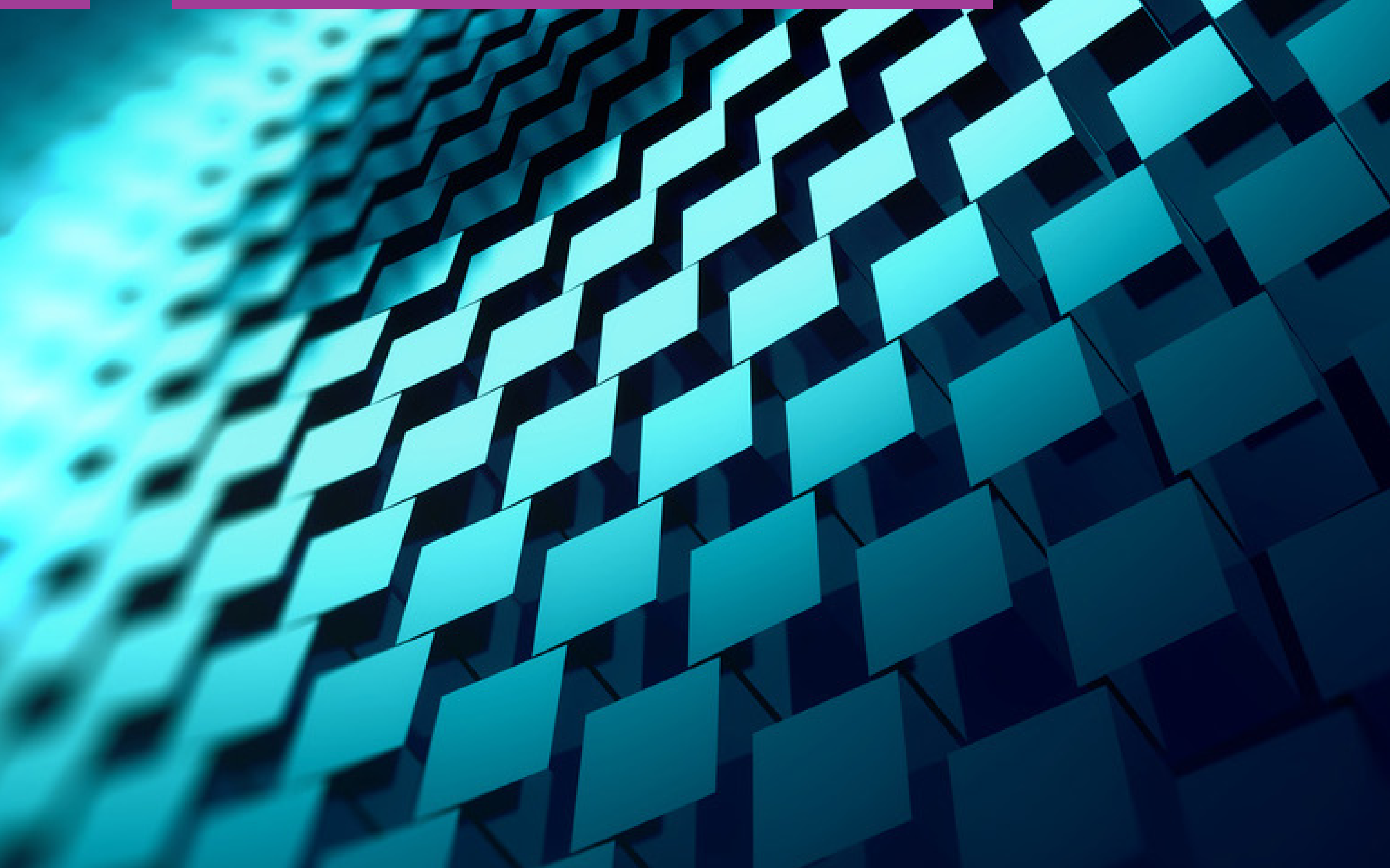
REPORT 4/2016

Towards material excellence

Evaluation of Tekes' programmes on materials

Juhani Timonen, Markku Antikainen, Amit Das,
Essi Sarlin and Jyrki Vuorinen

Tekes



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Evaluation Report

Tekes Report 4/2016
Helsinki 2016

Tekes – the Finnish Funding Agency for Innovation
Tekes is the main public funding organisation for research, development and innovation in Finland. Tekes funds wide-ranging innovation activities in research communities, industry and service sectors and especially promotes cooperative and risk-intensive projects. Tekes' current strategy puts strong emphasis on growth seeking SMEs.

Tekes programmes – Tekes´ choices for the greatest impact of R&D funding
Tekes uses programmes to allocate its financing, networking and expert services to areas that are important for business and society. Tekes programmes have been contributing to changes in the Finnish innovation environment over twenty years.

ISSN 1797-7347
ISBN 978-952-457-621-5

Cover image: Fotolia
Page layout: DTPage Oy

Foreword

Materials technology is one of the key technologies and most important areas of R&D in industrialised countries. It has fuelled progress in every industrial sector. Intelligent, embedded sensors and highly durable light structures, for example, are both successful products of material research. The scope of materials science is wide and involves the integration of many disciplines and experts, from fundamental to applied science in physics, chemistry and biology.

This evaluation covers two materials programmes. Pinta programme (2002–2006) was to achieve a comprehensive understanding of the phenomena of clean surfaces by combining several basic and applied disciplines. The focus was on preventing the fouling on surfaces made of steel, ceramics, wood, plastics or coatings. The Functional Materials Programme (2007–2013) aimed to develop new applications and competitive advantage through materials technology for Finnish industry. The main research areas of the programme were understanding materials and their features, tailoring functionality, and the control, production, application and disposal of materials.

The evaluation consists of international benchmarking, impact analysis of Pinta and relevance, efficiency and results evaluation of Functional materials. Since materials technology is truly global, an international benchmarking was made to give an overview of recent development. Several cases have been analyzed to get a versatile picture of the utilization of results in Finnish companies. The findings show the importance of skills development and expert rotation between universities and companies. Another good practice is about resilience and strategic reorientation when the operating environment changes.

The evaluation team consisted of experts from Virebit Oy and Tampere University of Technology. Tekes wants to thank Juhani Timonen, Markku Antikainen, Amit Das, Essi Sarlin and Jyrki Vuorinen for their comprehensive and persistent work. Tekes expresses its gratitude to all involved in steering group, interviews, survey and workshops. The report shows valuable findings and conclusions on the impacts and mechanisms, and it will serve as an important evidence base for on-going and future programmes.

Tekes

July 2016

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Operating Environment

1.1 Changes in the operation environment

Materials science is an enabling technology and thus plays a key role in virtually all fields of industry. Whether it is a question of sustainable energy, better drugs or implants, operational life of advanced batteries or sophisticated electronics, the applied materials have to meet the specific property and performance requirements. In Finland materials science has a great significance since it supports the fields of industry that boost national economy, improves the competitiveness and introduce new technologies through applications.

The "Clean surfaces" (PINTA, 2002–2006) and "Functional materials" (FM, 2007–2013) programmes were both related to materials science. PINTA concentrated around the phenomena affecting fouling aiming to clean surfaces in different industrial and every-day-life applications. The scope of the FM programme was wider aiming to new innovative material solutions, such as new biomaterials or hybrid materials, mainly in the fields of solar energy, printed electronics and heavy industry. Both of the programmes induced a good boost for the research activity of related topics in Finland and enabled long-span working among phenomenological and more applied challenges in research institutes and industry.

The general industrial and operational environment in Finland has changed clearly during the PINTA and FM programmes. For example, the stability in the pulp and paper industry and the tremendous success of the electronics industry turned into decrease during the 21st century whereas the manufacturing of electric machines and mining equipment kept their position.[1] The globalization of big as well as SM companies escalated towards the end of the century. In addition to global markets, characteristic for true success stories of this time were also renewable product palette and outstanding from competitors with new improved products.

An overview on the publication activity of PINTA and FM related research topics in peer-reviewed international journals during the 21st century provides an idea of the research trends and changes in them. When analysing these trends, the annual rise in the number of publications, which is roughly 5%[2], was regarded as the ground level. In Figures 1-1 and 1-3, the publication trends during 2000–2015 globally and in Finland of different PINTA and FM related topics are summarized. The publication activity has been divided into three groups: in very active areas (average annual publication activity growth in 2000–2015 more than 10%), in steady state areas (publication activity growth 3–10%) and in decreasing areas (publication activity growth less than 3%). The source for the publication activity statistics was the Scopus[3] database for peer-reviewed international publications.

Several PINTA programme related topics (Figure 1-1), such as atomic layer deposition (ALD), photocatalysis or nano coatings are still very actively studied topics both globally and nationally. Since the publication growth is evaluated during a long time span, the graph does not express well the current trends in the publications activity of these topics. Areas which still have a strong growth in the annual publication activity are hybrid coatings and biofilms. The annual number of publications in the other very active (green) fields has started to stabilize more recently. In some areas, such as in sol-gel coatings and in soiling related research, there was a clear increase in the publication activity in Finland during the PINTA programme but interest has faded more recently. The current unflattering trend can also be explained with changes in the terminology: for example, recently the sol-gel technology has become more complicated and other techniques are combined with it resulting in better representative terms such as "hybrid coatings" or "nano coatings" which in turn have high publication activity.

To highlight the effect of the PINTA programme, the achievements in academia and business in the field of atomic layer deposition (ALD) and atomic layer epitaxy (ALE) offer a good example (Figure 1-2): In 1974 the first patent on ALE[4] was filed and the first ALE related international article was published in Finland in 1981[5] and the first ALD

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1 E. Eloranta, J. ranta, P. salmi, P. Ylä-Antti: Teollinen Suomi – Tuotannon uudistuminen kriisin jälkeen. SITRA. ISBn 978-951-563-722-2

2 Larsen, von Ins, Scientometrics. 2010 Sep; 84(3): 575–603.

3 www.scopus.com

4 T. Suntola, J. Antson: Finnish Patent 52359 (1974) and US Patent 4058430 (1977) to Lohja Corp. Finland

5 M. Pessa, R. Mäkelä, T. Suntola: Characterization of surface exchange reactions used to grow compound films (1981) Applied Physics Letters, 38 (3), pp. 131-132.

Fig. 1-1. The publication activity in the PINTA programme related topics globally and in Finland.

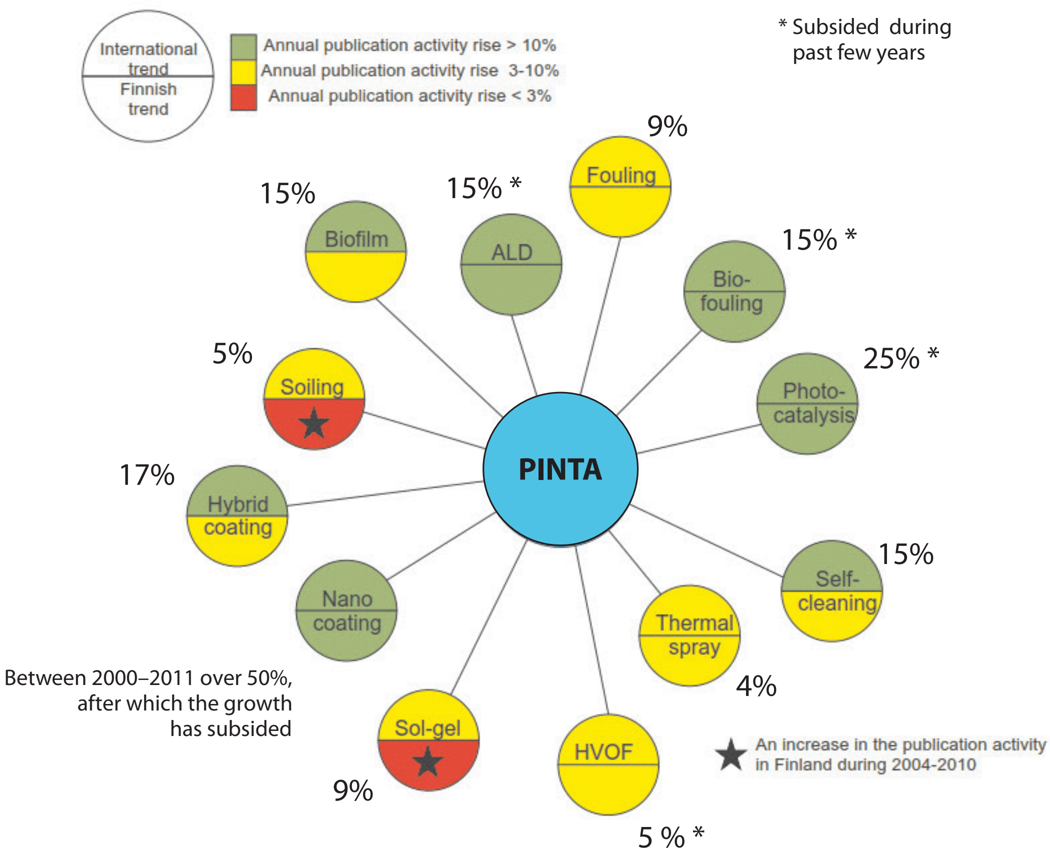
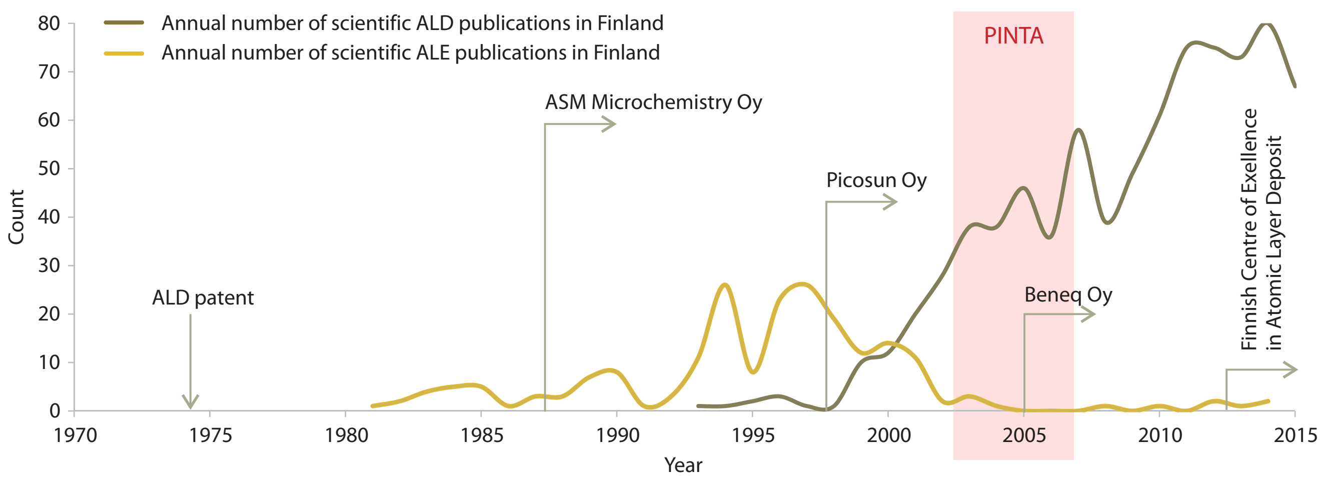


Fig. 1-2. Milestones in the research and business related to atomic layer deposition (ALD) and atomic layer epitaxy (ALE) in Finland.

