structured manner. All in all, 37 interviews were conducted with 39 experts in the scope of this project. The interview partners from science and industry were selected in the light of the widest possible distribution among the different partial areas of organic electronics and along the chain "from material to product". Accordingly, the experts were chosen from the areas OPV, OLED-light/display and OFET, as well as along the value-added steps material, device and process development, plant technology, application development and end users. The focus was mainly national, supplemented by some selected experts from other European countries and the U.S.

The expert circle comprised contacts from science, industry and politics, as well as the different science organisations.

Expert interviews and the available conclusion reports were also used to select completed and far-progressed BMBF-funded projects for the leading-edge innovation alliances for organic light diodes and organic photovoltaics to derive factors for success for future projects. The considered projects were selected in close coordination with the executing agency VDI-TZ of the BMBF.

The results of the examinations were reconciled with the present activities, initiatives and strategy work in Germany and abroad.

1.3 INITIAL POSITIONS

The ten following initial positions formed the recurrent theme for the interviews and are detailed in the following chapters of this statement.

> Initial positions on the importance of organic electronics in Germany

"Germany has a mainly leading role in organic electronics; it cannot be maintained without intensifying and focussing the present systematic funding, however."

"Organic electronics are a future technology that requires, among others, development of leading products for a commercial breakthrough."

> Initial positions on the chain "from material to product"

"To drive development of marketable products, organic electronics absolutely require close cooperation between material, device and process development as well as the associated plant technology."

"Understanding of the theoretic basics is an important prerequisite for development leaps in the capacity of materials for organic electronics."

"Differentiation between basic research and application-oriented research is not suitable in the area of organic electronics because it facilitates the appearance of a gap."

"Standardisation and production-accompanying quality assurance are prerequisites for efficient development and production of marketable products in organic electronics."

> Initial positions on promotion of young researchers in organic electronics

"There is a lack of young researchers in the area of general sciences for the strongly interdisciplinary organic electronics. The present thinking in terms of faculties makes it difficult to work in an interdisciplinary manner in organic electronics."

> Initial positions on promotion of organic electronics

"Flexible promotion models for development and operation of pilot plants in present centres are essential for implementation of research results in marketable products in organic electronics."

"Further development of organic electronics is performed in complementary centres with international connections that enable cooperation of leading-edge scientists across state borders as well."

"The insufficient growth funding of start-ups prevents early commercialisation of organic electronics in Germany."

1.4 STATEMENT STRUCTURE

To strengthen Organic Electronics in Germany, three large fields of actions become evident for science, economy and politics. This statement is structured accordingly. As an introduction to the subject and to mark the initial situation, chapter 2 provides an overview of the current situation and the development trends that become obvious for organic electronics in Germany, the backgrounds of research and development and an insight into the previous promotion of this area of research. The three subsequent chapters 3, 4 and 5 detail strengths and weaknesses and contain recommendations on the future alignment within the three fields of action research, development and implementation of results in marketable products, support of young researchers and promotion. Chapter 6 discusses recommendations that were not assigned to any of the three fields of action due to their cross-sectional character. These superior recommendations call for joint efforts of the actors involved. In the final chapter 7, organic electronics are placed in the context of material science and material technology, as well as nanoelectronics.

The common structure into the different subject areas of application of organic electronics is not used in this statement because the strengths and weaknesses, as well as recommendations for action often cannot be limited to one area, but must be considered across areas. Therefore, examples are used to refer to peculiarities of different areas in points where concretisation is required. The explanations of this position paper refer to all application areas of organic electronics equally where not specified differently.[8]

8 For better legibility, this paper dispenses with the female form. Even if only the male form of a term is used, the female form is meant as well.

2 ORGANIC ELECTRONICS IN GERMANY

2.1 A FUTURE TECHNOLOGY FOR GERMANY

Organic electronics have strongly increased in importance in Germany over the past years. Growing public interest and increasing activities of the companies and associations in organic electronics can be interpreted as indicators of pending market penetration.[9] The attention OLED-technology has received at the International Radio Exhibition (Internationale Funkausstellung) IFA 2010 in the form of TVs, video goggles and mobile applications shows the enthusiasm this new technology can inspire. Organic electronics raise hopes for new technology and environmentally compatible applications[10] and opportunities for a new industry sector in Germany.

A market volume in excess of €100 billion is forecast for organic electronics within the next 15 years.[11] For some areas, substitution of present products make it possible to build on present market data, e.g. in case of TV and lighting applications. In other areas, however, entirely new products and markets are created, e.g. for cheap printed electronics. This makes it more difficult to estimate the market. The current market penetration of organic electronics products is still low. Organic displays, however, have already gained significant market shares. The pioneer was the Japanese company Pioneer Corporation, which brought the first car radio with an organic display on the market in 1997.[12] This initiated the rapid development of organic displays, which achieved a global, strongly growing market of € 590 million by 2009.[13] Organic materials, as in other areas of organic electronics, hold a considerable share of the value generation.

The organic materials, their synthesis and optimisation, are of particularly high importance for the technology field of organic electronics. They are expensive and difficult to develop and produce and form the basis for electronics due to their electrical characteristics. The estimation that the driver for approx. 70 % of the mega trends is the material[14] can likely also be applied to organic electronics. A strong chemical industry and material-science know-how in Germany therefore are a good basis for global competition. Germany's chemical industry is one of the most innovative ones around the world. It has continually developed its important position on the global market.[15] German companies play an important role in the area of organic materials. Companies like BASF, Evonik and Merck, as well as start-ups like Novaled, have developed a strong position and excellent reputation beyond Germany.

An extraordinary position solely in the area of materials, however, is not sufficient to keep as great a part of value generation as possible within Germany. The past showed that forward integration of the value-added steps subsequent to material promises success. For example, cooperation enabled BASF to integrate the steps following varnish production by cooperation and to operate painting lanes in the automotive industry together with a partner.[16] In organic electronics, these value-added steps subsequent to the material correspond to the development and production of organic devices and integration of the devices into the final product.

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9 Cf. VDI 2008, p.118.
10 Cf. OPERA 2009, p.1.
11 Cf. Schwoerer 2008, p.29.
12 Cf. Brütting 2008, p.34.
13 Cf. Displaysearch 2010; conversion rate: 1.4 EUR/USD.
14 Cf. Höcker 2007, p.89.
15 Cf. BCG 2006, p.61.
16 Cf. BCG 2006, p.60 f.

Products represent integration of the device into an end-user compatible environment. This development and value-added step is only partially covered by large electronics providers in organic electronics yet, in particular in Germany.

Other opportunities of keeping value generation as high as possible at the site of Germany are offered by the option of establishing new value-added chains with new OEM beyond the present value generation structures. Device development is equal to development of products in some applications, e.g. for OLED lighting. Differentiation between lamp and luminaire is no longer sensible with organic LEDs. Device development and production in this case already comprises the essential step to the product. Product design merges with development of the device. This opens up opportunities for companies with device know-how to appear on the market as an end-product provider. The OLED lighting area offers a special opportunity in this context. The global market of the year of 2018 is expected to be at € 4.3 billion.[17] Supported by a strong illuminant industry (e.g. Osram, Philips) and start-ups (e.g. Novaled) and targeted promotion, Germany managed to achieve an extraordinary position. It offers the potential of serving a great part of the future global market for OLED lighting.

Another opportunity for organic electronics is also seen in addressing the low-price segment of everyday electronics that has not yet been developed due to the high costs of silicon-based electronics.[18] Cost-reduction potentials are mainly seen in the development of mass production procedures for organic electronics, such as the "roll-to-roll" printing technology.[19] Therefore, Germany is able to use the structure change in the strong printing industry[20] and to build on its strengths in machine and plant construction to take a leading role as technology supplier and user in organic electronics.

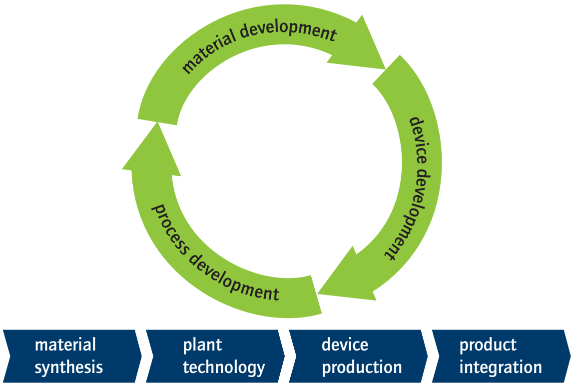
2.2 THE CHAIN "FROM MATERIAL TO PRODUCT" IN ORGANIC ELECTRONICS

The chain "from material to product" – and in organic electronics, this is in particular: "from molecule to product" – reaches from material research and the development of plants and devices to implementation of research results in marketable products. It therefore comprises all stages of the product development process and connects science and economy, linking research and development at all stages of the value-added chain.[21]

Fig. 1 sketches the chain "from material to product" for organic electronics. The low technology maturity and requirement of customised materials currently make the research and development steps particularly prominent. The circular area mirrors the typical strong links and the need for an iterative procedure in the development of organic electronics products. The main components of this chain are material development and synthesis, device development and production as well as the connected process development and plant technology. Product integration is a step specific to organic electronics in new products.

17 Cf. Displaysearch 2009, conversion rate: 1.4 EUR/USD.
18 Cf. BSI 2007, p.132.
19 Cf. Fix 2008, p.45.
20 Cf. Apenberg 2010.
21 Cf. acatech 2008, p.19.

Fig. 1: The chain "from material to product" in organic electronics (blue arrows). The circular area comprises theory, modelling and design and indicates the high demand for an iterative approach.



> Material development and synthesis

Organic electronics are characterised by a great diversity of materials. Among others, the characteristics of organic materials depend on the molecular structure and the orientation of the molecules in the device, which in turn is influenced by the process conditions.[22] In contrast to silicon-based electronics, in which the characteristics of the starting material are mainly known, the material and structural diversity of organic materials makes it difficult to understand the basic characteristics and interrelations of effects. Determination of quantitative structure-characteristics relations are essential here. Applications of organic electronics always require development of customised materials on a molecular level. For example, a special challenge is finding material combinations for printed transistors in which the different chemical substances in contact do not react with each other.[23] Because the organic materials decisively influence the performance of the device,[24] material development and synthesis is one of the main value-added steps of organic electronics, and thus an important research focus. Stability of organic materials for OPV-cells and organic electronics in general is particularly important; first progress could already be made for OLEDs.

> Device development

The device is the core of value generation in organic electronics. Technical and economic requirements to the device indicate the direction of research and development activities on all value-added steps. Device development as such is a complicated step in the development and value-added chain. Different materials must be combined in several layers of different thickness and great uniformity in each individual layer to achieve a certain function and performance of the device.[25] Device development therefore requires basic knowledge of the material characteristics and their interactions and, ideally, conclusions from the desired characteristics to the required molecular structure of the organic materials. This close technical link between material and device development requires a high degree of coordination and feedback along the value-added chain.

> Process development and plant technology

Devices are manufactured by coating and print procedures. For this, thin layers of different materials in the nanometer area are applied on top of each other.[26] Both procedure options – liquid phase technology known from the application of paper print and coating by deposition from the gaseous phase originating from semiconductor technology – pose specific requirements to the material to be processed, and are only partially competing technically.[27] Great potential

22 Cf. Schwoerer 2008, p.29.
23 Cf. Fix 2008, p.48.
24 Cf. VDI 2008, p.120.
25 Cf. OE-A 2009, p.51.
26 Cf. BSI 2007, p.139 f.
27 Cf. Leo 2008, p.40.

for low-cost mass production is seen in the print procedures. However, they still require high research and development effort.[28] Printable electronics are very important for further technology development, from development of materials and procedure technology to development of suitable print procedures and machines.

Production processes and plant technology must be optimised mainly regarding technical target figures like maximum material yield and homogeneous layer thickness.[29] Another requirement is serial capability, i.e. quick and efficient production, which is growing more and more important. Development of the production and process technology therefore is closely related to material and device development and cannot be performed isolated from these stages of development.

> Product integration and application development

Integration into an end product places organic electronics in an end-user environment. This results in essential requirements to the device, derived from the needs of the potential user. Thus, product integration and application development provide an interface between technology and market. The partially still-missing sales market is an obstacle to be overcome. In part, development of products is partially connected to development of an entirely new market in organic electronics. This gives product- and application development strong business-management characteristics.