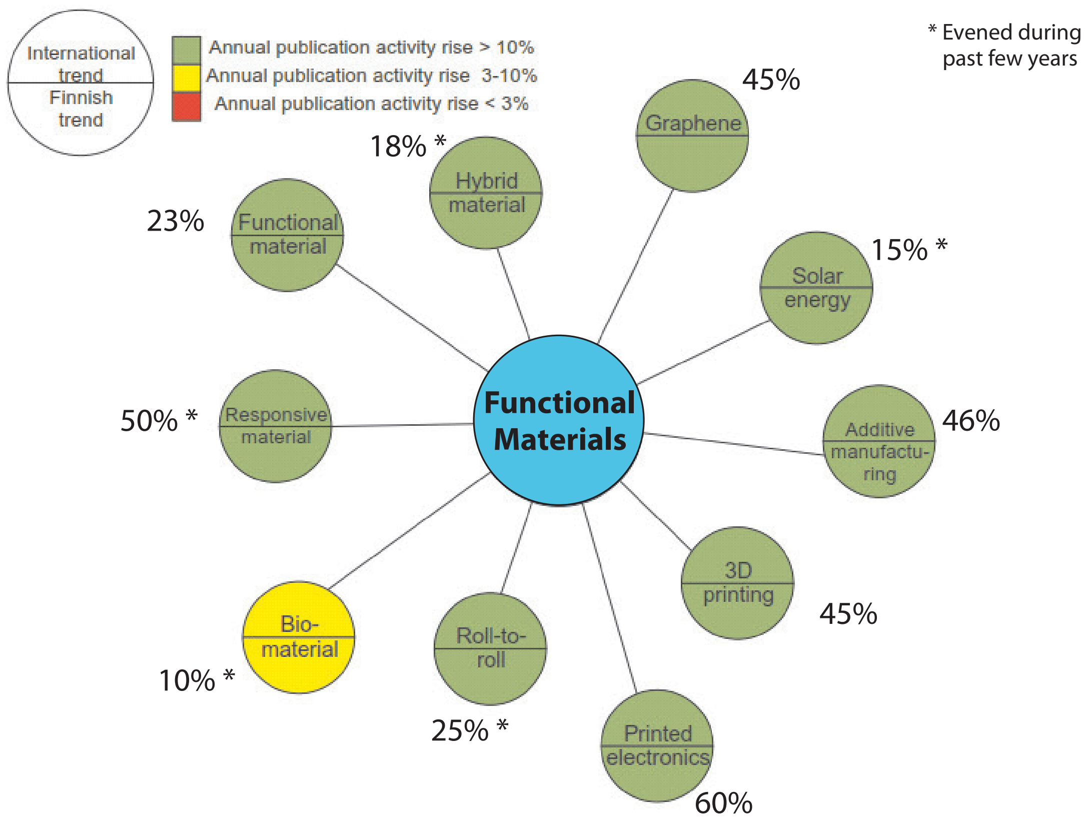


article in 1993[6]. Until 1991, the annual number of ALE/ALD related publications was small but since 1992 the publication activity has shown a steady annual growth. Taking place during the years 2002–2006, the PINTA programme has played an important role in establishing and strengthening the scientific ALD research and the ALD business in Finland. Also the tight collaboration between research institutes and companies taken place during the PINTA programme is still very active. The academic, industrial and collaborative basis created in this field in the early 21st century is visible to this day: Finland is ranked fifth in international ALD publication activity during 2010–2015 and the number of joint publications of academia and companies stays at a good level.

The publication activity in the FM programme related areas is still very high, mainly above average (Figure 1-3). Similar to the PINTA related areas, the popular publication themes include those in which the growth is still active (graphene, additive manufacturing and 3D printing, printed electronics and functional materials) and those in which the annual number of publications has started to stabilize (responsive and hybrid materials, solar energy and roll-to-roll methods). Here the solar energy is a good example on the on-going trends. Globally, there was a clear increase in the publication activity since 2007 (Figure 1-4.a) and in Finland it realized in 2009, two years after the FM programme started. With a two years delay the installed solar photovoltaic capacity starts to rise, as shown in Figure 1-4.b.

The development of a material from its initial discovery to its industrial application may take 20 years or more.[7] Thus, long-span work is required to achieve improved properties for an industrially usable new material. However, more recently the international and national trend has gone towards simultaneous modelling, simulation and experimental work, which accelerates the material development work. During the PINTA and especially during the FM programme the aim already was towards this kind of activity, but the goal was not yet achieved. Nowadays the computational power enables the routine-like processing of very large data sets and the application of big data and internet of things are the trends of today. However, in the field of materials science the benefit of the digitalization in accelerating the research and development work can be achieved only if continuous experimental validation work is done together with computer aided development work.

Fig. 1-3. The publication activity in the FM programme related topics globally and in Finland.

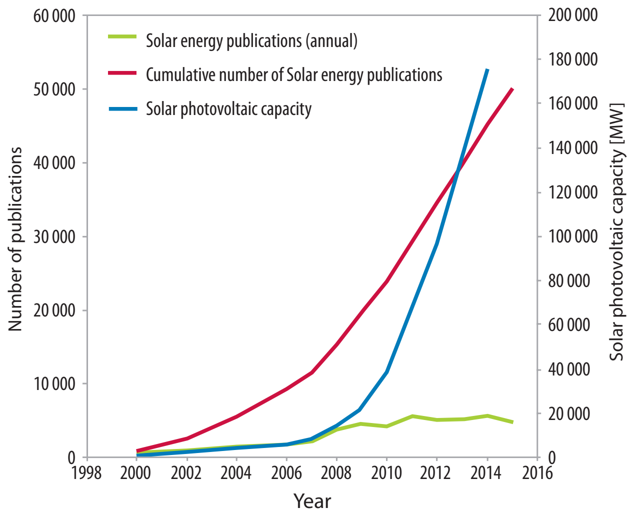


6 M. Ylilammi, T. Ranta-aho: Optical determination of the film thicknesses in multilayer thin film structures (1993) Thin Solid Films, 232 (1), pp. 56-62.

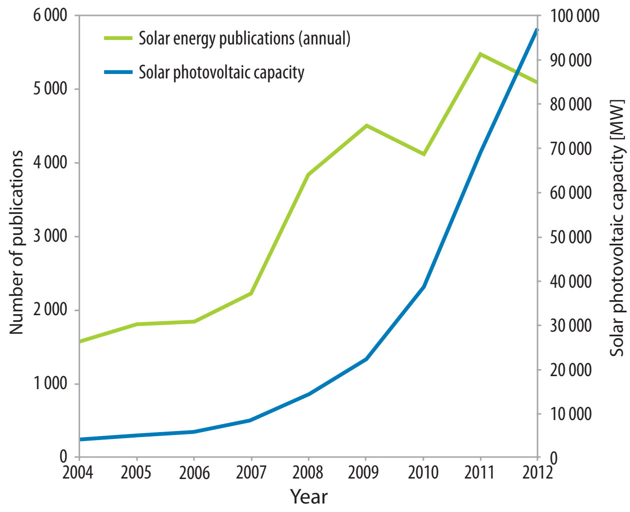
7 National Science and Technology Council, Committee on Technology, Subcommittee on the Materials Genome Initiative: Materials Genome Initiative Strategic Plan, December 2014. https://www.whitehouse.gov

Fig. 1-4. The annually published and cumulative number of solar energy related publications and the global solar photovoltaic capacity. The time span 2000–2015 is shown in (a) and a more detaile2004–2012 in (b).

a)



b)



1.2 International benchmarking

1.2.1 RDI International Benchmarking in Germany

The development of advanced material systems serves to improve the shape and mechanical characteristics of structures, and is increasingly bringing 'smart materials' to the fore. It has become one of the main research programme in Germany. The integration of functions in materials and components calls for new manufacturing and assembly processes. A lot of groups, universities, and institutes in Germany are actively involved with the focus on the concept of holistic manufacturing systems that harmonize functional materials, joining and assembly technologies, and state-of-the-art surface protection concepts. Particular attention is given to the areas of sensor-equipped components, surface engineering, and joining and assembly technologies. There are numerous centres, groups, universities, institutes and higher technical schools (Fachhochschule) who are very much active in research and development in the areas of functional materials. Some important and internationally visible ones are listed in the following chapters.

Organizations active in materials research in Germany

Fraunhofer Society

Fraunhofer Society in Germany orients in the advancement of applied research with 67 different institutes all over Germany. Among these clusters at least a dozen of such institutes are very much actively involved with the active and functional materials research program. Aiming at application of the developed materials they are giving focus on energy and resources, mobility and transport, communication and knowledge, security and protections, production and supply of service, health and environment issues. Such institutes are:

- Material and Beam Technology – IWS
- Surface Engineering and Thin Films – IST
- Wood Research, Wilhelm-Klauditz-Institut – WKI
- Applied Optics and Precision Engineering – IOF
- Applied Solid State Physics – IAF
- Chemical Technology – ICT
- Manufacturing Engineering and Applied Materials Research – IFAM
- Materials Recycling and Resource Strategies – IWKS
- Process Engineering and Packaging – IVV

Leibniz Association

The Leibniz Association is a union of German non-university research institutes from various branches of study. In 2011, 87 non-university research institutes and service device for science belong to the Leibniz Association. The fields range from natural science, engineering, and ecology, to economics, other social sciences, space science, and humanities. The Leibniz Institutes work in an interdisciplinary fashion, and connect basic and applied science. Naturally, the material development programme has become one of the integrated research parts of these institutes. Here is one example, The Leibniz Institute for Solid State and Materials Research Dresden – in short IFW Dresden – is a non-university research institute and a member of the Leibniz Association. It is concerned with modern materials science and combines explorative research in physics, chemistry and materials science with technological development of new materials and products. The research programme is focused on functional materials, which hold a key position in many fields of application: superconducting and magnetic materials, thin film systems and nanostructures as well as crystalline and amorphous materials. Further missions of the Institute are the promotion of young scientists and the training of technical staff as well as supplying industrial companies with the Institute's R&D know-how and experience.

Karlsruhe Institute of Technology, KIT

KIT is one of the largest institutes in Germany with more than 9,000 employees and an annual budget of about EUR 785 million. Some of the sub institutes are active in multifunctional materials programme, such as the partial Institute of Materials Science and Engineering (IAM-WK) focuses on research and innovation in the field of material structure. Thus the process-, structure- and characteristic-relations are derived. The development of mechanical, thermal and combined methods for the influence of mechanical characteristics are advanced and methods for the characterization of microstructure, stress state and near surface conditions of metallic and polymeric materials, composites and components made from these materials are promoted. Furthermore, practices are developed for the testing of materials and components under different load conditions, especially at dynamic, cyclic and combined loading. With the help of the characterization methods mentioned above these practices are used for the mechanism-oriented assessment of the deformation and failure behaviour. These activities are completed by simulations for the description of work processes and mechanical loading on the basis of mechanism-oriented, micromechanical methods. Thus, the interaction between microstructure and mechanical characteristics as well as between surface and mechanical characteristics is described. The knowledge obtained by this allows for the maximum utilization of a material in a component and for the creation of materials understanding in the product development process.

Ruhr-Universität Bochum, Institute of Materials, Faculty of Mechanical Engineering, Bochum, Germany

This group is working with the principle of combinatorial and high-throughput approaches and development and application of electrode arrays, micro-hotplates and cantilever arrays in materials science, and conventional and ferromagnetic shape-memory-alloys. Specifically, concerning functional materials in microengineering, this group is also involved to the development and application of micro-hotplates and electrode arrays in materials science and micro actuators based on shape-memory thin films. Other state-of-the-art subjects of their research programme are next generation energy materials, especially hydrogen research:

- Combinatorial thin film libraries of novel hydrogen storage materials (complex metal hydrides),
- Solar-water splitting (metal oxynitrides),
- Fuel cell materials (catalysts, diffusion barriers),
- Lithium-ion battery materials (mechanical effects during lithiation).