2.3 PREVIOUS PROMOTION OF ORGANIC ELECTRONICS

Research and development in organic electronics were strongly promoted by the Federal Ministry for Education and Research in two innovation alliances and a leading-edge cluster (Spitzencluster) in the last few years. The focus of these new promotional instruments, which were introduced in 2006 in the scope of the High-Tech Strategy, is on the interaction of science and economy. The objective is mobilising considerable industry investments, e.g. in case of the innovation alliances, where "one Euro of the Federation moves five Euros of economy".[30]

In the area of organic electronics, two innovation alliances (consisting of consortiums from industry and research institutes) have been developed to address the two future markets OLED and OPV. The "OLED-Initiative", which comprises four project areas with five to eight partial projects each in the first phase, processes questions from the area of organic light diodes for lighting applications and displays. With a public funding of € 100 million and another promised € 500 million from the industry, they are currently the biggest promotion initiative in the area of organic electronics.[31]

The "Innovation Alliance Organic Photovoltaics" (OPV), consisting of 15 project areas in the first project stage, primarily has the objective of improving the efficiency of solar cells made of organic materials and to improve their service life.[32] The "Innovation Alliance OPV" is publicly funded with € 60 million, as compared to € 300 million of industry investments.[33]

In addition to the two innovation alliances, an open-subject leading-edge cluster competition was performed in the scope of the High-Tech-Strategy. The connected promotion is intended to enable the competition winners to "sharpen their profiles, remove strategy development inhibitors and develop into nodes with international at-

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28 Cf. VDI 2008, p.118 f.
29 Cf. Leo 2008, p.42.
30 www.hightech-strategie.de/de/693.php [Version: 10.10.2010].
31 Cf. BMBF 2008, p.26.
32 Cf. BMBF 2009, p.37.
33 Cf. BMBF 2008, p.26.

traction".[34] One of the five winners of the first round is the "Forum Organic Electronics" in Heidelberg, which founded the Heidelberger Innovation Lab[35] as a joint R&D platform for university and industry in the form of a PPP; it is funded with € 40 million for a period of five years. In contrast to the two innovation alliances focussing on OLED and OPV, the leading-edge cluster takes up cross-sectional subjects that are relevant for all matters of organic electronics.[36]

In addition to intense promotion by the BMBF, organic electronics are promoted by the German Research Association (DFG). While the BMBF focuses strongly on know-how transfer between science and economy and therefore consistently requires industry participation as a prerequisite for funding of research projects, the DFG pursues open-subject, widespread funding of excellent basic research. Furthermore, the DFG has been supporting organic electronics since 2001 in the focus areas of organic field-effect transistors (OFET) and organic photovoltaics (OPV).[37] The Federal-level promotion is supplemented by many state-specific research, technology and innovation-political funding activities.[38]

On a European level, organic electronics, and in particular their further development to market maturity are also promoted considerably. In the seventh research framework programme, a promotion of organic electronics is planned in the scope of the specific "Cooperation" programme in the subject area of information and communications technologies. At this time, the planned funding totals at € 143 million.[39] The focus of the projects promoted here is on further technology development on all stages of the value-added chain.

Furthermore, promotion of production processes for producers of organic and large-area electronics (OLAE) is planned in the scope of the Public Private Partnership "Factories of the Future" (PPP FoF). It is to comprise a sum of € 20 million. The projects of this funding measure are to be industry-driven and also comprise quality control, test and assessment routines to prove feasibility of production on an industrial scale.[40]

The intense promotion on national and European levels significantly contributed to develop the position of Germany in the leading fields on many areas of organic electronics. To maintain and develop this position, which will be considered in even more detail in the following section, supplements and realignments will be required in future, among others on the promotion side (cf. chapter 5).

2.4 THE POSITION OF GERMANY IN THE LEADING FIELD IS CURRENTLY NOT UNCHALLENGED

The market for organic electronics is currently characterised by great dynamics,[41] making most science and economy leads only short-lived. This offers opportunities for Germany to take up other areas and value-added steps of organic electronics. At the same time, however, there is the risk of being pushed from the leadership position.

> Three regions compete for global leadership in organic electronics

Asia and the U.S. are the essential competitors of Europe in organic electronics. The experts asked concur that Germany

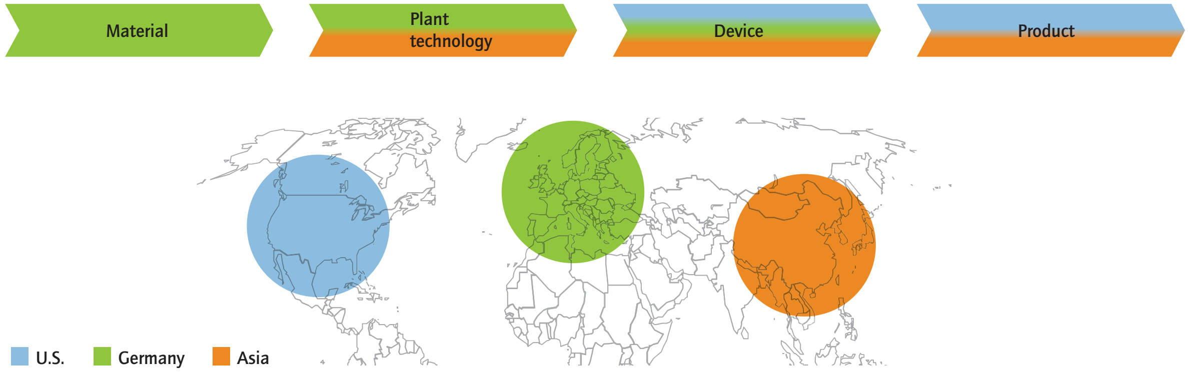
34 BMBF 2006, p.12.
35 www.innovationlab.de.
36 Cf. BMBF 2010a, p.142.
37 SPP 1121: Organic field-effect transistors: structural and dynamic characteristics (2001-2009, € 10 million) and SPP 1355: elementary processes of organic photovoltaics (since 2008, up to now 4.8 M. Euro).
38 Cf. BMBF 2010a, p.197 ff.
39 This number is comprised of the following individual sums: € 50 million from WP 2011 (p. 54), € 30 million from WP 2009/10 (p. 47) and € 63 million from WP 2007/08 (p. 28), each in Challenge 3: Components, Systems, Engineering.
40 Cf. Gillessen 2010, p.10.
41 Cf. OE-A 2009, p. 7.

holds a leadership position in global comparison and in particular in Europe. This leading role, however, is not unlimited. It does not apply for all stages of the value-added chain. Differentiated consideration throughout all areas of application along the value-added chain and referring to the different areas of application of organic electronics is required to specify the position of Germany in international comparison.

The position of Germany along the value-added chain through all applications of organic electronics is shown in fig. 2. One of Germany's strengths is seen in the globally established and committed chemicals industry, which supports both development and production of materials for organic electronics. Together with research facilities and innovative start-ups, this makes a considerable contribution to development of the know-how on organic materials and the subsequent value-added step of the devices. The leadership position of Germany in printing technology and the printing machine industry should also benefit successful economic implementation of organic electronics. Therefore, the commitment of large companies like Heidelberger Druckmaschinen AG is very important. Although engineering and plant technology are the "poster industries" of the German economy, in particular Asia now has some serious competitors. Experience in the production of OLED-displays and the present plant infrastructure for LCD production gives Asia a structural advantage that promotes further development of plant technology.

Therefore, Germany has to share its leading role in plant technology with Asia. In device development and production, the leadership position is also split between the regions. In future, Germany will need to increase its efforts for

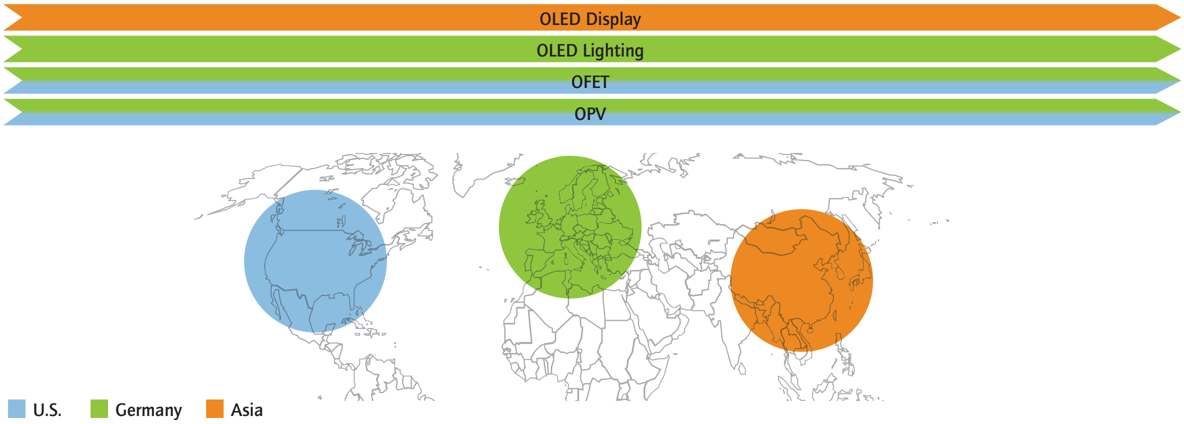
Fig. 2: Leadership positions along the value-added chain



generation of organic electronics end products. Asian and U.S.-American companies were able to put products on the market early and to achieve initial economic success. Opportunities for Germany to make good lost ground are present in particular in successful commercialisation of OLED lighting products. Their development on the end product level is already intensely driven in Germany by Philips and Osram (OLED-luminaries and lamps). In the area of OPV, first products have also been announced by Heliathek. PolyIC has performed initial customer sampling in the OFET area. Far-reaching new market potential is expected from development of organic electronics using cost benefits and flexibility for classic electronic applications.

Considering the present know-how in selected areas of application throughout the value-added chain, the wide placement of the research and development landscape in Germany (cf. fig. 3) becomes obvious. A leadership position is achieved in particular in the area of OLED lighting, where Germany is attributed the largest know-how around the world, along with some Asian companies (and specifically the Japanese ones). Initial OLED lighting products from Germany[42] reflect the currently present advance in this area of application. In the areas of OPV and OFET, Germany also has wide-spread and internationally recognised know-how, as do the U.S. Regarding organic displays, the Asian region, and in particular Japan, Korea and Taiwan, have an unchallenged leadership position that is not only reflected in the present know-how, but also in the current market shares.

Fig. 3: Leadership positions in selected areas of application



42 Examples are OLED lighting modules of the “Lumiblade” series by Philips and the light tile “Orbeos” by Osram.

Asian companies serve the currently strongly growing market for OLED displays of approx. € 590 million almost entirely.[43] Germany only has know-how in niche areas, such as micro displays or the much less developed printed displays.

All in all, it must be noted that Germany has a mainly leadership position along the value-added chain and in different areas of application for organic electronics in international comparison. Germany was able to achieve this position in particular due to targeted promotion in the past and intense commitment of industrial actors. Germany has the best prerequisites to hold key roles in decisive steps of the value-added chain and in most areas of application.[44] The current initial situation, however, is marked by a clear weakness: A development that has already happened in other technologies before is becoming apparent: While Germany has great know-how in rather application-remote stages of technology development, implementation of the excellent research results in products successful on the market is not driven with the required perseverance.[45] Considering this context in the light of the value-added and development chains, Germany's leading role is increasingly threatened with increasing market proximity. This must be countered specifically.

> Asia and the U.S. are moving towards commercialisation more strongly than Germany

In other regions, the transfer of research and development results to the market is driven more consistently. In particular in Asia, there are efforts to entirely claim value generation in organic electronics if possible. This strength for implementation in products accelerates further development of the entire technology field, in particular by high industry investments. To maintain the current technology advantage, Germany is therefore subject to considerable pressure to produce innovations, i.e. organic electronics products successful on the market, exceedingly quickly and frequently.[46]

In the competition for the leadership position in organic electronics, Asia holds a decisive advantage: the local OEM like Samsung, LG or Sony rule the consumer electronics industry.[47] Asia also holds a global market share of nearly 60% on the level of contracted work for electronics, giving it a better initial situation than Germany has.[48] These basic structural benefits are expressed in mainly compatible value-added chains and structures, e.g. in the production of LCD- and OLED-TVs. Quick commercialisation of organic displays in Asia proves that the local industry there is able to play its advantages. Many experts assume that in particular mass production of OLED displays may move entirely to Asia in the future.[49]

The present industry lead in the area of OLED-displays in Asia is supported by a targeted promotional policy; as experts believe, particularly exceeding the pre-competition stage. For example, the Korean government directly supports development of a mass-production capable production plant for OLED lighting and training of 300 corresponding workers.[50] To accelerate commercialisation, Asia started several national funding programmes. In Japan, e.g. the activities of NEDO[51] can be highlighted in this respect. Some of them are explicitly aligned with the commercialisa-

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43 Cf. Displaysearch 2010; conversion rate: 1.4 EUR/USD.
44 Cf. VDI-TZ 2009, p. 6.
45 Cf. Wissenschaftsrat 2007, p. 29.
46 Cf. Pickartz 2010.
47 BCG 2006, p. 51.
48 Cf. VDI-TZ 2009, p. 13.
49 VDI-TZ 2009, p. 31.
50 Cf. OSA 2010.
51 The New Energy and Industrial Technology Development Organization is one of the semi-state funding organisations in Japan, subject to the Ministry of Economy, Trade and Industry (METI).

tion stage of new technologies (cf. excursion on NEDO in chapter 5).

In the long term, it can therefore be assumed that production capacities for other areas of organic electronics will be developed in Asia. In this context, it is questionable whether the global change of the production focuses will also lead to a change of other value–added activities and in particular of research and development in the long term. Research and development activities making use of lots of implicit know-how and thus requiring close coordination of the knowledge carriers can only be performed sensibly at a joint site.[52] This mainly affects subjects close to production. What share of research and development and value generation can be kept in Germany?[53] Will Asia's leadership in the area of OLED displays be followed by leadership in other areas of application of organic electronics?

Such questions will arise if it is not possible to keep production in Germany.

The initial situation as described is characterised by acute danger to Germany's position in all facets of organic electronics. Material and plant technology from the Asian area are gaining an increasingly strong role on the global market, driven by technology synergies of the ambitious OLED displays. Even now, most of the materials for the displays are developed and produced in Asia as well.[54] Even German pilot plants, e.g. in the COMEDD at the Fraunhofer IPMS in Dresden, are realized with Korean coating plants due to the advantages of Asian plant technology.[55]

> The U.S. mainly focus on organic photovoltaics

While Asia has covered the field of organic displays, the U.S. seem to be striving for a leadership position in organic photovoltaics. One focus of U.S.-American funding programmes is on organic photovoltaics, founding great know-how in the U.S.[56] At the same time, the U.S. is an organic photovoltaics pioneer as well. The U.S.-company Konarka Technologies is the current technology leader. Other companies, such as Solamer Energy, Plextronics and Global Photonic Energy, clearly show the intensity with which the U.S. drives commercialisation of organic photovoltaics.

The U.S. efforts of conquering the market for organic photovoltaics are mainly countered by the activities of the company Heliatek and its outstanding know-how in Germany. Even though Germany has a good general initial situation for organic photovoltaics,[57] the intense activities in the U.S. are a threat to it. There are not only opportunities on a potential global market, amounting to about € 3.4 billion[58] by 2020. Technology synergies also act on materials and plant technology - similar as with OLED displays – and may launch off other areas of organic electronics. In particular, there are synergies between organic photovoltaics and OLED lighting.[59] The global leadership position of Germany in the area of OLED lighting therefore can be threatened by progress of the U.S. in the area of OPV, but is at the same time a great starting situation and opportunity for organic photovoltaics in Germany. In the area of OFET, the draft technology for integrated organic electronics components is an important subject. Adjustments and new developments are required to deal with the different characteristics of OFET as compared to silicon components. The great

52 Cf. Schuh et al. 2008, p. 851.
53 E.g. the German company Merck is a global market leader for liquid crystals for LCDs in spite of the dominating position of Asia in the end products (cf. BCG 2006, p. 60).
54 Cf. VDI-TZ 2009, p. 30.
55 Cf. COMEDD 2009, p. 15.
56 Cf. Furr 2009.
57 Cf. VDI-TZ 2009, p. 21.
58 OPERA 2009, p. 27.
59 Cf. VDI-TZ 2009, p. 29.

competence present in Germany for circuit draft and EDA can be used here to quickly achieve a leadership position in international competition.

It becomes clear that the quick commercialisation of the areas of OLED Display and OPV in Asia and the U.S. reduce the opportunities for German companies to gain a hold on these markets in spite of the present know-how. Furthermore, technology synergies between the areas of application of organic electronics, combined with the implementation strength of Asia and the U.S. also threaten the areas of OLED lighting, OPV and OFET, where Germany is still currently the global market leader.

Therefore, there is the question of how Germany can defend its leading role in OLED lighting, OPV and OFET and on the value-added steps materials, plant technology and devices, and take the present market opportunities.

2.5 CONSIDERABLE EFFORT IS REQUIRED TO MAINTAIN THE STRONG POSITION

In the last years, Germany has developed a great starting position in many areas of organic electronics. Maintaining this starting position and developing it further, however, is a great challenge in the race with the efforts of other regions. Organic electronics are only sustainable in Germany by faster implementation of research and development results in marketable products. This becomes clear in the critical condition of the position of Germany in global competition: Germany is falling behind more and more as compared to Asian and U.S.-companies with increasing market proximity.

The currently present implementation weakness becomes clear, among others, in the example of company foundations. In spite of the very good public funding for new foundations in Germany in international comparison[60], the founding climate is rather muted. Careful founding culture and low risk tolerance are significant inhibitors. Access to venture capital from potential investors also often poses challenges difficult to solve for young entrepreneurs (cf. chapter 5).

Regarding technology, organic electronics are not yet mature and partially only at the threshold to market maturity. There are still some essential research challenges in material development and development of production and process and the corresponding plant technology. Cost reduction and yield increase are necessary. Device concepts must have error tolerances and the lowest possible complexity to make production as simple as possible. In particular tasks resulting from "scale-up" – from lab to production scale – are very important (cf. chapter 3.1). To meet these challenges, science and economy increasingly demand development of suitable infrastructure in the form of pilot plants (cf. chapter 3.3). With increasing market development of organic electronics, the demand in qualified specialists will also increase, and must be met with adequate training opportunities (cf. chapter 4). In the future, funding must be aligned with the changed needs of the developing technology fields.

Germany's present know-how in the area of organic electronics could be achieved mainly by efficient funding, which is also positively emphasised abroad. The research tasks on the way to market maturity and the competition situation

60 Cf. GEM 2009, p. 26

caused by international market dynamics clearly show the need to adjust public funding (cf. chapter 5).

Germany has a great technology basis for organic electronics and well-developed infrastructure in its value-added chain to meet the technology, economy and politics challenges. Targeted measures in research (cf. chapter 3), young researchers (cf. chapter 4) and funding (cf. chapter 5) can meet such challenges and anchor organic electronics in Germany in the long term. However, joint efforts by all actors from science, economy and politics are needed to successfully solve the associated tasks (cf. chapter 6). The development and establishment of leading organic electronics products possible under these prerequisites enable perception of the technology fields on the market and thus increase demand for other organic electronics products. If this is not successful, Germany may fall behind internationally, as has already happened in the past in the area of organic displays.[61]

61 Cf. IZT 2008, p. 230 f.

3 RESEARCH, DEVELOPMENT AND IMPLEMENTATION IN PRODUCTS

3.1 CHALLENGES ALONG THE CHAIN "FROM MATERIAL TO PRODUCT"

The technology challenges of organic electronics are in particular improvements in the three dimensions of efficiency, service life and costs of the devices. Efficiency increases, for example, are expected from new, improved materials and alternative stacks of the different material layers in the device. To increase the service life, not only more stable materials, but also, for example, new and more efficient encapsulation materials and technologies are on the research agenda. Cost reduction is expected in particular from new production methods and plant concepts that enable better material synthesis, higher material yield and higher throughput while also minimising rejects. Furthermore function expansions, e.g. in the form of flexible or transparent devices are intended, for which mainly suitable substrates and materials for encapsulation must be developed.

The respective specific research challenges for the different areas of application of organic electronics were already addressed in many strategy papers: to coordinate national and European research activities, the strategic research agenda "Towards Green Electronics in Europe" was developed in the scope of a European research process, which has also developed the basis for the national equivalent "For Green Electronics from Germany ".[62] The Organic Electronics Association (OE-A) also collected a roadmap of the short, medium and long-term application potentials of organic electronics and the respective specific "Red Brick Walls".[63] In the Network of Excellence PolyNet, funded in the scope of the seventh research framework programme, the "White Paper on PolyNet Critical Research Issues" was developed to provide a well-structured collection of relevant research subjects of the 16 partners involved and their reconciliation with the above strategy papers.[64] Exceeding the natural and engineering sciences questions, the chain "from material to product" of organic electronics is characterised by a number of structural challenges in Germany that should also be at the focus of future activities.

Research and development of organic electronics are currently still mainly characterised by "Trial and Error" on several stages of development. Systematic trial achieves step-by-step approach of the solution of a practical task, e.g., development of a new organic material with certain characteristics in the device. This iterative procedure is characterised by a high degree of insecurity and low efficiency in particular in organic electronics. On the one hand, organic electronics has several input parameters on which later system characteristics depend: The diversity of organic and other materials and the complex layer structure of the device open up a great number of options of combinations from which suitable combinations must be selected and tested in experiments. Secondly, errors are often only found in late stages of development (e.g. when testing the device). This increases the effort of development projects. Long development cycles are a consequence of the interactive development step sequence; the success of research and development projects becomes difficult to calculate, in particular impairing implementation and thus the industry, and reducing willingness to invest. Progress is possible by application and further development of combinatory material research (in synthesis, formulation, screening etc.).

> Lack of understanding of basics makes efficient material development difficult

Currently, there is no systematic understanding of the effective interrelations of the molecular structure of the organic material and its electronic solids properties.[65] Knowledge of these structure-property relationships is the basis for

62 OPERA 2009; VDI-TZ 2009.
63 OE-A 2009.
64 Engquist 2009.
65 Cf. OPERA 2009, p. 8 sowie VDI-TZ 2009, p. 10.

simulation techniques that in turn are the starting point of targeted research away from "Trial and Error".[66] In the past, know-how gained in basic interrelations led to essential development benefits, e.g. the change from fluorescent to phosphorescent emitters in the late 1990s, achieved by growing understanding of the theoretic basics and leading to considerable increase of the luminosity of OLEDs.[67]

The difficulty in gaining this basic knowledge is in the already indicated diversity of organic raw materials and material structures, the complexity of the device structure and complex interactions of the active layers in the device.[68] Even though comprehensive understanding of theory cannot be achieved in the short term, increasing knowledge in these basics should be an objective. Better understanding of the structure-property relation forms the basis for targeted material and device development. Here, the organic material can be selected and developed based on its expected property in the device.[69] Following this construction-element-level-related subject is the draft method on system level, which must be aligned with making the best of the present device properties. This level must be included in development early on in the sense of "Concurrent Engineering". Since silicon technology in Germany already poses very good prerequisites for this, in particular reconciliation of the experts and coordinated cooperation are required.

The diversity of organic materials, which poses an opportunity and challenge in product development at the same time, can be limited with reference products to be determined. The materials and production technologies must be placed at the focus of the work that is required for development of the reference products.

Empiric research will remain an elementary component of organic electronics in the short and medium term. Only increasing technology maturity and limitation of the organic materials to a controllable number will create a basis for building a holistic understanding of the effect interrelations. This requires the corresponding framework conditions (better coordination between the promotion facilities, in particular the DFG and BMBF, and the research facilities, Max-Planck Institutes and universities on the one hand and Fraunhofer Institutes and industry labs on the other) to permit targeted empiric research while also supporting development of a systematic understanding of the theoretic basics.

> Cooperation of the knowledge carriers along the development and value-added chains

Empiric research is still very important, and the characteristics of organic materials and performance of the device are directly connected. This leads to a high coordination need across value-added steps and thus requires interdisciplinary reconciliation.

Interdisciplinary system thinking therefore is a prerequisite for success in research and development in organic electronics, also reflected in the requirements to young researchers (cf. chapter 4).

Another important prerequisite is close cooperation among the partners involved across value-added steps. Among others, this is due to the strongly fragmented value generation of organic electronics. In Germany, the value-added chain is little integrated in vertical direction, in particular regarding functional materials.[70] In contrast to strongly integrated chains, this lack of vertical integration leads to a high number of companies and research facilities that are involved with the path from material research to product innovation. Efficient development and production of organic electron-

66 Cf. MPG 2001, p. 54.
67 Cf. Thompson 2007, p. 21.
68 Cf. Lee 2010.
69 Cf. BAO 2007, p. 6.
70 Höcker 2007, p. 49.

ics products therefore are always based on the smoothest possible cooperation between companies and research facilities along the development and value-added chains. This insight is already used intensely, e.g. in the Science-to-Business Centres of Evonik. Researchers and developers cooperate along the entire value-added chain. The competences reach from basic research to product development to production of finished systems. Cooperation with universities, research institutions and potential customers intensifies the basic knowledge, and customer requirements can be considered early on. Thus, the period from invention to market introduction of a product or process is abbreviated. In 2005, the Science-to-Business Center "Nanotronics", focussing on integration of nanotechnology and electronics, was founded in Marl, in which projects like "printed electronics" or "low-cost, flexible solar cells" are processed.

COOPERATION ACROSS VALUE-ADDED STEPS IN EVONIK SCIENCE-TO-BUSINESS CENTRES[71]

At Evonik, innovations for which no technologies and markets are known yet are driven in so-called Science-to-Business Centres. Science-to-Business Centres are part of the strategic research and development unit "Creavis" (Creavis Technologies & Innovation). Their objective is developing sustainable business fields and future-oriented technology platforms.