Technical University Darmstadt, Institute of Materials Science

In addition to the development of high-performance materials for modern technologies, primarily construction materials for high temperature applications and for lightweight construction, both the study of materials with specific properties for use in microelectronics and the use of renewable energy are placed in the foreground. These areas represent major scientific and technological challenges, such as in terms of better utilization of energy and material resources and the competitiveness in the information and communications technology. The criterion of environmental sustainability plays here an important role. Human development has caused a depletion of natural energy resources and climate changes with non-predictable consequences. New energy concepts are required for the future of industrial society resulting in e.g. an ever increasing emphasis on improving the efficiency of electricity transmission and utilization and in the progressive replacement of oil-based combustion engines by electric motors in transportation. Subjects of materials research in this context are novel permanent magnets, magnetocaloric materials, magnetic shape memory alloys and materials for solid state hydrogen storage.

Erlangen-Nuremberg University (Friedrich-Alexander-Universität FAU)

FAU's Faculty of Sciences and Faculty of Engineering are renowned for their exceptional strength in new materials research and process technologies related to this field. The research activities in this area are mainly focused on the development of functional materials with structures, which are constructed hierarchically from the molecular to the macroscopic scale. New research approaches which cover a wide range of length and time scales are required in order to bridge the gap between molecular design and component design. This applies to simulation and modelling, structural analysis, properties analysis and process analysis, as well as manufacturing and processing technology. FAU researchers are leaders in the fields of particle technology, carbon allotropes, ionic liquids, cellular ceramics and self-organisation of nanostructures through anodization. New materials are expected to lead to scientific progress in energy and communication technologies, catalysis, lightweight materials and life sciences.

Institute of Materials Research, German Aerospace Centre (DLR)

DLR's mission comprises the exploration of the Earth and the solar system, as well as research aimed at protecting the environment and developing environmentally compatible technologies, and at promoting mobility, communication and security. DLR's research portfolio, which covers the four focus areas Aeronautics, Space, Transportation and Energy, ranges from basic research to innovative applications. DLR operates large-scale research centres, both for the benefit of its own projects and as a service for its clients and partners from the worlds of business and science. The main research focus of the Institute of Materials Research is the development of new material solutions and their processing techniques for applications in aerospace, in energy technology and in automotive engineering.

Ongoing research and development topics in the area of Functional Materials in Germany

Most of specific topics in the areas of Functional materials are application-oriented topics. The research portfolio covers across the fields of metallic structures, hybrid material systems, intermetallics, ceramic matrix composites, aerogels and aerogel composites, thermoelectric systems, green materials (environment), sensors, high temperature and functional coatings, electrode materials, energy storage etc. The development of numerical methods to simulate the behaviour of materials and components completes these competencies aiming at supporting the transfer of materials into industrial applications. Some examples of frontline research topics:

- High-temperature and functional coating
- Structural ceramics
- Metallic materials and structure
- Hybrid material system and intermetallics
- Thermoelectric materials and systems
- Aerogels and aerogel composites

1.2.2 Research Development and Innovation Benchmarking in China

Organizations active in materials research in China

Being a large fast developing country China has many research institutes and universities who are very active in materials research development. It is one of the nations who are increasing the quality of the publication in a very fast manner as compared with other developing nations like India. A global analysis by nature publishing group adds to evidence that China is rapidly boosting its quality research output, and becoming a global leader in scientific publishing and scientific research. In China the most famous research establishment focused on functional material development and research is Chinese Academy of Sciences. It is not in the university rank but much stronger/bigger than other universities/institutes in China.

The top ten universities of China are

- Tsinghua University,
- University of Science & Technology Beijing,
- South China University of Technology,
- Shanghai Jiao Tong University,
- Central South University,
- Beihang University,
- Zhejiang University,
- Harbin Institute of Technology,
- Tianjin University,
- Huazhong University of Science and Technology.

There are many other universities (50) also good in materials research like

- Northeastern University,
- Wuhan University of Technology,
- Northwestern Polytechnical University,
- Jilin University,
- Nanchang University,
- Beijing University of Technology,
- Tongji University,
- Beijing University of Chemical Technology,
- Zhengzhou University.

All the research institutes mentioned above are very productive nowadays in functional materials research, produce highly cited publications and are involved in very large number of patent application and publishing papers.

The **Tsinghua University** is very famous for its innovativeness in the area of materials technology and one of the well-known universities in the world in terms of very large number of patent applications. As part of the continuous drive at Tsinghua University to enhance the quality of scientific research, the major focus of efforts in patent administration has been shifted from management of applications to support for high-quality patents and technology transfer. With the help of the system, the number of domestic applied and granted patents has increased rapidly in recent years, while at the same time, the number of overseas applied and granted patents has also been growing year by year. In terms of the number of overseas granted patents Tsinghua University ranks top among Chinese Universities, and ranks 2th-3th among universities from all over the world (figures from 2013-2015). In 2015 a total of 500 overseas patent applications were made, and 390 overseas patents were granted. The total number of valid patents is around 15300, with 45%

maintained for duration of more than 10 years. The current research areas in the School of Materials Science and Technology are

- Materials in information technology, e.g., ferroelectric and dielectric ceramics & their applications;
- Piezoelectric ceramics & transducers;
- Microwave ceramics;
- Oxide phosphors;
- Packaging materials;
- Magnetic materials;
- Dielectric ceramics-based photonic crystals;
- Functional films.

This centre is also very active in nanomaterials research, e.g.

- Nanomaterials and nano-devices, e.g., nanostructures (e.g., nanowires)
- Nano-multilayers
- Patterned carbon nanotubes
- Polymer-based nanocomposites
- Particle-materials interaction, e.g., ion-beam modification & manipulation of materials.

The School of Materials Science and Engineering at **Zhejiang University** is one of the earliest organizations devoted to research and education in materials science and engineering in China. The School of Materials Science and Engineering hosts the State Key Laboratory of Silicon Materials which originates from the State Key Laboratory of High-Purity Silicon and Silane founded in 1985, and it was the first state key laboratory at Zhejiang University. Based on the state key second-level disciplines of materials science and materials physics and chemistry, the discipline of materials science and engineering became the state key first-level discipline. The School of Materials Science and Engineering consists of five institutes and one centre, which are

- Semiconductor Materials Institute,
- Metal Materials Institute,
- Inorganic Nonmetallic Materials Institute,
- Materials Physics Institute,
- Institute of Composite Science Innovation, and
- Centre of Electron Microscopy.

The School also hosts a series of high-level research platforms, including

- State Key Laboratory of Silicon Materials
- Research Centre of Ministry of Education for Inorganic Functional Materials for Surface and Structure Modification,
- Provincial Electron Microscopy Centre,
- Key Laboratory of Advanced Materials and Applications for Batteries of Zhejiang Province,
- Key Laboratory of Novel Information Materials Technology of Zhejiang Province.

The School of Materials Science and Engineering is devoted to the fundamental science research, application-oriented fundamental research and engineering technology development in the fields of materials micro- and nano-structures, information materials, energy materials, advanced structural materials and biomedical materials. The outstanding research achievements have nurtured different national and international prestigious prizes and awards. They also used to publish their scientific work in high-impact journals such as Science and Nature. For the subject of materials science, the School was ranked No.13th among all the universities in the world according to the essential science indicator (ESI) report in Dec. 2015.

The **Institute of Metal Research** (IMR) in the frame of Chinese Academy of Sciences (CAS) was founded in 1953. Since then, IMR has firmly established itself as an indispensable base for materials science and engineering research in China. Research at IMR focuses mainly on high performance metallic materials, new types of inorganic nonmetallic materials, and advanced composite materials. IMR's research is directed towards the understanding and characterization of materials properties, structure and performance, as well as materials synthesis and fabrication, processing, and application. Their mission is to excel in materials research, develop advanced materials technology and foster exceptional talents, thus serving the nation, society and mankind. IMR is home to the Shenyang National Laboratory for Materials Science, the Shenyang R&D Centre for Advanced Materials, the Laboratory for Corrosion and Protection, the Environmental Corrosion Centre, the National Engineering Research Centre for Corrosion Control of Metals and the National Engineering Research Centre for High Performance Homogenized Alloys.

The **University of Science and Technology Beijing** is now one of the top-ranking research universities in China in the area of materials research. While retaining its current leading position in metallurgy and materials sciences, it is making great efforts to develop other areas and to achieve a balanced disciplinary structure in engineering and technology, science, management, economics.

School of Materials Science and Engineering (MSE) centre in the frame of **South China University** of Technology is conducting research in the area of diversified areas of multifunctional materials. The partners are

- Department of Polymer Materials Science and Engineering,
- Department of Inorganic Materials Science and Engineering,
- Department of Electronic Materials Science and Engineering,
- Materials Science and Technology Institute,

- Materials Science Institute,
- Polymer Materials Institute,
- Polymer Electric and Light Materials and Devices Institute,
- Optical Communication Materials Institute.

Some of their recent remarkable achievements are
- Development green pulp bleaching method for paper industry,
- Waste paper management and utilization,
- Development of polymer optoelectronic functional material,
- Next generation internet and network demonstration,
- Dynamic plastic moulding technology and equipment,
- High-performance iron-based powder metallurgy parts forming series of technology and its applications,
- High grain glass fibre and single frequency fibre laser complete sets of preparation technology and application,
- Heat and mass transfer technology based on high-performance adsorption materials and its application.

Future trends

For the near future, there are several important directions in materials research that would be explored in a considerable way. Key materials will be developed in support of China's major national demands. Examples include research in aerospace technology, materials for energy, advanced manufacturing technologies, electronics and other high-tech industries. Materials research would be encouraged in profound way to make efficient use of Chinese natural resources, including materials recycling and reduction of pollution for sustainable development of the country.

1.2.3 RDI International Benchmarking in Japan

Organizations active in materials research in Japan

In Japan, the field of materials science is studied in various universities and research institutes. Below some Japanese research units focusing on functional materials are introduced briefly.

The University of Tokyo, Department of Materials Engineering

The Department of Materials Engineering at the University of Tokyo has been established as the Department of Mining and Metallurgy in 1886 and today its research fields cover the design, processing, utilization, and recycling of metals, ceramics, polymers, and semiconductors. The Department of Materials Engineering is considered as the Japanese leader in materials science and engineering education and research. University of Tokyo is within the top ten in the 2015 Nature INDEX list.

Kyushu University, Department of Materials Science and Engineering (MSE)

The Department of Materials Science and Engineering (MSE) of Kyushu University was founded in 1911. The department is focused on various functional materials including semiconductors and ceramics and on structural metals. For example, the synthesis of high-performance photo-catalytic and hydrophilic thin films is one of the key research topics of the department.

Okinawa Institute of Science and Technology Graduate University

The Okinawa Institute of Science and Technology is an interdisciplinary graduate school that conducts research in different fields of science and technology. For example, the research of the Nanoparticles by Design Unit focuses on optimizing the chemical and physical properties of nanoparticles for particular applications by combining heterogeneous gas phase synthesis, mass filtration, and controlled deposition techniques. All education and research of the Okinawa Institute of Science and Technology is conducted entirely in English.

National Institute for Materials Science (NIMS)

The objective of NIMS is to carry out fundamental and technology research and development in the field of materials science. The history of the institute goes back to 1956 when its first part the National Research Institute for Metals was established. The research fields of NIMS are divided under three main themes: Materials for Energy and Environment, Nanoscale Materials and Advanced Key Technologies.

RIKEN Centre for Emergent Matter Science (CEMS)

RIKEN is Japan's largest research institute (founded in 1917). RIKEN Centre for Emergent Matter Science (CEMS) focuses on developing new, more efficient technologies that will enable the production of energy in a sustainable manner as well as decreasing the energy consumption. They achieve this by combining advanced research in physics, chemistry and electronics in order to produce new technology such as highly efficient energy conversion devices and low-consumption electronics. RIKEN is within the 100 in the 2015 Nature INDEX list.

Ongoing research and development topics in the area of Functional Materials in Japan

The roots of the materials science and engineering units are typically in metallic materials, but nowadays nanomaterials, materials for energy technology and electronics have a strong role. Also the world leading role in photocatalysis research in the early 21st century is still visible in the research subject portfolio. Thus, the research is typically based on close collaboration between physicists, chemists, and electronics engineers. Next generation low-cost, high-performance energy harvesting and storage materials (e.g. perovskite solar cells and lithium ion batteries), next-generation photovoltaics, advanced strategic materials, lightweight high-performance hybrid and multifunctional materials are some examples of the current topics of the research projects. Also computational materials science plays an important role. There are several annual meetings and exhibitions for functional materials, such as the annual meeting of Material Research society Japan (MRS-J), the International Symposium on Functional Materials and the Highly-functional Material World which is the world's leading material show hold twice a year in Japan.

1.2.4 RDI International Benchmarking in South Korea

In South Korea, a lot of universities offer studies in materials science and engineering and there are also several research institutes in the field. Below some these units focusing on functional materials are introduced briefly.

Seoul National University, Research Institute of Advanced Materials

The Research Institute of Advanced Materials covers the fields of material design & characterization, structural & composite materials, functional materials, electronic materials, optical materials, carbon materials, energy materials, biomaterials, and ecomaterials. The institute has a wide range of materials characterization equipment and offers analytical services, educational services and consulting in addition to conducting research activities.

Functional Materials Research Lab, Department of Materials Science & Engineering, Korea University

The Korea University is considered one of the most prestigious universities in South Korea. The Functional Materials Research Lab at the Department of Materials Science & Engineering research is concentrated on the materials for new renewable energy and lithium ion batteries, composite materials and surface and corrosion properties of materials as well as on computational simulation of molecular dynamics. A strong focus is in tribological studies and applications. (http://fmr.korea.ac.kr/)

Korea Advanced Institute of Science and Technology (KAIST), Department of Materials Science and Engineering

The research fields at the Department of Materials Science and Engineering at KAIST cover materials for energy (production, conversion, and storage), optics and electronics, light and multifunctional materials, nanomaterials, interfaces and surface science as well as on computational materials science. KAIST was on place 16 on the 2014 QS World University Rankings in the subject of Materials Science. (http://mse.kaist.ac.kr/)

Pohang University of Science and Technology (POSTECH), Department of Materials Science & Engineering

POSTECH aspires to become one of the world's best in the field of next-generation materials. The Department of Materials Science is complemented by research institutes and infrastructures including the Max Planck-POSTECH Centre for Complex Phase Materials, the Graduate Institute of Ferrous Technology and the National Institute of Nanomaterials Technology. (http://www.postech.ac.kr/)

Korea Institute of Materials Science (KIMS)

The object at KIMS is to comprehensively facilitate R&D, test and evaluation and provide technical support related to materials technology in order to promote innovative technology and industrial development. It is focused on metallic and ceramic materials, surface related materials (e.g. functional thin films) and composite and hybrid materials and the related processing technologies. (https://www.kims.re.kr/eng/)

Ongoing research and development topics in the area of Functional Materials in South Korea

In South Korea, the focus of the field of materials science and engineering is in the materials for energy and electronics. Also research in the field of nano- and bio-materials combined with the life sciences are in the focus of the research. Elastic-composite energy harvesting devices based on an ultra-stretchable piezoelectric generator, eco-friendly friction materials for wind generators, and active nanowire waveguide probes that enable quantitative measurement of Cu_2^+ ions naturally present in single living cells are examples of the research highlights of the Korean universities in the field of materials science. The research is based on strong collaboration of industry, universities and institutes. The direct support of industrial enterprises, e.g. Samsung to university research is substantial.

1.2.5 Research, Development and Innovation Benchmarking of India

Organized approaches to basic research in materials science used to be the main part of research and development in India. Most of the high level research and development is taking place in the government funded research institutes but a few universities are well-known for this type of activity. These days the Indian Institute of Technology at various cities, Council of Scientific and Industrial Research (CSIR) research Institutes, Indian Institute of Science Education and Research (IISER) clusters and Indian Institute of Science are very much involved with material research. During the past fifteen years, the rapid increase in demand for higher education in India has led to increase the activity in materials research program. However, most of the remarkable research in materials science is associated with atomic energy, space, defence, medical and industrial technologies including biotechnology and most of the pioneered works have been done by Indian Defence Research Organisation (DRDO). Other research institutes and Universities are involved with this programme but their main output confines in academic type of work resulting only huge number of journal publications. Some examples of academic style research are given in the following.

Indian Institute of Science Education and Research (IISER) Kolkata

Advanced Functional Materials Laboratory (AFML) of IISER, Kolkata is one of the multidisciplinary research groups associated with functional materials development program. The research at AFML is focused on the fundamental and applied aspects of synthesis, characterization, and structure-property correlation of functional nanomaterials. The current research areas include quantum dot photovoltaics, electrocatalysis, photoelectrocatalysis, magnetism and magneto-transport, drug delivery, wastewater treatment, porous materials and carbon nanostructures.

CSIR-Central Electrochemical Research Institute Karaikudi

CSIR institute is associated with development of functional materials focused on energy and environment. The division concentrates on research activities relating to new materials for energy generation and savings. In addition, greener synthetic strategies for improvement of properties of existing materials are looked into. The institute concentrates on bimetallic nanomaterials, phosphors for CFL and white LED, materials for solid state ionics, materials for supercapacitors, organic materials for LED and OPV, conducting polymers for multifarious applications and carbonaceous materials. This division also concentrates on the computational materials science for simulation and modelling of battery materials, nanostructures, fuel cell catalysts etc.

Another group of this institute is dealing with electrochemical materials. This division has specialized knowledge and skills in preparing thin films of transparent conducting oxides, transition metal chalcogenides and metal/alloy nitrides, which find extensive applications in opto-electronic, electrochromic, photo-electrochemical and biomedical implant devices. Expertise is available to prepare these thin films using various techniques like vacuum/electron beam evaporation, RF/DC magnetron sputtering, sol-gel spin coating, spray pyrolysis, and pulse and brush plating. Electrochemical and spectral characterization of semiconductor thin films and nano powders are being carried out. Preparation of porous silicon /oxide structures for sensors, photovoltaic and LED applications. Development of low cost materials for DSSC and fabrication of large area cells are the strengths of this division.

Electro Organic department of this institute involved with the synthesis of environment friendly technology with unique selectivity towards oxidation, reduction and functionalisation. CECRI has developed many electro-organic processes over the years in this field. Some of the process that were commercialized include amino guanidine bicarbonate, unsymmetrical dimethyl hydrazine, calcium gluconate and potassium iodate. More effective anode and cathode materials are now available. Some separators like porous pot and asbestos should now be replaced with ion-exchange membranes and other new separator materials. Rotating electrodes and batch cells should be replaced by flow cells with higher space time yields. Fortunately, such updated modern flow cells are now commercially available.

Indian Institute of Chemical Technology -Hyderabad

Polymers & Functional Materials Division (PFM) Division of CSIR-Indian Institute of Chemical Technology (IICT) is well known nationally and internationally for its research programs in the area of polymeric and hybrid materials for different functional applications. The division conducts both basic and applied research with a mission to be a leading innovative eco-friendly solution provider through creation of relevant scientific knowledge base for understanding and expanding the science and technology of polymers, polymeric materials from renewable resources, nano and hybrid materials for coatings, inks, adhesives, healthcare, energy, and construction and other specialty functional applications. The ever growing advancements in synthetic organic chemistry, synthetic methodologies, and nanotechnology along with environment, energy and cost concerns make the functional materials research arena very challenging and dynamic. The strong interdivisional collaboration and support from the other divisions of the institute such as organic chemistry, inorganic & physical chemistry, lipids, biology and engineering has been one of the strengths to catch up with rapid advancements in science and technology of functional materials development. The division has close links and ties with industry, government great agencies and strategic sectors and several processes and technologies have been recently developed.

Indian Institute of Technology, Kharagpur

This institute is very well-known for its high class research activities towards more application oriented basic research. Materials Science Centre undertakes research activities in the areas of glass and ceramics, polymers, semiconductor, allied materials and composites. The development of know-how and manufacturing technologies of many strategic and advanced materials like opto-electronic materials and devices, semiconductor lasers, polymer blends etc. are the focusing topics by the centre. With state-of-the-art infrastructure the centre conducts major sponsored research projects and has developed a range of products today and applications, including ferromagnetic insulator cermets for telecom equipment, alumina composites, ceramic components by gel casting, synthesis of nano sized nonoxide ceramic powders.

Indian Institute of Technology, Kanpur

In this institute Advanced Center for Materials Science is conducting research in area of multifunctional materials. The centre has been serving the needs of the materials community from the institute as well as other academic and industrial establishments for over thirty-five years. Mainly this centre provides consultancy and testing services of global standard to the materials scientists.

Indian Institute of Science, Bangalore

This institute is the known to be a top research institute in India. The Materials Research Center in this Institute is pursuing research and development in the area of functional material. "Basic science to device prototypes" aptly sums up the research activities at MRC. Areas in which the Centre is currently active include the emerging field of nanomaterials, electroceramics, electro-optic functional materials, thermo-electric materials, structural ceramics and compound semiconductors. Faculty members are involved in all aspects of research, right from theoretical modelling, to processing these materials in diverse forms such as single crystals of various dimensions, thin films, nanowires, quantum dots and sintered polycrystals to studying their structure-property correlation by various advanced characterization techniques, to fabricating working devices either in the Centre itself or in collaboration with various institutions in India and abroad.

Though India is now going through a transition from 'developing' to 'developed countries', the application of the high class research findings (scientific publication) into practical or commercial purposes is very limited.

1.2.6 RDI International Benchmarking in USA

USA is and has been in the forefront of materials development. The materials research is divided between universities (and university related research centers), national laboratories, US army research labs and commercial enterprises. In the following a short summary of functional materials research in USA is given. The sampling is somewhat arbitrary and is based on the US top universities in the Times Higher Education World University Rankings, one national laboratory and DARPA. Universities selected are the five top US universities: California Institute of technology, Stanford University, Massachusetts Institute of Technology, Harvard University and Princeton University.

California Institute of Technology, CalTech

The California Institute of Technology is a private doctorate-granting university located in Pasadena, California, United States. It is well known NASA's Jet Propulsion Laboratory, which was established between 1936 and 1943 under Theodore von Kármán. Going through their resent research highlights shows a great variety of research related to functional materials such as bacterial motor, solar energy utilization, liquid fuels from carbon dioxide, novel phase a matter explaining superconductivity, polymeric fuel additive that can reduce the intensity of post-impact explosions, better memories by using short pulse lasers, self healing behaviour of jellyfish, new thin flat lenses, cool process to make better grapheme, new work on the role of irons magnetism on phase changes of steel etc.

Stanford University and SRI international

Though these two are not anymore related they are covered here in one chapter for brevity. Stanford University is a private research university in Stanford, California. The university's endowment, managed by the Stanford Management Company, was valued at $22.2 billion in August 2015 and in 2012 it become the first school to raise more than a billion dollars in a year. Stanford has over 2000 member staff with 20 Nobel laureates. SRI International is a non-profit research institute headquartered in Menlo Park, California. SRI formally separated from Stanford University in 1970 and became known as SRI International in 1977. SRI employs about 2,100 people. The lab has been very active in commercializing research and has milestones such as first transmission electron microscope in USA (1940), steel super alloys in 1950s, Fracture-Surface Topography Analysis (FRASTA) system and development of Zylon, high strength polymer fiber, in 1980s and Rapid Prototyping Method for Ceramics in 1990s show a steady innovation path in materials science. Current research highlights include MicroFactory Platform for Smart Manufacturing. SRI is applying its MicroFactory™ platform technology to the DARPA Open Manufacturing program. Micro-robots are used to build smart structures with high-performance mechanics. The vision is to enable an assembly head containing thousands of micro-robots to manufacture high-quality macro-scale products while providing millimeter-scale structural control. For example, some micro-robots will carry components (electronic as well as mechanical, such as truss elements), some micro-robots will deposit liquids, and others will perform in situ quality analysis. Mounted to a mobile robotic base, a microfactory will be able to build parts of practically any size.

Massachusetts Institute of Technology

The Massachusetts Institute of Technology (MIT) is a private research university in Cambridge, Massachusetts. Founded in 1861 in response to the increasing industrialization of the United States, MIT adopted a European polytechnic university model and stressed laboratory instruction in applied science and engineering. Researchers worked on computers, radar, and inertial guidance during World War II and the Cold War. The Institute is traditionally known for its research and education in the physical sciences and engineering, and more recently in biology, economics, linguistics, and management as well. The mission of MIT is to advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the nation and the world in the twenty-first century.

MIT research highlights include a biomimetic approach for making stronger and more durable concrete. In a paper published online in the journal Construction and Building Materials, the team contrasts cement paste — concrete's binding ingredient — with the structure and properties of natural materials such as bones, shells, and deep-sea sponges. Another research highlight was given as self-healing or maybe better self-diagnosing polymer gel. MIT researchers are making fluorescent polymer gels that change color when they're shaken, heated, exposed to acid, or otherwise disrupted. Given that response, these novel materials could be effective sensors for detecting changes in structures, fluids, or the environment. To create the gels, the researchers combine a widely used polymer with a metal that fluoresces and a chemical that can bind the two together.

Harvard University

Harvard University is a private research university in Cambridge, Massachusetts, USA, established 1636. Harvard has as honors 47 nobel laureates and 32 heads of state. Harvard University is made up of 11 principal academic units – ten faculties and the Radcliffe Institute for Advanced Study. The ten faculties oversee schools and divisions that offer courses and award academic degrees. In 2007, in recognition of the growing preeminence of engineering and applied sciences, the University transitioned the former Division of Engineering and Applied Sciences into John A. Paulson School of Engineering and Applied Sciences. Resent Harvard research highlights related to functional materials include: Bionic leaf turns sunlight into liquid fuel: a cross-disciplinary team at Harvard has created a system that uses solar energy to split water molecules and hydrogen-eating bacteria to produce liquid fuels, A thinner, flatter lens: A new meta-lens works in the visible spectrum, seeing smaller than a wavelength of light. Because of this development, high-efficiency, ultra-flat, or planar, lenses could replace heavy, bulky ones in smart phones, cameras, and telescopes, Printing metal in mid-air: Researchers at Harvard's Wyss Institute have developed a laser-assisted direct ink writing method that prints microscopic metallic, free-standing 3-D structures in one step and 4-D printed structure changes shape when placed in water: A team of scientists at the Wyss Institute for Biologically Inspired Engineering at Harvard University and the Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS) has evolved their microscale 3D printing technology to the fourth dimension, time.