Science-to-Business Centres cooperate across value-added steps. For this, employees for all research and development activities work together "under a single roof". This includes not only employees of Evonik but also young researchers, engineers and researchers from other companies. This vertical view of the innovation process from basic research to product marketing brings with it a high degree of interdisciplinarity. Cooperation with potential customers aligns research and development activities with their needs early on. This reduces the time from idea to marketing of the products.

The first Science-to-Business Center "Nanotronics" was opened in 2005. Its name symbolises the connection of nanotechnologies and electronics applications. Research objects are "printable electronics", "transparent, conductive layers" and "cost-efficient, flexible solar cells". The respective subject areas are organised in interdisciplinary project teams. They consist, e.g., of chemists, physicists, engineers of electronics and procedure technology, as well as scientists from the area of microelectronics and nanotechnology. The partners have dedicated facilities and labs available in the Science-to-Business Centres, improving networking among the partners on work level. The spatial proximity of all know-how carriers is considered a criterion for success.

Creavis mainly funds the Science-to-Business Centres from the research budget of Evonik Industries. Furthermore, individual projects are co-funded by public research budgets like those of the state of Northrhine Westphalia, the European Union or the BMBF. Successful projects are then partially transformed into start-ups.

In addition to research and development, cooperation partnerships are intended that lead to joint investments and venture capital contributions. In addition to development of technology competences, the Science-to Business concept is also targeted at its quick commercialisation.

71 Cf. Herzog 2007, Evonik 2009 and Wissenschaftsrat 2007, p. 66.

The success of Science-to-Business Centres is seen in the great research and development result based on integrative cooperation between science and economy along the value-added chain.

> The gap between basic and application-oriented research

According to the experts, basic research and applied research in organic electronics are less clearly separated as in other fields of material science and material technology. On the one hand, universities and research institutions have a great sense for applications and understanding of the industry. On the other hand, the industry still drives basics–oriented subjects in spite of a reduction of basic research in the industry. In organic electronics, in particular industrial activities in development of new organic materials can be highlighted here. According to experts, the interaction of university research facilities, Max-Planck, Leibniz, Helmholtz and Fraunhofer Institutes and the industry is considered unique even abroad.

The perceived gap between basic research and applied research, which may lead to an implementation weakness of the research results for marketable products, often originates less in task distortion among the researching institutions in case of organic electronics, and more in the interrupted funding of the chain "from material to product". This weakness and the possibility of removing it are discussed in chapter 6 of this position paper.

3.2 FROM LAB TO FAB – CHALLENGES ON THE PATH TO SERIAL PRODUCTION

The path from the lab stage to serial production is a long one. Current production capacities still mainly have the character of lab production and use method and technical solutions that hardly permit any economic application in serial production. Although significant progress has been made on the path to market maturity, development leaps in material and device development, as well as in development of processes and plant technology, are still required. The effort required for this cannot be reduced to pure further development or optimisation of present solutions. The transfer from lab to serial production brings with it new research challenges that must be on the agenda of future research and development plans.

> Scaling materials and devices

The so-called "scale-up" requires special efforts in production of many materials: increase of amounts also affects materials characteristics and may require new synthesis methods or new plant and process technologies for production and processing of the materials.[72]

In addition to scale-up of materials, transfer of the performance and quality lab results for a device to a serial product is not easy. Organic solar cells, for example, critically depend on device size in their efficiency, which clearly reduces as their size increases. The need for research and development that arises from the "scale-up" in organic electronics was already recognised, but not yet dealt with sufficiently. This results in insufficient funds and a lack of funding options for the prototype stage in which the scale-up is mainly performed.[73] The experts questioned mainly demand additional funding options for the "ramp-up", i.e. initial start-up production and operation of pilot plants.

72 Cf. acatech 2008, p. 20.
73 Cf. acatech 2008, p. 21.

> Plant technology and processes for mass production

Development of process parameters, production of demonstrators (prototypes to demonstrate technical feasibility) and collection of experience from production – in other words "the path from lab to serial production" – are currently limited on serial-capable plants. While the underlying plant technology is based on stabilised coating technologies, economic production of organic electronics products requires adjustment and further development of those plants and processes. Additionally, basic technology matters of production technology, such as the matter of securing homogeneous layer thicknesses on large areas must be dealt with. Other value-added steps also require suitable solutions for serial production. On a material level, for example, this includes printable materials suitable for mass production by continuous print procedures.[74]

> Production-accompanying quality assurance

An essential part of economic serial production is availability of production-accompanying and thus serial-capable quality assurance procedures. Not only the function of the goods produced has to be verified. A statement on the permanent function of the products must be made as well. This demands statistic security not only based on experience but also requiring basic knowledge on effect interactions, damage mechanisms and error chains. Furthermore, present quality assurance measures from lab production, such as layer thickness measurement by piezoelectric crystals, are not suitable for serial production. In addition to the required basic understanding on quality assurance, methods and corresponding systems also have to be developed for production-accompanying quality assurance of organic electronics.

On the design-side, there is the dedicated development of design measures to ensure functional safety and responsibility, e.g. correct determination of draft margins and use of redundancy and error-correcting architectures. Such techniques that are generally known can only be applied sensibly if the interrelations between the physical basics and effects on system level for the expected component imperfections are known and understood.

> Standards for products and processes

Standards are little established yet in organic electronics. The importance of standards – i.e. the standardised measurement of device performance on the one hand, that of product standards on the other – is considered high by all the experts asked. Organic electronics have already achieved a degree of maturity that would benefit considerably from development of standards.

Standardised measuring methods are in particular required in this context to ensure comparability of lab results. The performance capacity of a device is determined by different parameters that are often in conflict with each other. Efficiency-increase in OLEDs often correlates to reduced service life. To warrant comparability of research results from different facilities, standardised measuring practices are required; however, they have not yet been established. An exception in this context is organic photovoltaics, where standardised measuring practices are already established and certified measuring labs are present.[75] In the areas of organic electronics, the corresponding standardisation activities also have to be striven for and developed.

Another field of action for standardisation steps are the organic electronics products. Standardised production requirements should be developed early on to prevent disappointment of potential users. A great example for lack

74 Cf. Fix 2008, p. 49.
75 E.g. the NREL in the U.S: or Fraunhofer ISE in Germany.

of product standards is the differing definition of different manufacturers for "white LEDs". An early (product) standardisation is always required, but the experts asked believe that it must be mainly initiated by the industry.

The challenges indicated here on the path from lab to serial production have one thing in common: they require considerable and sustainable investments, e.g. for procurement and operation of suitable plant infrastructure or financial security of the initial pre-serial production.

3.3 PILOT PLANTS AS A BRIDGE TO MARKET MATURITY

Pilot plants are test plants in which the issues of a new technology can be examined. On the path from lab to serial production of marketable organic electronics products, pilot plants are mandatory, e.g. to enable testing and optimisation of devices, development of process technology and quality assurance measures or production of demonstrators and pre-series. They therefore comprise the connecting link between lab and serial production and are a prerequisite for mastering the challenges on the path to serial production and paving the way for reference products of organic electronics. Pilot plants therefore have the character of (pre-competition) lab plants as opposed to serial plants with competitive character. Provision and maintenance of pilot plants in the area of organic electronics are connected with high investments and costs that even large companies want to avoid. Provision of such plants is vital in particular for start-ups, small and medium-sized companies that usually do not have the resources for their own plant infrastructure.

The term "pilot plant" as such does not say a lot about what type of plant is meant specifically. In organic electronics, many different types of pilot plants are present, each aligned with different materials, process steps and processes and meeting different requirements.

The plants are differentiated, among others, by type of production method, i.e. liquid phase or gaseous phase processing, and by type of the applications to be produced, e.g. OLED, OPV, OFET, etc. Furthermore, the required output quantity and the plant technology directly connected to it, e.g. roll-to-roll or sheet-to-sheet-technology, must be specified. Pilot plants can be either small lab plants consisting of different modules, or fully linked plants. These examples show that this subject area must be considered in a differentiated fashion.

The great importance of pilot plants is taken into consideration by the COMEDD[76] in Dresden, the InnovationLab in Heidelberg, a pilot production (Osram) in Regensburg (under construction) that is promoted by BMBF and a VTT[77] pilot plant in Finland already.

Nevertheless, some experts believe that Germany does not have enough pilot plants. At the same time, they indicate that the present pilot plants are not utilised to capacity. One cause for this would be that the present pilot plants are no "open" plants, e.g. plants that are not available to external users, or only available to them under more difficult conditions. The plant and the products produced in it are, however, highly sensitive. Therefore, demands to high-cost maintenance and prevention of contamination are great, and it is understandable that the operators of pilot plants often exclude use by third parties. The lack of pilot plants therefore has to be specified more clearly; it is not plants as such that are missing, but plants that comply with certain technical and organisational requirements. They must be determined in advance for new products and compared to the present plant infrastructure in Germany and Europe.

[76] Center for Organic Materials and Electronic Devices Dresden.
[77] VTT Technical Research Center of Finland.

Plant technology for organic light diodes can generally be transferred to organic photovoltaics. This means that plants in which OLED can be produced are also generally suitable for production of OPV devices. Due to the different materials used for OLED or OPV production, this technical flexibility is, however, not yet implemented in practice. Since the materials used are difficult to remove from the plants without residue, there is a risk of contamination that the plant operators do not wish to run. Another weakness is in funding. While funding of the procurement of the corresponding plant technology is still possible in the scope of project funding according to the experts asked, funding of operation and initial start-up production often cause problems for the actors involved. In addition to these financial bottlenecks, there are other impairments that prevent widespread use of the present pilot plants. Technical impairments are mainly due to the results achieved being strongly plant-specific and the fact that they cannot be transferred easily. Another impairment that is significant in particular for industry customers is the handling of usage and utilisation rights in the results achieved. An example of this is the restrictive IP rule of Fraunhofer Society, which often prevents use of its plants by the industry.[78]

The weaknesses named here show clearly that in particular future-oriented operation and business models are missing that would enable the development and long-term operation of present and new pilot plants for organic electronics. There are still many open questions on the development models. What institution is suitable as an operator of pilot plants? Who will receive usage rights in the research results gained? Who may use the plants under what conditions and at what costs? These and other questions must be dealt with to verify in how far such a concept of "open" pilot plants can be implemented at all.

3.4 RECOMMENDATIONS TO STRENGTHEN RESEARCH, DEVELOPMENT AND IMPLEMENTATION

In spite of promising success in the past, the chain "from material to product" has some weaknesses that slow down efficient further development of organic electronics in Germany and implementation of research results in marketable products. In the following, we make some recommendations for removing identified weaknesses and closing the gaps in the chain.

Increasing understanding of the theoretic basics enables targeted research and reduces the effort of development projects. Empiric research is not replaced in the short and medium term, but can be performed in a more and more systematic manner. It makes an important contribution to uncovering basic theoretic phenomena. The objective therefore should be a balanced relationship between empiric and targeted research aligned with theoretical understanding to ensure efficient further development of the different areas of organic electronics.

> acatech recommends

to consider not only empiric further development, but also research aligned with basic understanding of organic electronics in addition to be very important. Joint research between institutes of the Max-Planck Society (MPG), Leibniz Society and the universities on the one hand and the institutes of the Fraunhofer-Gesellschaft (FhG) and the industry on the other hand should be promoted to improve the target figures (efficiency, service life, costs) for concrete target products of organic electronics. Ideally, this research should be combined "under a single roof" with extensive infrastructure (e.g. joint institute of the MPG and FhG) in direct proximity to relevant industry and where researchers from basic research to application research, from plant technology to

[78] Center for Organic Materials and Electronic Devices Dresden.

production and process technology meet for a limited time from case to case (up to 5 years).

An integrative manner of work and close cooperation of the value generation and development partners is a necessary prerequisite for research and development success in organic electronics. Although this has already been recognised in the past and led to promising developments like a focus formation under strong involvement of the industry or the Evonik Science-to-Business Center Nanotronics, efforts in this direction must be clearly increased. The network must be further developed and expanded, in particular in the light of unique competences (cf. chapter 6.2).

Production-oriented research subjects will become more and more relevant the closer the developments of organic electronics come to the market. The transfer from lab to serial production has a considerable research demand that must be at the focus of future research and development activities to enable implementation of research results in marketable products. Implementation of cost reduction potentials and techniques to increase yield and reliability are also mandatory to provide serial-capable mass-production procedures. In this context, pilot plants are critical.

> acatech recommends

to pay special attention to research challenges concurring with a scale-up of materials, devices, as well as production and process technology and to support development and use of open pilot plants with suitable business models under consideration of national and European situations to secure implementation in marketable organic electronics products by the industry in Germany.