Princeton University

Princeton University was chartered in 1746 and is the fourth-oldest college in the United States. Princeton provides undergraduate and graduate instruction in the humanities, social sciences, natural sciences and engineering. It has more than 1,100 faculty members that instruct approximately 5,200 undergraduate students and 2,600 graduate students. Resent Princeton research highlights include following: New low-temp method makes efficient solar cells: a simple, low-temperature method to synthesize an efficient solar cell interface. The interface plays a critical role in converting sunlight to electrical energy. Princeton researchers deposited a thin 'hole-blocking' layer of titanium dioxide on a hydrogen-capped silicon surface to form a $TiO2/Si$ interface whose performance matched the leading classic interface, $SiO2/Si$. The interface was synthesized at 100 °C, much lower than the ~800 °C temperatures typically required and a story that shows that 3-D printed parts provide low-cost, custom alternatives for lab equipment: the 3-D printing scene, a growing favorite of do-it-yourselfers, has spread to the study of plasma physics. With a series of experiments, researchers at the Princeton Plasma Physics Laboratory (PPPL) have found that 3-D printers can be an important tool in laboratory environments. "The printer is now a crucial piece of our laboratory and used regularly," said Andrew Zwicker, the head of Science Education at PPPL and lead author of a paper that reports the results in the current issue of the American Journal of Physics. "The versatility of the printer is such that our first reaction to an equipment need is no longer whether we can find or purchase the required piece of equipment, but can we print it?"

Los Alamos National Laboratory

Los Alamos National Laboratory (LANL) is a United States Department of Energy national laboratory, managed and operated by Los Alamos National Security, located in Los Alamos, New Mexico. The laboratory is one of the largest science and technology institutions in the world. It conducts multidisciplinary research in fields such as national security, space exploration, renewable energy, medicine, nanotechnology, and supercomputing. LANL recent research highlight showing commercialization of research include: plasma technology for textile finishing, improved medical implants comes from nanostructuring and successful optimization of diaper manufacturing and manufacturing design.

DARPA

The Defense Advanced Research Projects Agency (DARPA) is an agency of the U.S. Department of Defense responsible for the development of emerging technologies for use by the military. Its purpose was to formulate and execute research and development projects to expand the frontiers of technology and science, with the aim to reach beyond immediate military requirements. DARPA is independent from other military research and development and reports directly to senior Department of Defense management. DARPA has about 240 employees. Their research highlights include: Atoms to Product (A2P) program that develops the technologies and processes required to assemble nanometer-scale pieces, whose dimensions are near the size of atoms, into systems, components, or materials that are at least millimeter-scale in size. Many common materials exhibit unique and very uncommon physical characteristics when fabricated at nanometer-scale. These "atomic-scale" behaviors have potentially important defense applications, including quantized current-voltage behavior, dramatically lower melting points and significantly higher specific heats, for example. The challenge is how to retain the characteristics of materials at the atomic scale in much larger "product-scale" (typically a few centimeters) devices and systems, Compound Semiconductor Materials on Silicon (COSMOS) program develops viable process for the fine-scale heterogeneous integration of compound semiconductor (CS) devices within standard Si complementary metal oxide semiconductor (CMOS) technology and to establish that this integration enables superior performance in specific mixed-signal circuit demonstrators, the DAHI Foundry Technology program thrust seeks to establish an accessible, manufacturable technology for device-level heterogeneous integration of a wide array of materials and devices (including, for example, multiple electronics and MEMS technologies) with complex silicon-enabled (e.g. CMOS) architectures on a common silicon substrate, Living Foundries program leverages the unparalleled synthetic and functional capabilities of biology to create a revolutionary, biologically-based manufacturing platform to provide access to new materials, capabilities and manufacturing paradigms and Local Control of Materials Synthesis: coatings, thin films and advanced surfaces are important aspects of systems, devices and technologies critical to the mission of the Department of Defense. Despite decades of work, methods that enable atomic through millimeter-scale control over structure and properties of materials deposited on surfaces are still underdeveloped. For example, structural organization of high-value thin films is typically controlled by high-temperature deposition or annealing, but the temperatures employed during thin-film synthesis and deposition exceed the limits of many relevant substrates, restricting application opportunities.

2

Evaluation of PINTA Programme

2.1 Impacts: permanence, comprehensiveness, significance

Profile of PINTA and its projects

Fig. 2-1 illustrates the continuum of research and development from science to product development. In the left end of the field is fundamental scientific research, aiming at increasing of mankind's understanding of nature's laws and phenomena, and producing published scientific results. In the rightmost end is development work of enterprises targeting proprietary commercial product or service innovations.

The model also has a linkage to the Technology Readiness Level (TRL) model, as applied by European Commisison[8]

- **TRL1** basic principles observed
- **TRL2** technology concept formulated
- **TRL3** experimental proof of concept
- **TRL4** technology validated in lab
- **TRL5** technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- **TRL6** technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- **TRL7** system prototype demonstration in operational environment
- **TRL8** system complete and qualified
- **TRL9** actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

The form and motivation of public interventions, like funding, varies between different categories. The area of the Academy of Finland is shown with the green oval. The black oval shows the area, where Tekes is active. It also covers the different types of projects funded and coordinated by PINTA programme. In PINTA the idea was to cover the whole chain from raw material suppliers to end users and from research to application.

Tekes has a central role in the Finnish innovation system as an enabler of joint efforts between research institutions and industries. It is believed that public support enables and encourages such R&D investment that have positive returns on national level but that would not take place by market mechanisms only due to short perspective and sub optimization of individual companies.

Strategic research is scientific basic research in such subject fields that have been given special emphasis in the innovation strategies. Industrial Leadership is one of the pillars of European Commission Horizon 2020 programme strategy. Horizon 2020 will have a strong focus on developing European industrial capabilities in Key Enabling Technologies (KETs):

- Nanotechnologies
- Advanced materials
- Advanced manufacturing and processing
- Biotechnology

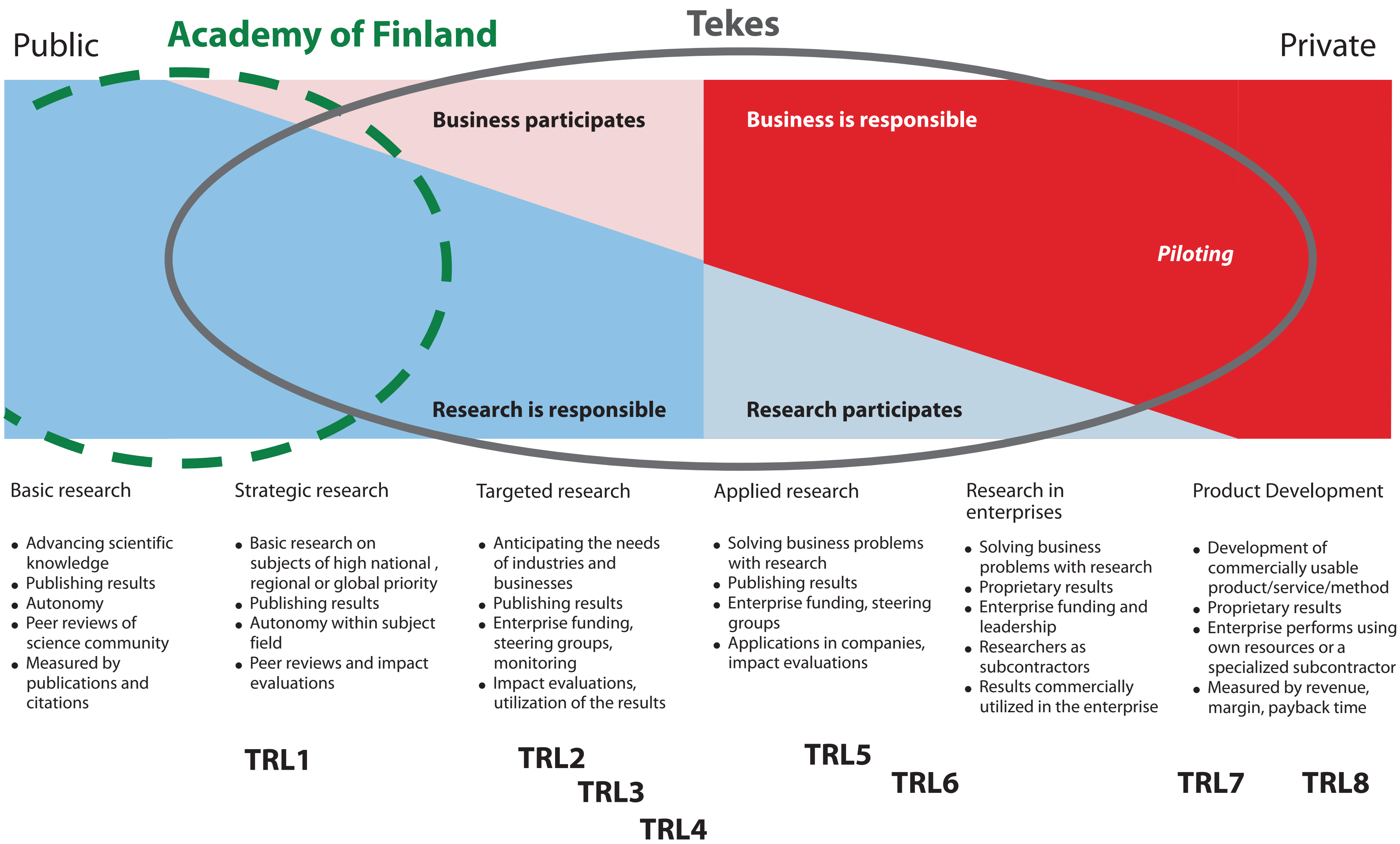
Nanosciences, nanotechnologies, materials and new production technologies were one of ten strategic focus areas also in the seventh Frame Programme, which preceded Horizon 2020 in years 2007–2013.

Research in nanotechnologies and advanced materials have been selected by Academy of Finland and Tekes to be strategic targets for funding and promoting. Tekes also tries to get the industries involved and committed to both target setting and monitoring of such research. Since the results of this kind of research are mostly quite generic and practical applications require years of additional work, the participation of enterprises tends to be thin and also the financial contribution is often minimal ('coffee money'). Yet also in PINTA there were exceptions that the participating companies were experimenting and doing genuine cooperation with the research institutes. Commitment of the company is strongly dependent of the representing person and a wide variety of the degree of commitment and activity was also experience in PINTA.

In basic research, high quality scientific results can be obtained, but they serve to add their share to the global state of the art knowledge of the subject and are freely available to anybody with the capability to adopt the

8 "Technology readiness levels (TRL)" (PDF). European Commission, G. Technology readiness levels (TRL), HORIZON 2020 – WORK PROGRAMME 2014–2015 General Annexes, Extract from Part 19 – Commission Decision C(2014)4995.

Fig. 2-1. The continuum of research and development from science to product development. Technology Readiness Levels placed in respective places.



knowledge. In PINTA, the subprojects SURFOX, SHINE PRO, and ELPI would fit into this category, where the academic freedom was strong.

In the next category, titled here as 'Targeted research', the companies did have more to say about the definition of the research problem. Here the research aims at clearly stated applications that reflect everyday concerns of the industry. PINTA projects in this category were:

- PILESKA: Catalytic prevention of contamination of paper machines
- BIOFOULING: Prevention of biofouling by polarization in paper machines and heat exchangers
- KEMLIKA: Chemical fouling
- SONOCLEAN: Ultra-sound aided cleaning of hard surfaces
- RAKFUN: Functional surfaces in building applications
- PUHTEET: Clean and environmentally friendly metal products

The research party was responsible for the project and the results were published on the normal scientific fora. However, the participating enterprises may have invested sizable resources in the projects and consequently have expectations about concrete results that can be commercially utilized within reasonable time. This may cause clashes between the research agenda and enterprise expectations. Although the parties have shared overall target setting, the different views about urgency and concreteness of real life applications may cause friction.

Generally, the existence of basic research in Finland is seen to give advantage also for Finnish companies participating in research. For example, research results are available for own use of the participating companies much earlier than they become public. It may be that the results of a 3-year projects will be published only after the project is finished.

In this presentation the distinction between 'Targeted research' and 'Applied research' is made depending on whether the research body or a company/consortium of companies is responsible for the project. In PINTA, the research institution-driven projects were also called applied research projects. As a matter of fact, in PINTA there were no company-driven applied research projects, where the results would have been published through the normal scientific channels. All company projects were more or less confidential and the results were planned to stay primarily in the use of the participating companies. So the company projects funded in PINTA were mainly in the category 'Research in companies', using research parties as subcontractors in variable degree.

Some funding was also given to company internal product development projects fulfilling certain criteria with respect to subcontracting and international networking. The R&D inside the companies aims at proprietary know-how and innovations that the company can commercially utilize. The results are measured by business income, and the payback time and related risk level for the R&D investment have to be defined. Leaking of R&D information out of the company, especially to competition, is not in the interest of the company.

One of the main challenges for the national innovation system, and a central motivation for the existence and activities of Tekes, is the difference between the scientific agenda of the academic institutions and the business requirements of the companies competing in the market. Product development of the companies needs scientific knowledge and can benefit from cooperation with the academic world. Also the universities have the long term success of the society and industries as a target, although the academic agenda is built to promote the progress of independent science. As seen from enterprise point of view, however, the academic world may be too interested in understanding abstract problems instead of understanding the actual needs of the customers. This duality is clearly visible also in PINTA and gives its flavour to the opinions of both academic and enterprise parties about the achievements and impacts of the programme.

Apart from the production of scientific results, academic research has an important role as a platform of education. In the recent years, researcher training has been lifted to a new level both qualitatively and quantitatively. Participating in scientific research is a prerequisite of becoming a competent researcher. This is relevant also from industry point of view, since majority of the doctors will be employed outside universities. PINTA was a good example how it is possible to achieve a strong understanding on phenomenology. This is then possible to apply and implement in numerous different fields and applications.