4 PROMOTION OF YOUNG RESEARCHERS

4.1 TRAINING OPPORTUNITIES FOR YOUNG RESEARCHERS

Organic electronics are a comparatively young field of technology with applications on the threshold to market maturity. The often-forecast strong market growth raises the question of whether Germany has the staff for this development or will have to expect a personnel bottleneck in the medium to long term. Even though no lack of qualified specialists can be complained about yet in the area of organic electronics, it must be verified early on whether current training and further training opportunities in this area will be able to continue covering the demand of science and the economy. Experts for organic electronics agree that even now efforts must be made for the promotion of young researchers to cover tomorrow's demand. What are the specific requirements young researchers must meet to be best prepared for future development tasks of organic electronics? In how far are present training offers able to convey the competences required? These questions are answered in the following.

> Organic electronics is a cross-sectional discipline

Interdisciplinarity is immanent to organic electronics. Organic electronics as a partial area of material science and material technology are a cross-sectional technology that can be assigned to the initial disciplines of chemistry, physics, electrical engineering and engineering equally. Fig. 4 makes the interdisciplinary character of organic electronics clear.

The questions in the area of chemistry mainly refer to subjects of material synthesis and material development. Development of new materials, e.g. for emitters (OLED) and absorbers (OPV), encapsulation and barrier layers comprises an essential share of chemical questions. In the further course of the value-added and development chains, the subjects are increasingly characterised by physics. Physicists are in demand in particular for the development of devices. Subjects of processing and quality assurance are part of the physical area as well. The importance of engineering increases from the device to component design to the product. Electrical engineers and engineers are needed in particular in the areas of circuits and component design or processing and plant technology. Quality assurance procedures also require the know-how of engineering disciplines, in particular where production-accompanying inline solutions with a high throughput are required.

Fig. 4: Sorting of organic electronics and some specific questions into the different starting disciplines

	CHEMISTRY	PHYSICS	ENGINEERING	ELECTRICAL ENGINEERING
ORGANIC ELECTRONICS	Material development	Device development	Plant technology	Circuits
	Encapsulation	Modelling	Processing	Device development
	Design	Processing	Printing machines	Transistors
	Material synthesis	...	Meassuring procedures	Linking
	Modelling	Quality assurance	Quality assurance	...
	Substrates	Design	...	Design
	Emitters	Measuring procedures	Coating	System integration
	Processing	Material development	...	
	...			

> High requirements to young researchers

The requirements to young organic electronics researchers are characterised in particular by a need for interdisciplinary understanding and system thinking due to the complexity of this research area. Experts emphasise that deep specialist knowledge in one specialisation more and more often requires an expanded view, integrating matters of the adjacent disciplines and permitting a change of perspective. This does not so much require an interdisciplinary manner of work. It rather requires the ability to communicate with the different adjacent disciplines, i.e. the joint language and a mutual understanding of the problems of the respective other discipline. One example is the electrical conductivity of an organic material: it depends both on the structure of the material's molecules and on the orientation of the molecules within the material and in the final device. Efficient material development therefore does not only require synthesis of a material with a corresponding molecular structure. A morphology also must be generated beyond the molecular structure to achieve the desired characteristics of the material. This also includes detailed characterisation from molecular to macroscopic structure. On the other hand, the device physicist must be able to suggest suitable molecular structure and material morphology to the chemist based on the desired material characteristics. The disciplines must have this mutual understanding of the subject. Only then will the strong link between research and development activities be possible and the high coordination need for among the developers involved along the value-added chain be met. Short feedback cycles, e.g. from device development and processing to material development, are decisive for success for efficient system optimisation.

Such challenges on the qualification side are not yet sufficiently countered by training opportunities for organic electronics specialists in Germany. Experts see a lack mainly in the still-too-few and too little coordinated training opportunities that comply with these requirements to content.

> Present training opportunities

Internationally, only few universities offer dedicated courses of studies or graduate studies in organic electronics. In Europe, these are the Linköping University in Sweden and the three French universities Limoges, Bordeaux and Toulouse, which have been offering a joint, distributed master course of studies since 2009.[79] Apart from this, several European universities offer individual events like lectures or practical training in the area of organic electronics.[80]

At this time, Germany has no dedicated course of studies to prepare young researchers for their tasks within the area of organic electronics in a targeted fashion. The current university training in the area of organic electronics takes place mainly in the different lectures of natural and engineering sciences courses of studies, such as chemistry, physics or electrical engineering. Furthermore, student research papers and diploma theses, as well as Ph.D. theses at departments and institutes with the respective research focuses, permit detailed further training, even though it is not aligned with the present (previous) training offers. In the scope of the leading-edge cluster "Forum Organic Electronics", the universities Heidelberg and Karlsruhe have started a project for integrated promotion of young researchers in the area of organic electronics. The objective of this project is comprehensive training and further training of scientists in the area of organic electronics, to be achieved among others by a Joint-Master course of studies focussing on organic electronics.[81]

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79 Horowitz 2009, p. 6.

80 E.g. the lecture "Plastic and Molecular Electronics" at the University College London in Great Britain or the practical training "Organic Electronics" at the Ecole Nationale Supérieure des Techniques Avancées ENSTA in France.

81 Universität Heidelberg 2009.

Experts agree that in the light of the enormous market potential expected with the breakthrough of organic electronics, current training opportunities will not meet the expected demand of this research and development area in terms of capacity or content, and neither regarding the needs of the economy nor those of the universities.

4.2 THREATENING LACK OF YOUNG RESEARCHERS IN ORGANIC ELECTRONICS

The already-present lack of young researchers in Germany in the so-called MINT-professions hits organic electronics as well as other areas of the economy.[82] The demand in engineers has been growing continually in the last 25 years, and this trend is still continuing.[83] By the year of 2004, this was additionally countered by decreasing numbers of new students in the affected subjects.[84] While the number of new students in the MINT-subjects rose again in the years of 2005 to 2008, several trends support the forecast lack of technical specialists and generalists.[85] In particular the effects of demographic change, increasing academisation of activities in the companies, increasing demand for new technical products and services, and the fact that Germany as a high-technology site lives on implementation of inventions into marketable products, which requires qualified specialists, are aspects that must be highlighted.[86] Therefore, the Federal government has already devised objectives and measures with the qualification initiative for Germany that intend, among others, specific incentives for students in the MINT-subjects.[87]

> Lack of highly trained young researchers in organic electronics

According to the experts, organic electronics are suffering from a lack of highly trained young researchers who not only have a solid specialist training in one discipline, but also understanding of the adjacent disciplines and are able to think "in the system". The requirements to young researchers in the strongly interdisciplinary organic electronics can, according to the experts asked, only partially be met by the current courses of studies and training offers. An essential part of the interdisciplinary skills must be gained outside of organised training paths.

Some large companies maintain targeted cooperations with universities and research facilities for regional focuses on organic electronics to access qualified young researchers. In particular small and medium-sized companies with a less detailed network with universities and research facilities often have difficulty in finding and attracting qualified specialists with the respective background in organic electronics. Even some research facilities and chairs find it more and more difficult to cover their own need of young researchers, according to their own statements.

On the one hand, the lack affects specialists like device physicists, quantum chemists or material scientists needed to meet the developing technology field. On the other hand, there is a lack of general organic electronics scientists that will grow more acute with increasing market proximity of the individual technologies. If the partially very optimistic market assessments of organic electronics applications are even marginally achieved, a demand in qualified specialists will result that cannot be covered by German universities in the short term.

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82 Cf. acatech 2009, p. 62.
83 Cf. acatech 2006, p. 58.
84 Destatis 2005, p. 46 f.
85 Cf. BMBF 2010b, p. 44.
86 acatech/VDI 2009, p. 13.
87 Cf. BMBF 2009, p. 86 ff.

In addition to the lack of young researchers on the university-training side, the experts asked also believe that a lack of lab assistants and lab technicians is expected. No significant lack in these areas is currently noticeable, but increasing market penetration of organic electronics products will increase the demand. To avoid bottlenecks in future as well, this should be countered in time by the corresponding training offers and further training measures.

> Migration of specialists into other countries

This situation is also expected to grow more acute because qualified young researchers move to other countries. A survey of the European career portal Stepstone among 21,000 specialists and managers from nine European countries showed that Germany is far behind on rank 15 in the question of what European country specialists and managers would want to work in. The leaders are Great Britain, France and Spain.[88]

The problem in the field of action of promotion of young researchers therefore affects not only assurance of an excellent training level, but also in particular retention of excellent young researchers in the country. This also applies regarding German top scientists who find more attractive framework condition for their research abroad and leave for this reason. On the other hand, there are international students who study in Germany but return to their home countries after completing their studies or move to another preferred country. According to the experts, the problem of highly and highest-qualified persons migrating away is particularly bad for organic electronics, since there are only few leading-edge scientists available in this area of research in Germany, anyway. Emigration of these few leading-edge scientists would lead to a clear and sustainable weakening of the German science landscape in organic electronics.

> The faculty limits

It is a centuries-old experience of the science system that the different disciplines are not always willing to cooperate. The change of the university landscape to the Bachelor-/Master system in the scope of the Bologna process, however, offers the general opportunity of restructuring the courses of studies for diverse combination options in study design and thus to reduce the separation between the faculties. The modular structure of the studies and the option of non-consecutive courses of studies in which the Master's course of studies takes place in another (but related) discipline than that of the preceding Bachelor's course of studies show promise for interdisciplinarity. Critically viewed, however, there is the question of how far intense training is possible in the short time of the Master's course of studies (no more than two years including Master's thesis). There is the danger of not being able to utilise the basics gained in the Bachelor's course of studies within the Master's course of studies in another discipline. In practice, experts say that faculty barriers increased even more by introduction of the Bachelor-/Master system.

According to a story of HIS (Hochschul-Informations-System GmbH), there are several reasons for the difficulty in implementation of interdisciplinary study options: The spatial distance between the faculties, problems in coordination of schedules between the different departments, the generally short timeframe in the Bachelor's studies and the examination organisation in interdisciplinary options.[89] These difficulties must be overcome to enable interdisciplinary teaching in general and qualified teaching of organic electronics in particular.

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88 Stepstone 2006.
89 Cf. HIS 2008, p. 26.

4.3 RECOMMENDATIONS ON TEACHING AND SECURING OF YOUNG RESEARCHERS

The threatening lack of qualified young researchers and organic electronics specialists is perceived by science and economy. To meet the challenges described and to continue to ensure qualification of excellent young researchers in organic electronics, the necessary prerequisites must be created early on.

Interdisciplinary teaching can generally have two forms: an independent interdisciplinary course of studies or stronger integration of interdisciplinary subjects in other, existing courses of studies.[90]

A wide-spread introduction of specialised Master's curricula does not currently seem sensible in the light of the risk connected with the forecast market development in organic electronics. Rather, integration of technical lectures on organic electronics into present courses should be preferred.

Implementation of these training options requires provision of additional funds, in particular the development of additional teaching staff. This will increase the perception of this new area of research in the students. Companies increasingly have the opportunity to actively participate in teaching[91] and long-term cooperation between science and economy are promoted.

Such study offers will provide the opportunity of raising enthusiasm for the new technology field in students with previous specialisation in an area in particular for organic electronics. Of course, the interdisciplinary training must not be at the expense of a well-founded basic training.[92] Disciplinary competences form an essential prerequisite, but are no longer enough on their own to successfully process research tasks resulting from the classical subjects and disciplines.[93]

In addition to training of excellent young researchers, considerable efforts are required to also keep them in the country and to prevent their migration or return to their home country after their training. Attractive framework conditions must be created for this to also ensure research and a work landscape in Germany that are competitive in international comparison. To bring together the best heads and to equip them appropriately, 'organic electronics lighthouses' must be created in Germany to also attract international top scientist.

> acatech recommends

to increase the attractiveness of studying organic electronics, to integrate organic electronics into present courses of studies in the present centres (where the required framework conditions are present, otherwise establishing a master course in organic electronics), to support cross-faculty work, to facilitate the recognition of studies at other faculties and to develop interdisciplinary teaching and research staff. To raise the students' interest, the degree of familiarity with the new research area should be increased and the industry should participate in presentation of career opportunities.

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90 HIS 2008, p. 25.
91 Cf. Stifterverband 2009, p. 5 ff.
92 Cf. acatech 2008, p. 26.
93 Cf. Mittelstraß 2005, p. 20.

5 FUNDING

5.1 STRENGTHS AND WEAKNESSES OF THE PREVIOUS FUNDING

Experts agree that Germany's position in the leading field of many areas of application of organic electronics and various stages of the value-added chain is strongly due to the early and intense funding of the past years.