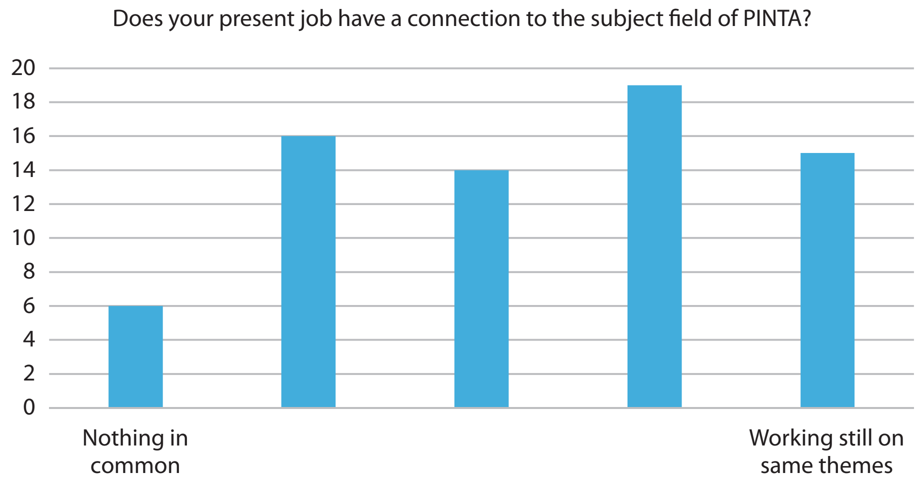
On the Impacts of PINTA

Generally, PINTA was seen as multidisciplinary and fruitful. The main contribution of the programme was the creation of research competences and methods. Bringing together chemists, physicists and engineers, the programme created knowledge and networks that led to significant scientific results and has laid basis for several further projects. In many research subjects, the work done in PINTA continued in Functional Materials programme, a number of EU- projects, and is still active in e.g. FIMECC HYBRIDS programme.

The programme was a starting point for the surface and coatings science at VTT, and boosted materials research in universities. The programme also created new knowledge for the industry, and transferred knowledge between different fields of industry.

In spite of the important role of PINTA in Finnish surface research, some research topics and networks of the programme are not active any more. This may be due to

Fig. 2-2. Change of survey respondents' field of work after PINTA (y-axis is the number of respondents, total=70).



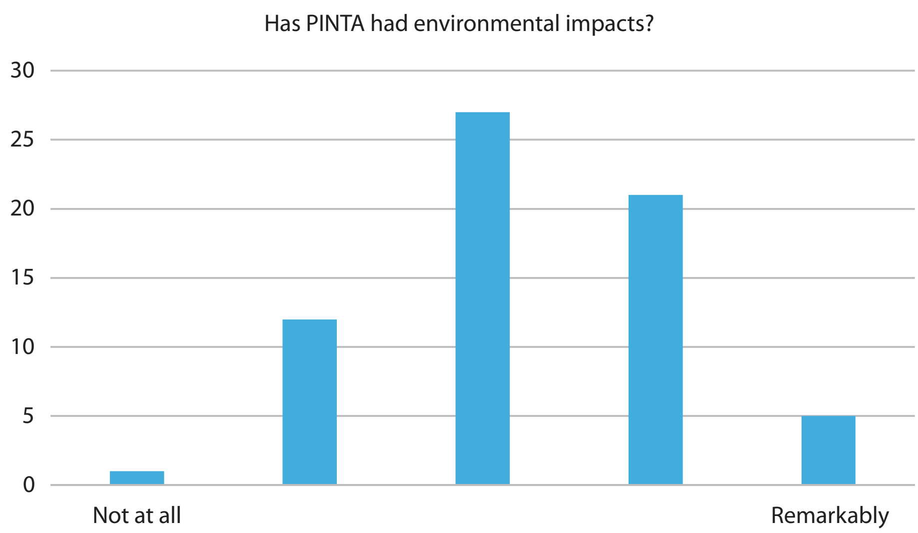
changes in the universities' research politics, lack of funding, or replacement of research spearhead topics by more promising application areas.

The web survey examined the retention of PINTA programme participants within the field of professional activity where they had been during the programme ten years ago. Fig. 2-2 shows the distribution of the 70 respondents. It shows that quite many respondents are still involved in same type of research/development/business than during PINTA. Here, like in the other web survey results, it must be kept in mind, that the sample of respondents is biased towards programme contact persons, who tend to have more permanent positions e.g. in the universities than the junior researchers. Many students that had participated in the projects of the programme were not reached for the survey.

2.2 Impacts on environment

During the planning phase of the programme, environmental impacts were expected e.g. about diminishing the need of cleaning chemicals. The projects of the programme searched for several new industrial applications with environmental and health impacts, e.g. antibacterial door handles, antimicrobial coatings for hospitals, prevention of fouling in e.g. bathroom tiles, a device for cleaning swimming hall surfaces, etc. Very few real commercial breakthroughs, however, have emerged from these initiatives. Generally, the know-how created and disseminated in the programme has promoted environmentally sound microbe control by replacing the use of chemicals by functional surface properties and more efficient processes. Environmentally motivated development

Fig. 2-3. Web survey respondents' evaluation of environmental impacts of PINTA (n=66).



of lead free bronzes for bearings has produced results and continuing development. Improved understanding of heat exchanger fouling has led to better control and improved energy efficiency. Developed corrosion prevention surface treatments lead to longer product life cycles.

A central theme of PINTA was clean surfaces. Easy to clean surfaces are still one of the main targets but nowadays the requirements are more demanding and also other functionalities, such as good mechanical properties or UV resistance are required for the coatings. The diversity in materials has grown explosively after PINTA, and the scope of the chemistry to be controlled is much wider today.

Mitigating of environmental impact was considered motivating for researchers, but as Fig. 2-3 shows, web survey respondents evaluated the environmental impacts as existing, but moderate. In many cases the measuring of environmental impact is not easy but the impacts may also be indirect and "hidden" in industrial processes. More indirect benefits have been achieved e.g. with photo catalysis and solar cells applications.

2.3 Impacts on wellbeing of society

The impacts related to the wellbeing of citizens are often linked closely to environmental aspects. It is customary to consider the interrelated HSE (Health, Safety and Environment) aspects together, and PINTA programme was expected to have significant impacts in this field. However, the evidence of concrete HSE impacts remained somewhat vague. This can be seen also in the web survey respondents' view about wellbeing related impacts (Fig. 2-4). HSE target setting also traditionally comes mainly through regulation; enterprises naturally emphasizing the economy, although sustainability is continuously rising in importance as a competition factor of companies.

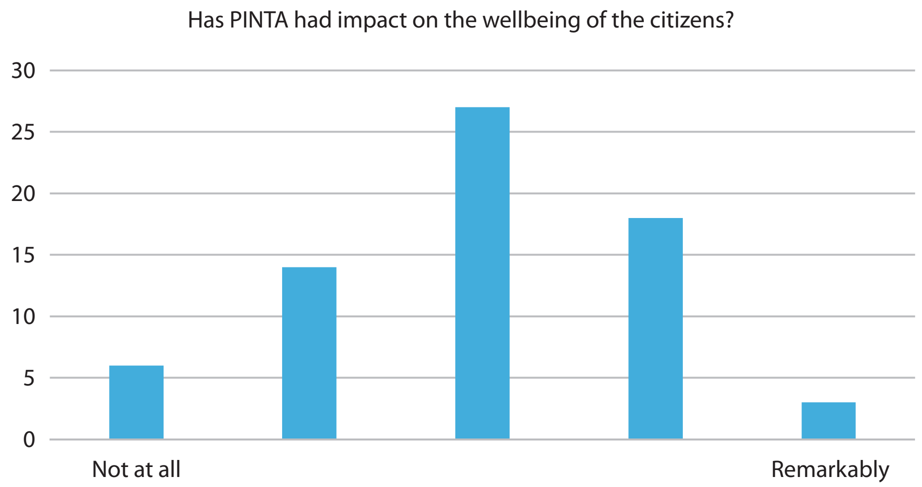
Some developed technologies were seen to help to improve the hygienic level e.g. in hospitals. Antimicrobial and self-cleaning surfaces have clearly positive impacts. As a concrete example it was reported that in a nursing home, where PINTA-developed surfaces were piloted, the consumption of detergents was remarkably lowered and the yearly norovirus epidemy stayed away. The ability to present the right questions to chemical sellers was also considered a positive outcome of the projects. Also, the ability to operate without biocides has been raised to a positive value, the biocides being mostly as harmful to people as to the microbes.

The cleanliness of the surfaces began to interest widely during the programme which had also a somewhat unwanted result: utilization of antimicrobial additives has increased. However, this is probably more due to a parallel general international trend than PINTA programme actions. Anyway, self-cleaning surfaces are not yet commonplace. Also the regulation in this field is just taking shape.

It was also reminded that new research knowledge always improves welfare of people in some time frame. An example of health related application of PINTA basic research is presented in the following case description. It describes well an attempt to apply scientific knowledge for new commercial activity. It also demonstrates well the role of basic research as an enabler of unforeseen application areas. During PINTA programme and its SURFOX project, coating medicine particles was not planned to be an application target area.

The impact on wellbeing is very much connected with the amount of educated people, gained knowhow, understanding of phenomena (physical, chemical, multidisciplinary), dissemination of knowledge into enterprises, and the creation of new businesses. Again, the indirect impacts may be the most significant. In beginning the results are visible in doctoral theses but will gradually be transferred to the use of industry.

Fig. 2-4. Web survey respondents' evaluation of wellbeing impacts of PINTA (y-axis is the number of respondents, total 68).



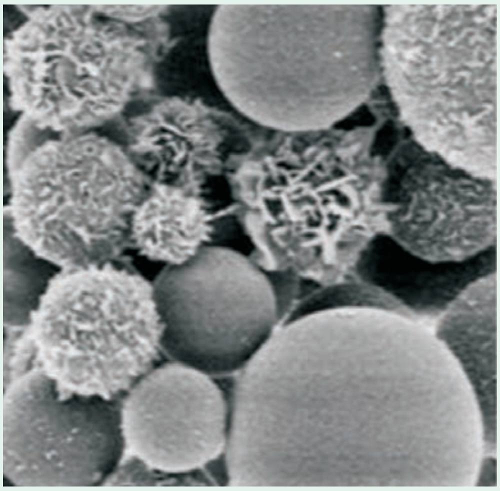
CASE: Inhalable Drug Powders of Premium Performance

In PINTA project SURFOX, one of the main research topics was particle deagglomeration in turbulent gas flow. An application of this know-how is the production method for pharmaceutical powders in the field of respiratory therapy. This has been developed by Teicos Pharma Oy, a spin-off from the Helsinki University of Technology (Aalto University), founded in 2007 by four leading senior scientists from materials, characterization and aerosol technologies.

The method reduces the amount of drug administered via pulmonary tracts which, as a consequence, minimizes possible side effects caused by excipients. In the technology of Teicos Pharma the drug particles are coated with the nanosized crystals of amino acid L-leucine. The coated surface is thin and rough that provides excellent properties to the powders for dosing and delivery to the lungs. The coating technology can be applied to all solid particles and it does not rely on the size, shape or crystallinity of drug particles. The coated drug particles can be dosed via inhalation for local or systemic diseases.

Benefits of the coating by Teicos Pharma technology are as follows. The drug particles can be dosed from dry powder inhalers with minimal amount of additional material. This method is applicable to drug particles which cannot be coated with any other known method. Drug particles are prepared and coated simultaneously, which reduces the cost of energy. The method is applicable to small and large scale powder production.

Teicos Pharma is seeking partnership with pharmaceutical companies with the need for formulating drug molecules into dry powders with superior aerosolization properties. The offerings are pilot projects, development projects, FDA approval projects and licensing.



Salbutamol particles coated with leucine

Patents: US 8,349,295; CA 2688288 A1

2.4 Impacts on skills and competences. Persons, organizations, networks

"Best results are achieved in the environments where people meet and where there is diversity among skills and viewpoints. Interaction is most important."

Whereas concrete impacts of PINTA in form of measurable new business activity, employment, or breakthrough innovations are scarce, the pioneering role of the programme in bringing engineering surface science and applied microbiology together was widely acknowledged. The programme created environments with diversity of skills and viewpoints, and results were found through interaction among people with different backgrounds and expertise. The multidisciplinary "language skills" and communication between different operators within research and industry was considered to have improved significantly. The programme in its time was unique also at international level.

The understanding of surface materials and biofilm/fouling was enhanced to a new level. ALD research is still strong in Aalto and UH. New materials and thin coatings are being developed. ICG of UH is Academy of Finland Centre for excellence – for a part also due to PINTA. SHINEPRO was a kick to start the research of photocatalytics, clearly a fruit from PINTA. Other PINTA teams still exist as informal networks even if the research has been suspended in the lack of financing. If the financing would be there, the research could be commenced with short notice.

Understanding of surface phenomena was increased remarkably due to PINTA. The phenomenological knowledge gained is very important for research groups also years after programme. The generic research projects (SURFOX, SHINEPRO, PILIESKA) created know-how that has been utilized in broader sense.

Nano cellulose, which is studied a lot currently, was found in PINTA from the paper machines and studied for the first time in Finland. Titanium methoxide process, nowadays used in semiconductors, was developed in PINTA. Co-operation with some new companies was initialised during PINTA and some of the new networks still exist.

Programme participants also reported a lot of improvement in 'softer' skills like communication, and ability to cooperate with representatives of different fields towards a shared goal. The programme provided for academic researchers a view to the company world and for the enterprise R&D useful basic knowledge and new approaches for product development. Improved understanding of the underlying physical phenomena also helped the work in customer interface.