> High effectiveness of the previous funding

The funding enabled increase of the technical performance of various technologies of organic electronics and improvement of Germany's international competitiveness. The economic importance of organic electronics in Germany has also increased over the past years due to intense promotion and will continue to grow. According to experts, this is shown, among others, in increasing employment figures and the creation of organic electronics start-ups. The effects of the last years' funding are seen very positively by companies and research institutions. In particular the two BMBF innovation alliances are highlighted by science and economy experts as an example for success. The leading-edge cluster "Forum Organic Electronics" of the Rhine-Neckar metropolitan region is another important step in this direction. With these new support instruments, large industry investments could be mobilised. The main funding for joint projects with partners from research institutions, universities and industry working together on a research project are considered an extraordinarily important funding principle by science and economy. According to the experts, the strong integration of companies leads to research in organic electronics in Germany being very practice-oriented.

> Strong application focus of the funding programmes

Previous funding programmes have rightly been characterised by clear market focus. Large sums were invested in application-oriented projects. The basis of these funding focuses was an engineering-driven technology development strongly aligned with certain markets (e.g. lighting). Conscious definition of funding focuses[94] is a sensible approach to drive promising areas of application and commercialisation of the underlying technologies in a targeted manner and under strong involvement of the industry. Monolithic interpretation of funding, however, entails the danger of neglecting niche areas of currently less prominent areas of application like organic batteries. Furthermore, it does not leave sufficient space for cross-sectional subjects that would benefit several areas of application. With the leading-edge cluster "Forum Organic Electronics", in which projects of different areas of application of organic electronics are promoted, this deficit has now been countered with another funding instrument.

According to experts, promotion of organic electronics in Germany currently has some weaknesses that lead to funding gaps along the chain "from material to product".

> Coordination of funders

Many experts say that even better coordination between the different funding organisations, and in particular between the DFG and the BMBF would be desirable. The same goes for consistent support on the path from perception to implementation and thus to product innovation. While DFG funds basic research subjects that generally do not need to be application-oriented, the funding instruments of the BMBF are aligned with research subjects or projects that have a direct application connection. Generally, this separation is sensible, but there is the danger of creating a funding gap for subjects that are too remote from application for BMBF-promotion (under industry contribution), but too close to application for DFG-promotion. In the past years, both the DFG and BMBF have taken measures to support

[94] Including, e.g., the funding focuses organic photovoltaics in the "Innovationsallianz OPV" or organic light diodes in "OLED Initiative".

the transfer from basic research to applied research. The so-called "Transferprojekte in Sonderforschungsbereichen" ("transfer projects in special research areas") of DFG have the objective of continuing technology developments of completed DFG-basic projects and bringing them a little closer to application to achieve a knowledge transfer between research and application for mutual benefit.[95] Within the framework programme "Materialinnovationen für Industrie und Gesellschaft - WING" ("Material Innovations for Industry and Society")[96], BMBF created the funding measure "scientific preliminary projects" to supplement present research funding and to bridge the gap between basic research and industry-managed joint funding.[97]

Also, coordination between sponsors on Federal and state level should be improved. Synchronisation of the funding programmes should be striven for and intensified to bundle forces, increase efficiency of the promotion and achieve sensible complementation of funding from the Federal budget by funding from the state budget and vice versa.

> Funding for implementation of research results in products mature for the market

Once technical feasibility has been proven, further development of technologies of organic electronics to market maturity is still connected with considerable effort. In Germany, the total funds available for funding in the validation or implementation phases are too low.[98] This affects organic electronics as well as other fields of technology. The Federal government therefore announced that a new measure to support validation will be started to contribute to better economic utilisation of the potential of results from academic research.[99] The high research demand in particular in the areas of organic electronics on the way to serial maturity (also see chapter 2.2) is not yet taken into consideration sufficiently by funding according to the experts asked. The basis for further development of project results or technologies of organic electronics to market maturity is in particular development and operation of the required, partially highly differentiated plant infrastructure that is currently only insufficiently covered by funding. The dedicated design technology for integrated organic electronics also must be considered an important factor for success. The step from proof of technical feasibility to technologies and products ready for the market is connected with high effort and considerable risk in particular in organic electronics – effort and risks that companies often do not want to take for economic reasons.

In this context, the question must be raised in how far sufficient public funding until market maturity is possible without leaving the area of pre-competition.

> Flexibility of funding programmes

Organic electronics are characterised by high dynamics both in technology development and in market development at this time. In the light of this, experts criticise a certain slow reaction of funding that does not comply with the needs of quickly changing technology fields. Foreign funding like the U.S. funding by the Department of Energy (DoE) is considered more dynamic and flexible in general by the experts. The main criticism in this context is targeted at the periods within which project applications can be filed and at the close guidelines within which funding is possible. To drive promising research subjects with a longer-term focus beyond the funding periods of individual joint projects, alternative funding models are required. Such funding programmes should enable short-term generation of new applications or conversion of current funding applications to new questions that arise, At the same time, they permit use of plant technology procured in the scope of a funded project outside of the project.

95 Cf. DFG 2010, p. 1.
96 BMBF-WING 2003.
97 Cf. BMBF 2008b.
98 Wissenschaftsrat 2007, p. 89.
99 BMBF 2010b, p. 11.

> Framework conditions for commercialisation of organic electronics by start-ups

Start-ups hold a key role in implementation of research results in marketable products. They are a very effective possibility for technology transfer that large entrepreneurs cannot provide. With their specific know-how and a quick adaptation capability, they have the required dynamics and speed of action to put products on the market quickly. The high importance of company foundings for Germany's economy and innovative power is undisputed. According to a current study of the centre for European Economy Research, the number of companies founded from 1995 to 2007 has, however, decreased.[100] Funding for technology-intensive foundations is provided on Federal level in particular by the Hightech founder's fund, which is funded by the Federal Ministry for Economy and Technology (BMWi), KfW Bankengruppe and six private investors. Various founder initiatives of the states complement Federal-level funding.[101] These great and now established instruments to fund company foundations must be strongly developed, and highly innovative areas like organic electronics must be strengthened and integrated in a targeted manner. In spite of conditions growing more difficult[102], the past years have seen several successful start-ups of organic electronics founded in Germany. For example, the new company Heliatek repeatedly achieved records in the efficiency of organic solar cells.[103] This development is extremely important in particular in the highly dynamic technology field of organic electronics for the international competitiveness and innovative power at the site of Germany.

5.2 EXPERIENCE FROM BMBF PROJECTS

In the following, experience from BMBF-funded organic electronics projects is discussed that covers examples of concrete science progress, superior benefits, structures of the project organisation and possible problems in putting together the project consortium. The considerations focus on experience from funding projects of the two innovation alliances Organic Light Diodes and Organic Photovoltaics. The projects of the first phase of the OLED initiative are already completed, and the projects funded within the innovation alliance OPV have also progressed far – initial perceptions are discussed in this place to provide suggestions for the design of future projects. While projects have already started in the leading-edge cluster, they are still at a very early stage at the time of this statement and therefore not considered in this observation.

In the first phase of the OLED initiative, a total of four joint projects were funded with a total volume of approx. € 52 million. The innovation alliance Organic Photovoltaics currently comprises 15 joint projects with a total funding of approx. € 55 million. The mainly mixed consortiums of the funded joint projects – comprising companies, research facilities and universities – cover large parts of the value-added chain.

According to the experts, the last years' funding made it possible to significantly increase the technical performance of several organic electronics technologies. For example, the project "OPEG"[104] increased the efficiency of organic solar cells to 8.3 % – from approx. 5 % before the project. A cen-

[100] Cf. ZEW 2009, p. 12.

[101] BMWi 2010a, p. III.

[102] Seed financing and coaching measures mediate the required starting capital and necessary guidance and support for the management of young companies in the founding stage (cf. BMWi 2010b, p. 5). In the subsequent growth phase, young entrepreneurs increasingly depend on the venture capital of private investors. The venture capital market for funding innovations, however, is clearly underdeveloped in Germany (cf. BMBF 2006, p. 15). The little-developed German founder mentality, combined with a lack of "Business Angels", leads to difficult framework conditions for young entrepreneurs, in particular technology-intensive start-ups. Organic electronics, however, depend on sufficient subsequent funding in the growth stage (e.g. for cost-intensive plants) to drive commercialisation of products.

[103] Heliatek 2010.

[104] "OPEG – Organische Photovoltaik zur integrierbaren Energieversorgung", term: 01.07.2008 – 30.06.2011, funded with approx. € 16 million.

tral as yet unsolved problem is economic implementation of these project results. A possible subsequent project therefore is planned to transfer already-achieved cell efficiency to module efficiency at the same level. Only this will provide the basis for high-performance products. The market-oriented implementation of the project results is planned by Heliatek Company for 2012. In the project "OPAL"[105], the project results achieved were transferred to initial product development at Osram even during the course of the project.[106] The efficiency, service life and surface of organic light diodes could be increased during the project so that the first small batches – produced on the plant prototype also developed in the "OPAL" project – were marketed shortly after completion of the project.

Joint projects are particularly important for promotion of young researchers. Integration of research institutions and universities into project work – as part of a project consortium or via sub-orders – enables young researchers to perform practical research on a project-specific level in the scope of Ph.D. or diploma/master's theses, giving them their field experience with industry.

Alone the projects "OPAL" and "OPEG" allowed the performance of nearly 50 Ph.D. theses..

A particularly important factor for success according to the persons asked is a smooth transfer to successor projects. This aspect is particularly relevant for universities to prevent the appearance of funding gaps and thus interruption of theses. An example in this context is the smooth transfer between the "OPAL" project and the successor project "TOPAS"[107], enabling uninterrupted continuation of the research by the research institutions and universities involved.

Good cooperation between science and economy is the basis for project success and therefore must be emphasised specifically. Publicly funded industrial joint projects act as "enablers" for this type of cooperation. They create a "bracket" around the project consortium and the partners involved and enable open communication and trustful cooperation. Joint projects strengthen present contacts between know-how carriers, create new ones and prepare long-term cooperation beyond the concrete research project. Joint projects therefore form a bottom pillar of networking of science and economy in the area of organic electronics in Germany (cf. chapter 5.2). It is also driven across projects in the funded projects, i.e. between different project consortiums. For example, a cooperation was initiated between the "TOPAS" and "So-Light"[108] projects of the second phase of the OLED initiative to use synergies and support subject-specific exchange of ideas and experiences.

The cooperation of the project partners involved was described as partially difficult in the area of plant technology. While this value-added step is usually represented by at least one partner in most projects, cooperation between device developers and plant constructors is less open in some. According to the project participants, this is primarily due to the different target systems. While plant constructors want to develop their plant technology further with the objective of marketing, device developers fear draining of their know-how. Plant development therefore is often performed by the device developers alone and without a plant constructor.

105 "OPAL – Organische Phosphoreszenz-Leuchtdioden für Anwendungen im Lichtmarkt", term: 01.03.2006 – 28.02.2009, subsidised with approx. € 29.3 million.
106 Cf. Osram 2009, p. 104.
107 „TOPAS – Tausend Lumen organische Phosphoreszenzbauelemente für Anwendungen in Licht-Systemen".
108 „So-Light – Forschung und Demonstratoren hinsichtlich Spezial-Beleuchtungs- und Signage-Anwendungen basierend auf OLED-Lichttechnologie".

One factor for success named is a project consortium size that can be handled well, with about three to four core partners, permitting close cooperation of the partners involved. Depending on the subject width of the project, however, much larger consortiums may be of advantage. Good experience with a large consortium was made, e.g. in the "OPAL" project. This is the largest joint project of the two innovation alliances up to date. It was internally structured by three subject-related partial associations, each of which was controlled by one partner of the consortium. The consortium partner responsible for each of the respective partial associations was responsible for the alignment and organisation of the semi-annual, two days long working meetings in which the subcontractors involved contributed as well. This example shows that larger consortiums can also use focussed cooperation of the partners involved but require thought-through organisation.

The innovation alliances have already achieved considerable scientific progress. The first marketable products of organic electronics (cf. chapter 2.4) were developed as well. To maintain or develop the positioning in the international competition, consistent continuation of intense research and promotion is required.

Companies striving for development and marketing of organic electronics products must have a strong perseverance. This is also required by funding to enable harvesting the financial success of the efforts of many years. The following section therefore discusses approaches for the future promotion of organic electronics.

5.3 RECOMMENDATIONS FOR FUNDING FOR ORGANIC ELECTRONICS IN GERMANY

In spite of promising success in the past, considerable efforts must still be taken to pave the way for the still-young technology field of organic electronics to market maturity and to enable its commercialisation in Germany. To meet the specific scientific, technical and economic challenges, targeted adjustments of the promotion of this dynamic technology field are required. Based on the expert interviews, the following approaches can be identified.

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to ensure the continuity of funding throughout all stages of the development and the value-added chains, bundling funding and further improving coordination between the Federation and the states. Alternative funding and financing models – e.g. in the scope of Public Private Partnerships – should be developed to enhance project-independent sustainable research efforts.