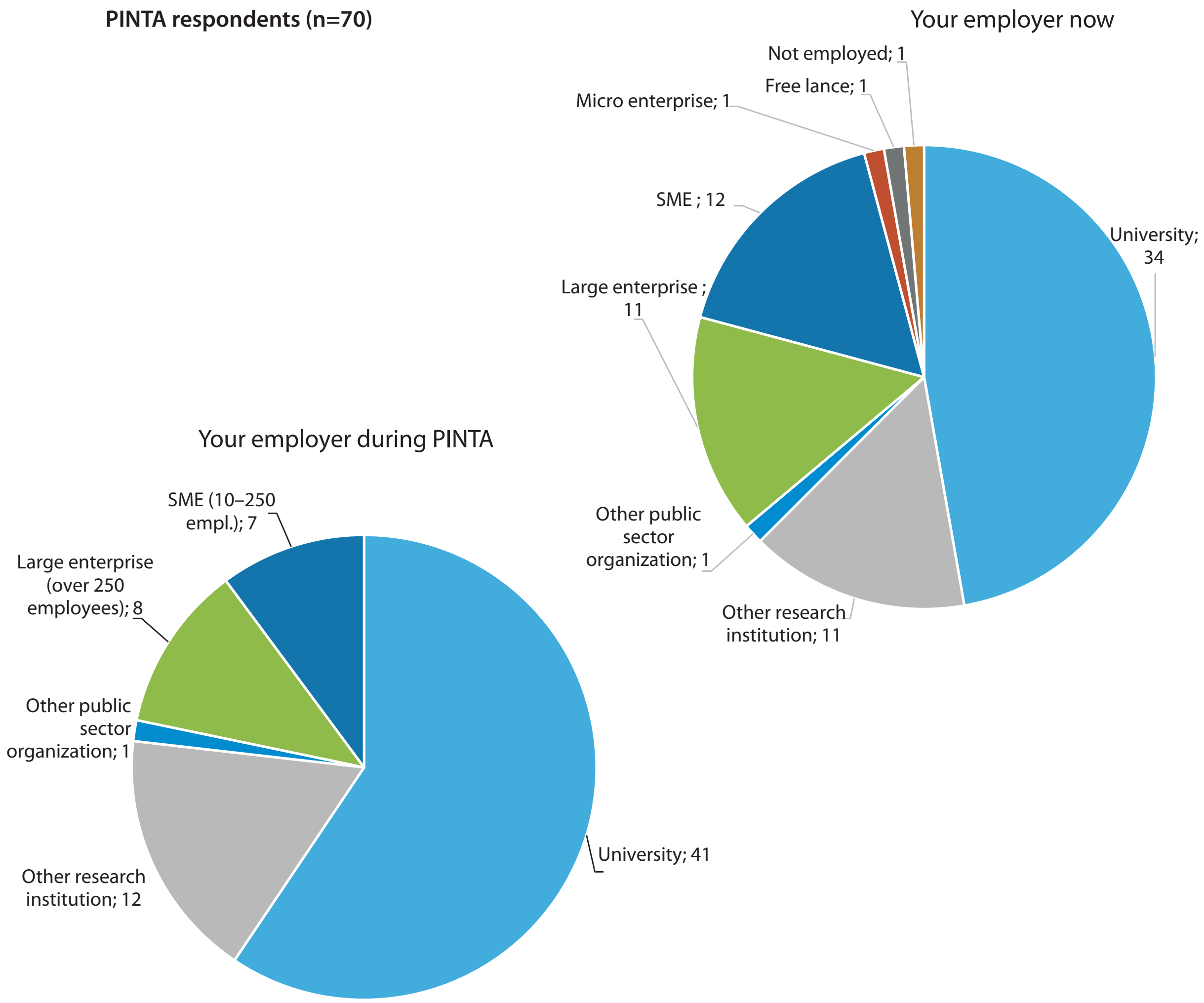
"The subjects were at that time new for us and now they are refined further. From zero to a remarkable research field."

Networking was the best outcome of PINTA. The programme created cooperation between research fields, e.g. material technology and microbiology. The wide networks built during PINTA have led to several (inter)national projects also afterwards. For example, the collaboration with the University of Manchester (UK) and Fraunhofer Institute (Germany) and company assignments, also from outside EU are results of PINTA in the field of surface science. Also, the international visibility of Finnish research was improved. Research teams have been able to get into EU projects by means of the competences created in PINTA.

"In a sense, our whole present business is based on the projects in PINTA and FM, where the basic surface functions were examined."

Tekes seminars were seen as an excellent opportunity for networking. The financing enabled participation in international seminars, conferences and research exchange. Some researchers did also find new jobs through these networks. Generally, enterprise cooperation motivates young researchers, as well as contacts with basic research are educating and motivating for the technical experts of the industry.

Fig. 2-5. The change of employment structure of PINTA web survey respondents.



One important form of knowledge dissemination in the professional communities is the migration of experts between organizations. We used the web survey to get a view about the movement of experts from one employer to another. Fig 2-6 and Fig. 2-7 show some results of this mapping. Fig 2-5 shows the distribution of 70 respondents by type of employer during PINTA programme and now, ten years later.

Fig. 2-6 shows a more detailed map about the transitions between employers. The numbers inside the circles indicate the persons that have stayed with the same (type of) employer than ten years ago. (Minor differences in the numbers in the two pictures are due to some respondents skipping some questions.) The general observation is that the mobility of the programme participants has been amazingly low. The reason to this is that the survey was built on the project contact person data, that is biased towards senior researchers and managers, who tend to have more permanent positions in their organizations than the junior members of the teams. The interviews confirmed that the future jobs of the project participants differed a lot: in some cases, all the team members with doctoral or master thesis graduated during projects were employed by the industry, in some case none of them.

Fig. 2-7 shows that the web survey respondents quite unanimously saw that PINTA had improved the level of skills and knowledge. The evaluation of networking between different types of actors showed similar pattern.

Fig. 2-6. The transitions between different types of employer among PINTA web survey respondents.

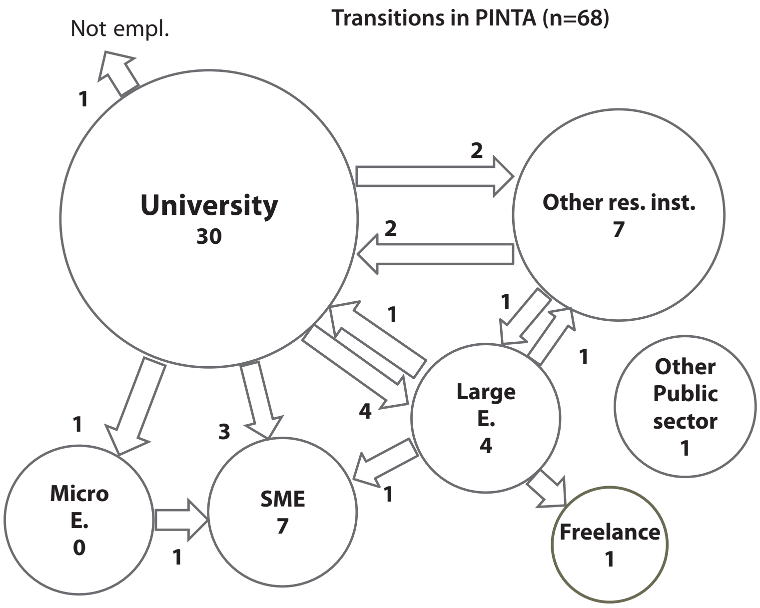
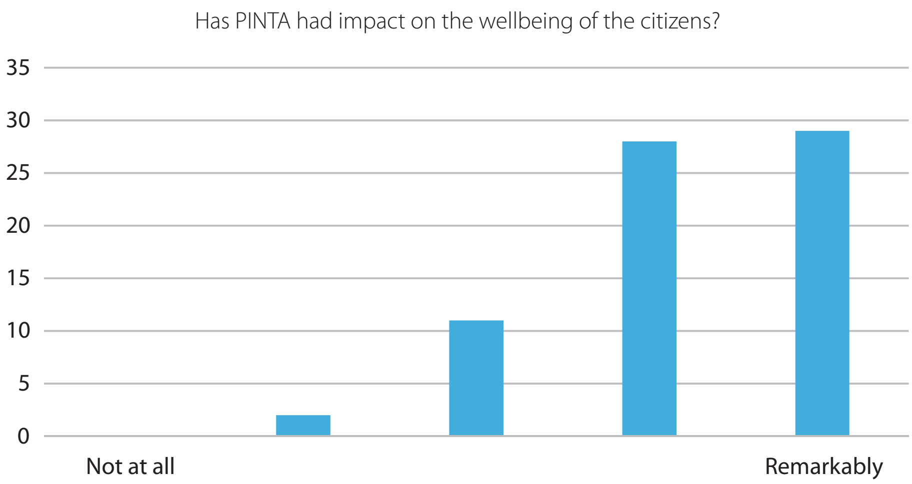


Fig. 2-7. Web survey respondents' evaluation of skill and knowledge impacts of PINTA (n=70).



The own R&D organizations of the companies are often very small, which makes it difficult to understand research and development environments. Joint projects may open a view to systematic research and development activities and lower the threshold to contact academy and researchers.

"The programme was one great disco – First time there was for the students some other programme than boring data."

2.5 Impacts on industry

When looking for the industrial impacts of R&D programmes, the first thought may be to count the new start-up businesses that have their roots in the work and inventions made with the support of the programme. Less visible, but usually more important, is the impact that the research has had in the product portfolio and process infrastructure of established companies.

PINTA has led to several business initiatives or contributed to development of existing ideas. Some of them have grown to promising SME companies, some have failed, and some are still in investment phase. One enterprise impact was that some companies were experimenting with new materials. The main result from the research cooperation was that the companies did not need to test such materials that in the laboratory had been found unsuitable.

The basis of the success of a company is the cumulative know-how of own resources. Each programme where the company has participated, adds to these assets. Also in the case of PINTA, the creation of new business purely as a consequence of the programme is unlikely, whereas the improvement of products is much more probable. Not many enterprises based only to PINTA results exist, but better understanding of surface phenomena has had a wide impact. The enterprises have found new solutions to fouling problems and so reached some cost savings. Developed new coatings have brought new markets to the surface treatment companies. A public example of commercialization is the CleanVent-concept that was created as a result of cooperation of VTT, FläktWoods and Millidyne.

It is widely approved in the industry that the basic research is useful and that the deepening of the basic knowledge leads also to industrial benefits. The industry has recently voiced some concern about the diminishing resources of the basic research. In cooperation with the research parties the companies expect that the researchers should have some such know-how that the enterprise doesn't. The same applies for recruiting post-docs: the person must have substance from a specific area, so that the company does not need to educate from the beginning. Some successful companies trained their own R&D people and provided thesis work opportunities.

"Saving young R&D people by hiring them so early that the academic research work has not spoiled them."

The interviews brought up examples where the knowledge created during the programme was transferred to industry and the results were beneficial e.g. for simulation solutions utilized by industry and the implementation of the results improved the products. The participation of the users/customers enables direct feedback in the projects and more generally: commercialization of a solution will speed up if a wide network of manufacturers, customers and researchers can participate.

Research and industry may have a different view of the usefulness of the results. The path from publishable scientific findings to commercially usable solutions tends to be long. The enterprises with very high expectations may get disappointed when the expectations do not quickly become reality. The growth of business to a profitable level based on a material technology innovation may easily take 10 years.

"During PINTA the understanding of the phenomena was increased but the usefulness to enterprises' customers not seen."

Apart from commercializable scientific findings, the cooperation with research institutions brings some fringe benefits. Universities can provide some analysis services that a small company cannot afford itself. Free capacity of available analysis equipment can be shared. The programme may help in recruitment of new employees and in getting new enterprise contacts and customers.

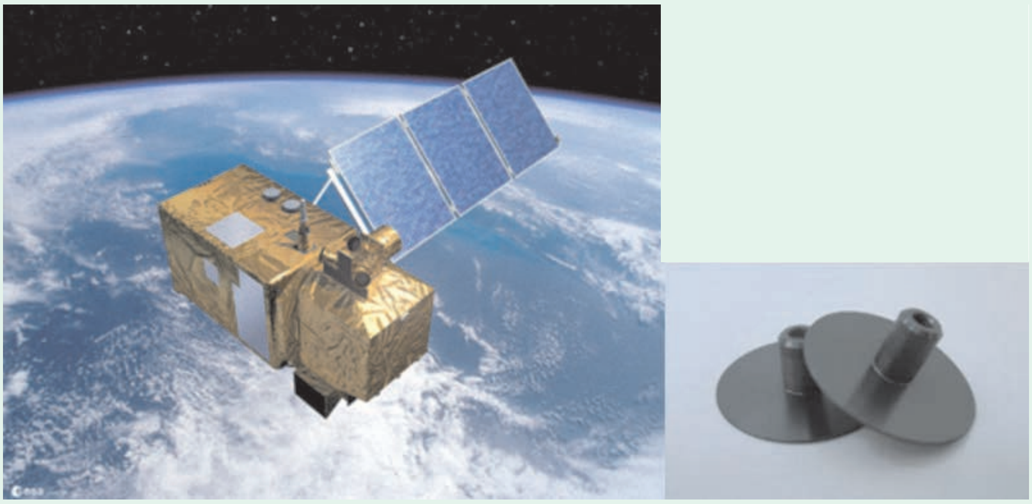
ALD was in an important role in PINTA, and there are three good companies making ALD equipment in Finland today, albeit none of them in in great volumes.

CASE: DIARC Technology Oy – Smart Surface Solutions

DIARC-Technology Oy is specialized in manufacturing of thin films coatings based on DIARC's unique FCAPAD method. Customer applications range from high precision tools and components to functional applications. DIARC does a lot of R&D focusing in development of new coating materials, customer applications and advanced coating manufacturing technology.