Increasing technology maturity of organic electronics makes technically-economic aspects more important. The challenges posed by scaling of materials, devices, processes and plant technology will have to be targeted more strongly by funding as well in future. Highly specialised production plants are required for production start-up for organic electronics products.Even if they are successful, their costs will pay off in the medium term only. Funding of the initial start-up production currently poses a bottleneck that impairs implementation of excellent research results and therefore must be removed.

Public investments must not prevent private investments. To meet the danger of displacement, the eligibility of such infrastructure must be verified carefully. Funding in the prototype phase and scaling subjects always walk the line between competitive and pre-competitive funding.

According to experts, other countries deliberately leave the area of pre-competition to enable direct and quick implementation of research results in products on the market. One example for successful funding of technology commercialisation is the Japanese "New Energy and Industrial Technology Development Organisation" (cf. NEDO excursion).

ALTERNATIVE FUNDING MODELS AT THE EXAMPLE OF THE "NEW ENERGY AND INDUSTRIAL TECHNOLOGY DEVELOPMENT ORGANISATION" (NEDO)[109]

The semi-governmental "New Energy and Industrial Technology Development Organization" (NEDO) is Japan's largest organisation for funding of research and development projects and for distribution and commercialisation of energy, environmental and new technologies. It invests approx. € 2.3 billion[110] per year in projects with companies, universities and research institutions. The focus is mainly on technologies for which development entails a high risk for companies.

The superior objective of such investments is strengthening the local economy and thus international competitiveness. Investments are made in the technologies selected based on regularly generated market trend analyses. To efficiently use public funds, only technology projects are supported for which considerable market potential is expected in case of successful development.

Two funding models are available for research and development work: An "outsourcing model" is used for projects managed by the NEDO and funded completely. This is done mainly for long-term and high-risk research and development projects. A "subsidy model" is used for projects where project management remains in the supported organisations and NEDO only contributes to funding. This model makes flexible and quick reactions possible in short-term projects. Performance of all funded projects is evaluated regularly, and this evaluation is the basis for decisions on further project funding. To assess the long-term success of funding, the projects are also evaluated beyond the term of the funding.

Development of technologies is driven at NEDO with the explicit objective of commercialisation. In addition to pure research and development, approx. € 120 million[111] per year are used to support technology commercialisation as well. The objectives of the funding measures are quick development of the associated market and stimulation of the economy.

The success of project funding is expressed in the commercialisation rate. The commercialisation rate (i.e. the ratio of the number of projects commercialised after 5 years to the total number of funded projects) was at 16 % in 2008, clearly exceeding the comparable commercialisation rates in Western regions.

The NEDO example shows how commercialisation of technologies can be successfully supported. Support of the commercialisation stage is perceived as a promotion task and technology developments are consistently supported to market maturity.

109 NEDO 2008/09 and www.nedo.go.jp.
110 NEDO 2008/09, conversion rate 114 Yen/EUR.
111 NEDO 2008/09, conversion rate 114 Yen/EUR.

Funding of organic electronics in Germany are mainly characterised by short and medium-term support in the scope of joint projects. This type of project funding, however, does not seem suitable for long-term establishment and operation of organic electronics "nodes" where research efforts are driven bundled and project-independently. To close this gap, founding of an institute (institutional support) where basic research and application-oriented research in the area of organic electronics are combined, may be suitable.

The diversity of organic electronics can only be covered insufficiently in an exclusively monolithic promotion. To meet the dynamics of the developing technology fields and the young market of organic electronics, funding must become more flexible both by subject and by structure.

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to continue funding the innovation alliances "Organic Light Diodes" and "Organic Photovoltaics" with their complementary focuses while also creating suitable space for innovative ideas, e.g. in the area of organic batteries and printed electronics. Due to the high economic potential and synergy effects, however, further development of organic displays should also be driven in Germany.

An important objective must be strong reduction of the through-put time of the entire innovation path – i.e. the path from basic research insights via applied research to market success. Transfer to products promising success will be possible if the research activities focus on contents required for implementation of innovative reference products.

Start-ups make a decisive contribution to the transfer of research results in products on the market and therefore should be intensely and sustainably supported. This support must go beyond financial funding. In addition to adjustments of the funding measures, a number of accompanying steps are required as well. They mainly refer to promotion of communication and networking of the know-how carriers in Germany and intensification of publicity work. Basic educational work on the science and economic developments and potentials of organic electronics is required to increase the degree of familiarity of this promising technology field as well as the resulting market opportunities in particular for small and medium-sized companies.

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to develop present funding offers for start-ups and spin-offs and to align the amounts of the funds with the respective technologies, to use a transfer platform to mediate contact with venture capitalists and that politics, sponsors and centres pay increased attention to publicity work for organic electronics to increase the founding motivation in the area of organic electronics.

6 STRENGTHENING ORGANIC ELECTRONICS IN GERMANY

6.1 RECOMMENDATIONS FOR DEVELOPMENT OF A JOINT RESEARCH STRATEGY

Intense international competition in organic electronics forces Germany to adopt a coordinated and decisive procedure (cf. chapter 2.5). Even now more and more companies from emerging countries also surge into the high-tech industries, increasing the pressure on Germany for driving innovations more strongly.[112] In a high-tech area like organic electronics, innovation capacities therefore are a required prerequisite to persist in global competition.[113]

Better coordination of research and development activities enables more efficient use of the available means and will make additional funds available in the long term – e.g. by mobilisation of additional investors. To increase the efficiency of investments in research and development, activities in science and economy must be bundled.[114] Coordinated procedure of all actors is the required initial basis for increasing innovation speed and quick implementation of all research results in products on the market.[115] A diverse landscape of actors dealing with research and development of organic electronics is present in Germany. Research and development activities are performed and funded by private and public institutions alike. Many different companies and research institutes are active on the different value-added steps.

A joint research strategy requiring the consent of all actors is an important milestone towards designing the future of organic electronics in Germany.[116] This kind of strategy process should be initiated by a central body (BMBF) to give the strategy the required commitment. If this enables coordination of all organic electronics actors in Germany, the probability of successful commercialisation of research results is essentially increased.

The strategy must have the objective of developing areas of application with a high benefit potential. Development of the strategy must consider, among others, development of the benefit potentials, technology options and the arena of global competition. The strategy has consequences (according to the guiding question of: What does generally have to happen?) for areas of application like public funding, pre-competition joint research, interaction of science and economy, training and further training, etc. The research programme can be derived from this. This seems urgently required in the light of the not yet optimised concentration of forces. It will also enable identification of necessary subject areas that were not yet at the focus of organic electronics and integrating them in research. One example for this are printed electronics.

A joint research strategy should mainly lead to coordinated action of companies, research institutes and universities focussing on certain areas, because they operatively deal with research and development as well as economic utilisation.

Since public funding and thus also private-economy investments decisively influence such activities,[117] not only politics but also the funding science organisations should be integrated in strategy creation. Furthermore, early integration of users into the strategy process is particularly important.

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112 Cf. Pickartz et al. 2010.

113 Cf. VDI-TZ 2009, p. 8.

114 An example for success is provided by the BMBF, which initially distributed funding of organic electronics among five technical departments. As it turned out, assumption of management by one department already led to clear progress in technology penetration of the subject area (cf. VDI-TZ 2009, p. 4).

115 Cf. VDI -TZ 2009, p. 11.

116 Joint appearance and consistent research strategy among all actors makes organic electronics more attractive for potential investors as well. The expectations of investors in the further development of technology and the only little-developed market are currently characterised by great insecurity. This insecurity inhibits investments that are decisive for market development. The coordinated procedure of all actors makes organic electronics more calculable as a profitable business area, and will therefore make other private-economy funds available.

117 Cf. Pickartz et al. 2010.

Users are the interface between the value-added chain of organic electronics and the market and thus a key factor for implementation of organic electronics in products on the market that has been neglected until now.

If coordination and networking of all actors of organic electronics and formation of strong centres are successful, commercialisation will develop in Germany. Amortisation of the sums invested in development of the technology field by public and private sources will only be possible by economic implementation of the research results. Commercialisation of organic electronics in Germany, in turn, enables development of new trades and thus new value-added chains.[118] Reference products from Germany are indicators and initiators of this development at the same time.

Reference products of organic electronics are applications produced in an economic environment and achieving considerable penetration of the sales market. This includes sales volumes that make development, production and sales in Germany interesting and performance capacities of the products that inspire enthusiasm on the sales market. In the light of this, reference products are indicators for successful commercialisation on producer and purchaser sides.

Consideration of technology synergies shows clearly that reference products are also initiators of further commercialisation. Synergies are present, e.g. in the areas of OLED lighting and OFET, which require similar materials and production procedures.[119] Development of the reference product is expected to have effects on other products of organic electronics on the technology as well as on the market-side. The commercial success of an organic electronics product is connected to an increase of trust in the entire technology field. This would inspire further companies and capital providers to invest in organic electronics.

Development of reference products is performed by interaction of "technology-push" and "market-pull". "Market-pull", in this context, is orientation along market and customer requirements. In contrast to this, the "technology-push" does not have market and customer requirements as a starting point, but the performance capacities of a technology.[120] The difficulty in development of reference products is in the fact that the corresponding sales market and customer structure for organic electronics are not yet established.

No application has yet been found that would lead to any massive breakthrough of organic electronics products.[121] This could be achieved either by substituting present products or by satisfying a new market need. Except for the areas of OLED displays and OLED lighting, there also are not yet enough products that can meet this demand and that can be commercialised in the foreseeable future. Products in the other areas of application are, according to expert statements, still in the demonstration stage and not yet mature for serial production. Companies rightly fear that market introduction performed too early would lead to warranty claims and disappointment among the users. On the other hand, high-performance competitor technologies make using organic electronics more difficult. Once more, we refer to the example of LCD technology, where the performance limits are more and more extended, reducing the performance lead of organic display technology. There is a certain hesitation in Germany to put technologies on the market before they are fully mature. This poses the risk of losing the innovator lead as compared to bolder regions. The courage of marketing partially optimised technology concepts as reference products and with a clear benefit potential and to continually develop them further to market maturity must be present in society, politics and economy – if required, supported by the corresponding safety mechanisms and incentives.

[118] Cf. VDI-TZ 2009, p. 9.
[119] Cf. VDI-TZ 2009, p. 29.
[120] Cf. Schuh/Klappert 2011, p. 172 f.
[121] Cf. OE-A 2009, p. 7; VDI 2008, p. 122.

Both on a national and European level, various strategy processes have already been kicked off and several strategy papers have been generated. This development must be generally assessed positively, even though the present efforts by the organic electronics actors are not yet given the required consideration. Timely further development of organic electronics in Germany mainly requires selection of target areas and products to enable quick implementation of research and development results into marketable products.

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the founding of a strategy group from the circle of actors (research and industry), in particular to make binding decisions on priority of developments regarding the target or reference products and to determine the manner and demand of pilot plants, and to procure them in a joint effort. Additionally, beside organic light diodes and organic photovoltaics, organic displays should be considered as well.

6.2 RECOMMENDATIONS ON LINKING ALL ACTORS ALONG THE ADDED-VALUE CHAIN

Joint efforts by all actors require a working network. Development success in organic electronics is only possible by interdisciplinary cooperation along the development and value-added chains (cf. chapter 5.1). Cooperation across value-added steps – in organic electronics usually across organisation boundaries – requires a detailed network without which potential cooperation partners cannot meet.

Networking among the know-how carriers is necessary both within the areas of application and between the different areas of application of organic electronics: within the respective areas of application to facilitate scientific exchange, and between the areas of application to use technology synergies and to enable learning from advanced areas.

This formation of networks should involve not only science and economy actors, but in particular politics and the funding organisations. Networking between science and economy on the one hand and politics on the other means that important bridges are formed. Politics must be able to react quickly and flexibly to technology and market changes and therefore require a "direct connection" to the operative actors.

Actors leaving and entering organic electronics is a natural development situation of this still-young technology field. Network formation therefore can never be fully completed.

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to design the network of actors in organic electronics to be flexible, open and sustainable and to integrate potential users, in particular small and medium-sized companies with potential for new application options for organic electronics (e.g. the printing industry) at an early point.

Networks should also be flexible towards actors from abroad. Companies and research facilities in Asia, the U.S. and European countries sometimes have know-how that is available hardly anywhere in Germany. This is already reflected in the present development and value-added chains. Know-how from abroad, such as the coating plant technology from Korea, is used both for research and production in German companies.[122]

[122] Cf. Mst online 2008.

Networking demand is present in particular between the present research areas in Germany. According to experts, cooperations between the present research sites currently are mainly based on personal attraction and not systematically anchored. Actors should strive for intense cooperations based on unique competences. Networking with the German centres, in contrast, is perceived to be outstanding. Each of the centres integrates a great part of the value-added chain "under a single roof". The spatial proximity in the centres and use of a joint infrastructure (e.g. pilot plants) promotes networking of scientists across organisation boundaries.

A strong network enables intense communication and co-operation between the actors of organic electronics and simultaneously results from this cooperation as well. Integrated cooperation of the organic electronics actors, in particular in joint projects (cf. chapter 5.2), builds new contacts and intensifies present ones. An essential contribution to the success of this cooperative manner of work is the trust of the partners among each other, since it permits open contact between the partners involved, the basis of close cooperation.

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the organisation of regular status-quo events for the actors from the centres, the remaining focuses with special competences and the projects to strengthen cooperation with and between the centres, discussion of problems, progress and possible implementation and coordination of solutions or further procedures. Such meetings should be organised by the executing agency.[123]

6.3 RECOMMENDATIONS ON ORGANIC ELECTRONICS CENTRES

Centres are places where the activities of organic electronics actors are bundled. They are characterised by spatial proximity of the different actors and thus combine scientific and commercial top contributors beyond the duration of a project. They are network nodes and thus the first point of contact for companies and scientists. Centres provide the infrastructure for cooperation between science and industry and are characterised by plans for the future that are coordinated among the partners, e.g. in the form of joint roadmaps. Centres therefore deliver good framework conditions for research and development, because resources are available and further development perspectives are present.

Organic electronics centres play an important role in the scope of the joint efforts of all actors. They should contribute to increased innovation speed and larger innovation volumes, create national and international networks and promote young researchers. Centres have diverse benefits. First, centres offer excellent framework conditions from integrative cooperation and the prerequisites for high-quality research and development from intense technical exchange. One of the greatest benefits in product generation is the spatial proximity of all know-how carriers.[124] The combination of competences of different value-added steps from science and industry "under a single roof" with connection to an excellent infrastructure therefore is an essential benefit of centres. Additionally, centres form the basis for networking between the actors of organic electronics on site and outside of the centres. The presence of personnel and material resources on site, together with initial success in science and industry, generate an important outside effect nationally and internationally. As "lighthouses", centres therefore attract scientists and companies from around the world.[125]

123 In the U.S., such meetings have already been established. The annual "Solid State Lighting R&D Workshop" is an event organised by DoE (Department of Energy) with the objective of providing a forum that promotes the formation of alliances and networks, as well as exchange of strategies in the area of SSL-technologies.

124 Cf. Kopp 2007, p. 28.

125 Cf. Grisolía 2003, p. 2.

Such centres have already become established abroad and enjoy great global renown.

HOLST CENTRE: A "LIGHTHOUSE" OF ORGANIC ELECTRONICS[126]

The Holst Centre is a partially government- and partially industry-funded independent research centre in Eindhoven (Netherlands), focussing on "open Innovation"[127] and cooperative research. It was founded jointly by Belgian "Interuniversity Microelectronics Centre" (IMEC)[128] and Dutch "Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek" TNO in 2005[129]. The Holst Centre therefore is the first cross-national research centre for organic electronics. About 150 scientists from 25 nations investigate and develop technologies for wireless, autonomous electronic microsystems and polymer-based electronics at the Holst Centre. The research contents are located between academic research and industrial development, comprising both basics and application-oriented questions.

The Holst Centre is targeted at achieving a particularly strong innovative power from integrative cooperation of industry, in-house scientists and university partners.

Research and development in the Holst Centre are performed in two types of research programmes: In "Technology Programs" (TP), basics-oriented research matters are dealt with. In contrast, the subjects of "Technology Integration Programs" (TIP) are strongly application-related. In the research programmes, partners from science and industry cooperate with the scientists of the Holst Centre. Roadmaps targeted at market maturity of the technologies named after three to ten years of research deliver the general alignment within the research programmes and offer long-term orientation for involved and interested partners. Development and continuous rework of these roadmaps are performed together with present partners and under integration of potential other partners. This provides for a joint basis and alignment for the cooperation of all parties involved at all times, with researchers from science and economy cooperating in interdisciplinary teams with the Holst Centre's scientists. Currently, the subjects of "OLED lighting", "OPV" and "Smart Packaging" are investigated there with a strong application focus. Printing technology as a production procedure for organic electronics is a focus of basic research.

The basis of this cooperation at the Holst Centre is a sophisticated IP-arrangements that determines the utilisation rights of the partners involved in the jointly developed project results and only provides for exclusiveness in exceptions. Research and development work is partially performed in the in-house Holst Centre infrastructure. The core of it is a "roll-to-roll" production plant for printed electronics. This infrastructure is complemented by those of the parent companies (TNO and IMEC) and the resources of the "High-Tech-Campus Eindhoven".

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126 Cf. Holst Centre 2009 as well as www.holstcentre.com.

127 "Open Innovation" means opening of the innovation process to the outside, e.g. by integrating suppliers or customers in the innovation process of a company with the objective of increasing the innovative potential.

128 IMEC is an independent research centre in the area of nanotechnology and electronics, headquartered in Leuven (Belgium)

129 TNO is the largest private research organisation in the Netherlands, headquartered in Delft and focussing on applied research.

Placement on a high-tech campus with eighty companies and five research institutions means that the Holst Centre is also networked very strongly in subject areas away from organic electronics. Additionally, the Holst Centre has a special "Outreach" program for targeted promotion of networking with young researchers and users, e.g. by informal exchange between designers, engineers and scientists.

The Holst Centre enables integrative cooperation of science and industry, combines international know-how carriers along the value-added chain "under one roof", offers excellent infrastructure for joint use by all partners, actively contributes to networking of the actors in the area of organic electronics and thus has implemented essential requirements to centres of organic electronics. It therefore developed into an internationally perceptible "lighthouse" of organic electronics, among others shown in the present cooperations with various organic electronics key companies. Support with governmental funds, which was already important for its founding, is still one of the bases for the presence of the Holst Centre.

Whether the concept will prove its worth without governmental funding as well and whether the business model and the limited usage rights regarding the results achieved will be acceptable for the industry, will be seen in the coming years.

Regional focuses have developed in Germany in the past as well. In particular the regions of Dresden and Rhine-Neckar around Heidelberg are highlighted as outstanding research regions in Germany. Both centres are industry-led and combine research institutions, universities and companies on all value-added steps of organic electronics.[130] Dresden with "Organic Electronics Saxony" (OES) is able to look back on a long history of organic electronics going back to the time of the GDR. The OES is characterised by strong bundling of competences and, according to experts, the largest research site for OLED in Europe.[131] Dresden has already developed a great international reputation. The close network there between key actors of organic electronics also makes Dresden interesting for foreign companies. The Forum Organic Electronics in Heidelberg, one of the winners of the leading-edge cluster competition of BMBF in 2008, is only under development as such. Of course, the leading-edge cluster is based on the long-term experience of large industrial actors like BASF, Merck and Heidelberger Druckmaschinen, which, together with the contributing universities, have the best prerequisites to quickly achieve international visibility. In the form of InnovationLab GmbH, which holds the cluster management for the "Forum Organic Electronics", a promising concept has been launched. It focuses on cooperative research with the Universität Heidelberg being integrated, transfer of inventions into marketable products and training of young researchers.[132] This concept is expected to bring great success. Dresden and Heidelberg are characterised by different focuses in particular in plant and process technology. While the OES in Dresden has its focus on vacuum-based coating procedures for small molecules, the leading-edge cluster Forum Organic Electronics focuses on liquid phase processing. This is also due to the fact that the Rhine-Neckar area – under integration of the Institut für Druckmaschinen und Druckverfahren in Darmstadt – is a globally leading printing technology centre. However, Dresden and Heidelberg also differ structurally in that Dresden is clearly characterised by start-up-companies growing from the university, while Heidelberg stands for cooperation of large companies and an excellent university. Both paths have their benefits. The university of Cologne also plans to establish a new organic electronics centre. The focus of

130 Cf. VDI 2009, p. 13.
131 Cf. IZT 2008, p. 216 ff.
132 http://www.innovationlab.de/de/innovationlab/uebersicht/[Stand: 15.11.2010].

these activities is development of the Ideas Factory Cologne (IFC), which – funded by a Public Private Partnership model – is to close the gap between university research and industrial commercialisation of organic electronics.

Development of centres in Germany, however, should remain limited to two or three to avoid impairing the desired lighthouse effect and to bundle the funds, in particular for provision of the cost-intensive but necessary infrastructure. Independently of this, research and development competences like printing technology in Chemnitz or OLED pilot production in Regensburg have developed which should, however, be closely linked to the centres and integrated in the joint strategy.

The organic electronics centres already established in Germany are an excellent starting base to build and develop "lighthouses of organic electronics" with international renown. Prerequisites for this are great networks and in particular a technically driven, close cooperation within and between the present organic electronics centres. The essentially complementary alignment of the centres in Heidelberg and Dresden provides an important basis for this. Strong domestic competition hardly appears beneficial in the light of the strong international competition.

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not to increase the number of centres in Germany to avoid impairing their visibility and attractiveness for cooperation on scientific and economic, as well as on national and international basis. Public Private Partnership models with key companies of organic electronics should be developed from the centres, not only to finance implementation-oriented developments in the centres, but also to improve combination of science and industry, in particular of companies with a high application potential for organic electronics, and to increase attractiveness of training in the area of organic electronics.

7 PERSPECTIVES

The semiconductor structures of microelectronics have been growing smaller and smaller for decades. Their performance is increasing exponentially, while the costs are reduced exponentially. In the scope of this miniaturisation, microelectronics now move towards nanoelectronics, characterised by structures of less than 100 nanometers. When layers are only a few atom layers thick, silicon technology is reaching its thresholds. This calls for a radical technology change, search for new materials, (lithography) procedures, construction element concepts and design.

Since the mid-20th century, semiconductor transistors stood opposite to vacuum electron tubes. Now, new horizons are opening up again in electronics: spin electronics and quantum computers are concepts currently under development; molecular electronics and use of DNA-strands as electrical conductors able to self-organise are investigated intensely.[133] Organic electronics were able to establish itself here as the first concrete field, and to present all the strengths of molecular electronics: the functional diversity of organic semiconductors results from the variation of size and shape of the molecules, which in turn can be modified by chemistry à la carte.

Of course, it would not be accurate to say that organic semiconductors will replace silicon. The strengths of the high-performance and stable silicon-electronics definitely still will be used. Organic electronics are a supplement with new functions like lighting, cost-efficient in general, suitable for mass production and promising weight savings. Their relevance has already been documented by awarding of the Nobel Prize for chemistry 2000 for the discovery and development of electrically conductive polymers. In particular physical basic research will still have to create basic understanding of the processes from load transport to stability of organic materials.

In 2010, the Nobel Prize for physics was awarded to the scientists devoted to the research of graphene, a material consisting of individual layers of carbon atoms. Computer chips will become faster and much smaller still if this material is used for field-effect transistor. Once more, it becomes obvious that material science and engineering, which incorrectly was considered to be unattractive, is an innovation driver – in this case for the entire field of information and communications technology.

133 acatech 2011.

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ANNEX: PROGRAMME OF THE INITIAL WORKSHOP

Date: 18 May 2010
Place: Frankfurt am Main

10:30 hours	**Begrüßung und Einleitung**	Hartwig Höcker
10:45 – 11:00	**Organische elektronische Materialien – nicht nur die üblichen Verdächtigen**	Klaus Müllen (Max-Planck-Institut für Polymerforschung)
11:15 – 11:30	**Materialentwicklung für Organische Elektronik bei BASF**	Karl-Heinrich Hahn (BASF SE)
11:30 – 11:45	**Materials for organic electronics at Merck**	Thomas Geelhaar (Merck KGaA)
11:45 – 12:30	**Diskussion**	
12:30 -- 13:30	**Mittagspause**	
13:30 – 13:45	**OLED – Organische Elektronik in Sachsen**	Karl Leo (Fraunhofer IPMS, TU Dresden)
13:45 – 14:00	**OLED – Lighting global und in Deutschland**	Dietrich Bertram (Philips GmbH)
14:00 – 14:15	**Novaleds Sicht auf die Organische Elektronik**	Jan Blochwitz-Nimoth (Novaled AG)
14:15 – 15:00	**Diskussion**	
15:00 – 15:30	**Challenges of the physics of organic electronic devices**	Siebe van Mensfoort (Philips, NL)
15:30 – 16:00	**Kaffeepause**	
16:00 – 16:15	**Lösungsbasierte organische Elektronik**	Klaus Meerholz (University of Cologne)
16:15 – 16:30	**Status und Herausforderungen der OPV in der anwendungsorientierten Forschung**	Wolfgang Volz (Robert Bosch GmbH)
16:30 – 16:45	**Organic photovoltaics - from lab to fab**	Andreas Rückemann (Heliatek GmbH)
16:45 – 17:30	**Diskussion**	
17:30 – 17:45	**Schlusswort**	Hartwig Höcker

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