The development work done in PINTA and Functional Materials programmes brought valuable knowledge about the basic surface properties of nanomaterials. This knowledge has been utilized later when developing application and customer specific functional surface solutions. Functional coatings have become one of the cornerstones for DIARC in addition to the more traditional wear resistant and low friction coatings.

During PINTA programme DIARC studied especially functional nanocarbon coatings to improve the surface properties of polymer, metal and ceramic materials. As a result, novel hydrophilic, antistatic ESD protection and barrier coatings were developed. These coatings are applied now e.g. in precise instruments of medical and paper industry to protect the parts from corrosion or as a protection against ESD. DIARC also developed a coating material which can be used to improve the adhesion of lacquer and glues both on metal and polymer surfaces. This innovation is today known as DIARC® Bindo which is utilized especially in improving the adhesive bonding of materials like stainless steel, titanium and polymer materials. DIARC® Bindo combines large surface area and hydrophilicity of nanostructured carbon which gives strong bonding for the adhesives and eliminates the need for using of primers and harmful chemical treatments prior to bonding.



The Finnish Patria Aerostructures has utilized DIARC® Bindo coating in adhesive bonding of titanium parts in satellites

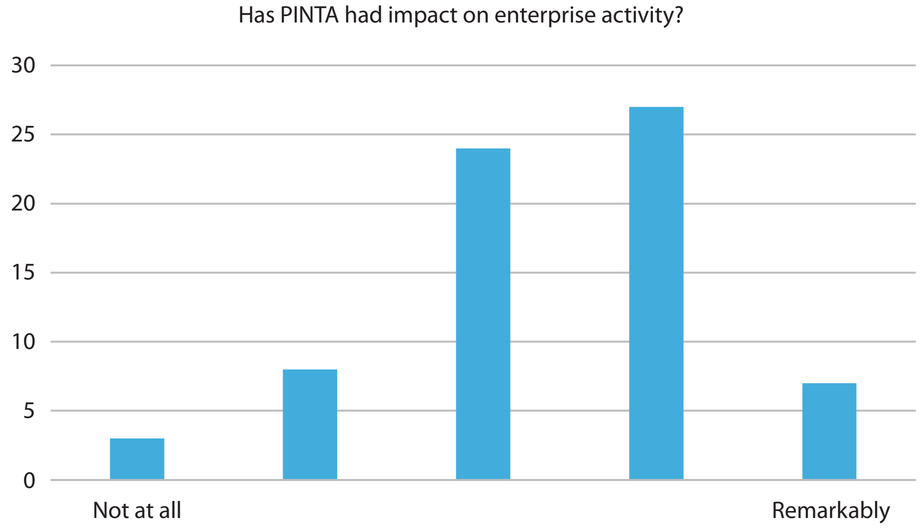
During the Functional Materials programme the development of novel materials was continued focusing on the development of temperature and pressure sensing nanocarbon material. As a result of this work a new product DIARC® Senso was launched and it is nowadays utilized in applications where high sensitivity temperature and pressure measurements and fast response times are needed.

DIARC FCAPAD Coating machine

"We became familiar with own basic competences and e.g. limitations of different surface treatments. Also the understanding of customers' processes was improved. Better knowledge helped to avoid unnecessary moves in business."

As seen in Fig. 2-8, web survey respondents recognized impacts on enterprise activity, although some sceptical views also exist.

Fig. 2-8. Web survey respondents' evaluation of enterprise impacts of PINTA (Responses total=69).



3
Evaluation of Functional Materials Programme

3.1 Relevance and challenge of objectives, contribution to implementation of national and Tekes strategies

The materials science has a critical role in the advancements in many, if not most, of technological fields. The competitiveness of a nation and its industrial base requires good knowledge on the advancements of materials science and of advanced materials. Materials science and engineering is also a well-recognized discipline with its dual grounding in basic science and engineering, which gives especially strong role to Tekes programmes in the field of Materials Science. The programmes must combine similarly the basic science approach for creating new enablers and find applications to give rise to engineering and further to boost the economy.

In 2006, Tekes started the preparation of the Functional Materials programme (later also FM) by launching a study for finding answers to the question: *"How should Tekes strategy be implemented and funding be directed for maximum impact in the field of materials technology?"* The cornerstones of the programme are stated in its Vision and Mission[9] as follows:

Vision:

Finnish industry utilizes advanced material technology more efficiently than competitors and therefore gets competitive advantages in the global market. Industry has access to the best expertise on production and application of materials through national research organizations and their international networks.

Mission:

As a result of the program, business opportunities in Finnish industry have been significantly improved through effective exploitation of the latest results of materials R&D.

Functional Materials programme is an umbrella for a broad spectrum of research within the materials science. The programme was started in year 2007 in a situation where the perceived state and expectations of industries as well in Finland as globally were far more positive than the real development during the subsequent six years turned out to be. The programme started with the focus in research. The target was to plan the research and subsequent enterprise projects so that continuous and functioning value chains based on functional materials could be created. Accordingly, the programme was divided to five baskets:

1. Understanding materials and their properties
   - materials physics and chemistry (including nanoscale research)
   - modelling and simulation
   - characterization
2. Control of materials properties and tailoring of functionalities
   - physical and chemical properties
   - durability to wear and temperature changes and against corrosion
   - stability, self-cleaning properties
   - biocompatible materials, materials for welfare, antibacterial properties
   - reliability, lifetime in specified conditions
3. Processing aspects
   - processability
   - designability
   - coating technologies
   - production technologies
4. Examples of application areas of functional materials
   - printable electronics
   - sensors
   - applications based on functional metals and their alloys
   - applications based on polymers and other organic materials
   - optics and optoelectronics
   - functional construction and packaging materials
5. Life cycle management of materials
   - materials and energy efficiency, life cycle assessment, Environment, Health and Safety (HSE) issues
   - supply and recyclability of raw materials
   - recyclability

9 Tekes Functional Materials Programme 2007-2013 Sustainable material solutions – From Finnish research to global business – Tekes report 2/2014. http://www.tekes.fi/globalassets/julkaisut/functional_materials_programme_final_report.pdf

The development in functional materials was foreseen to enable renewal and business potential and to assist in finding new positions in the global value chain for four strong Finnish industry sectors:

- metal industry
- mechanical engineering
- forest industry
- energy industry

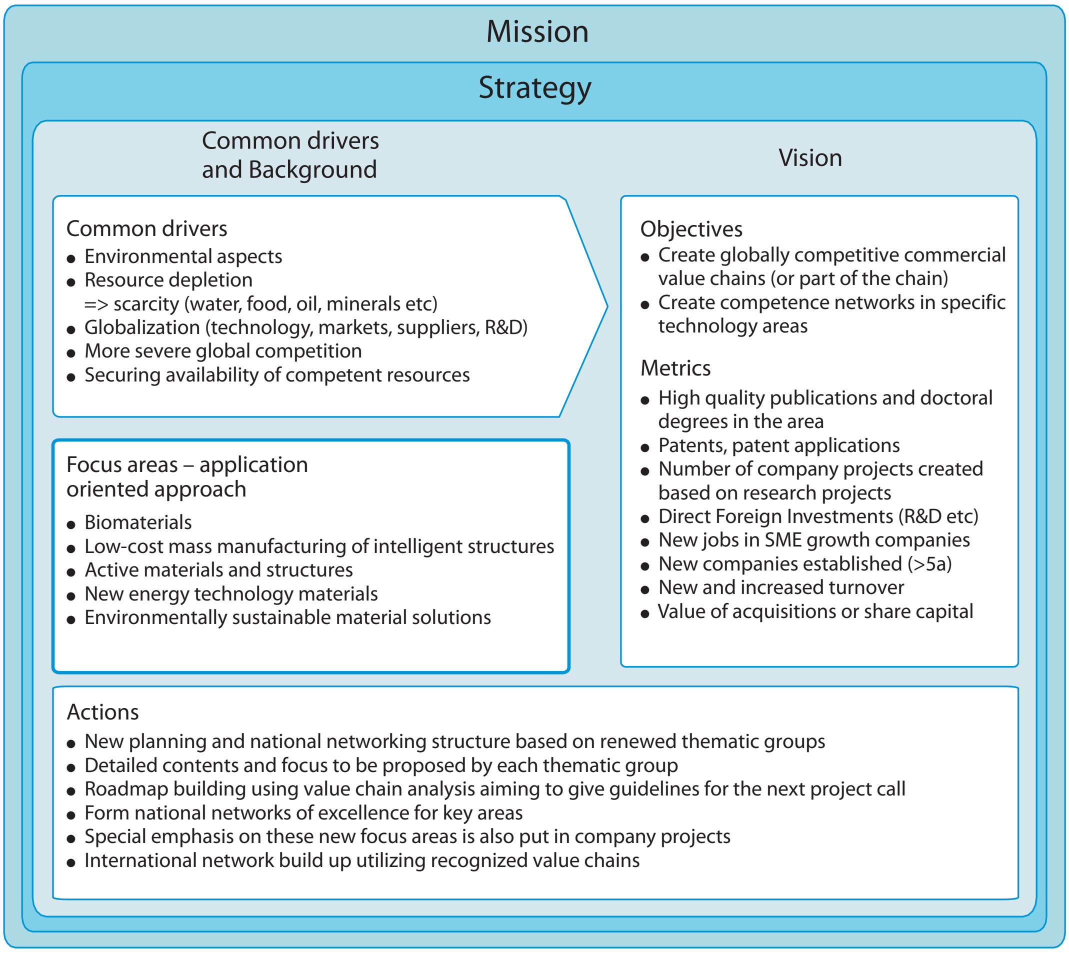
Other industrial sectors in Finland, such as the ICT industry and producers of biomaterials applications, expected also to benefit of the functional materials research and development. The plan was to provide support and services to SMEs for commercialization of new materials and processes.

In the middle of its lifetime the programme had to face three major changes in the operating environment:

1. The change of Finnish innovation policy led to the launching of the SHOKs (Strategic Centres for Science, Technology and Innovation), and the re-allocation of Tekes funding caused a cut in programme budgets. Functional Materials total budget decreased from 215 M€ to 150 M€.
2. The world economy sank in 2008 to a crisis, which hit Finland in full force in 2009.
3. A major change in the industrial structure of Finland, in addition to the global shift of manufacturing labour to low cost countries, was caused by the collapse of Nokia mobile phone business in the market and the decline of the paper industry, especially printing paper grades, where Finnish companies were traditionally strong.

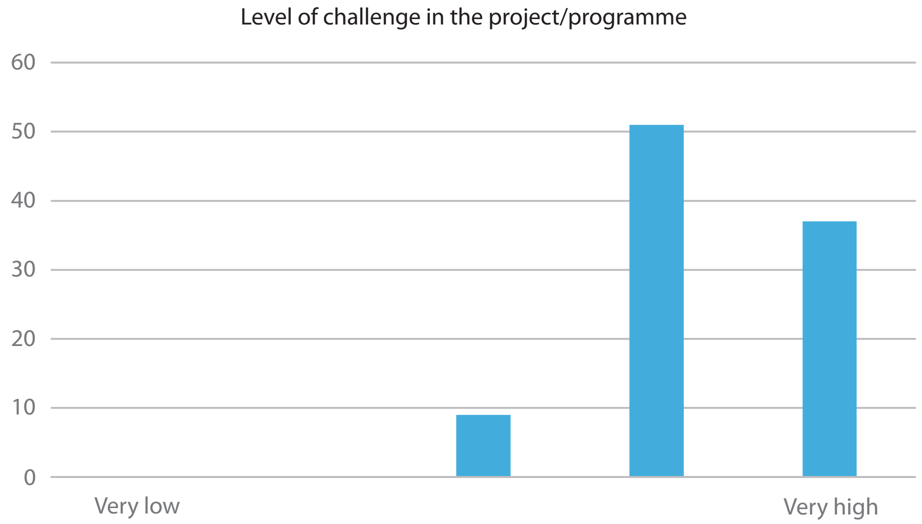
As a consequence the programme adjusted its strategy (Fig. 3-1[10]). There was also a change in the Tekes way of thinking during the programme. The focus of Tekes changed from technology to customer needs and Tekes organization was changed accordingly. As a result of changes in the Tekes and programme strategies, the aspects of utilization and environmental sustainability were

Fig. 3-1. Strategic framework of the Functional Materials programme[11].



[10, 11] Tekes Functional Materials Programme 2007-2013 Sustainable material solutions – From Finnish research to global business – Tekes report 2/2014. http://www.tekes.fi/globalassets/julkaisut/functional_materials_programme_final_report.pdf

Fig. 3-2. How challenging the survey respondents saw the programme/project? (n=97).



emphasized in FM objectives stronger than in the research phases of earlier materials programmes of Tekes. Thus the perspective of development projects was broader than mere technology, causing change of thinking in the field. These aspects are important in commercialization and marketing. Consideration of them already in research phase improved the usefulness of the results.

As of technology development, the programme directed materials research to a new way. Earlier Tekes focus had been rather in heavy industries but now the aim was at e.g. renewable energy technologies, batteries, health applications and biomaterials also from forest industry point of view.

The intermediate evaluation of the programme took place as planned in 2009. The findings were mostly concentrating in operational aspects of the programme and use of certain programme services. The target setting was not challenged in the evaluation.

We share the opinion that the target setting of the programme, after the adaptation of the strategy to the changes in the operating environment, has been adequate. We asked in the web survey the view of the respondents about the level of challenge in their target setting. Since vast majority of the respondents has worked in a single project within the programme, we can assume that the result reflects rather the challenge of single projects than the outspoken target setting of the whole programme. As seen in Fig. 3-2, the participants have seen their work in FM rather unanimously as challenging.

3.2 Achieving objectives

FM programme emphasized functionality and continued the material and nano technology programmes of Tekes. A part of the projects was continuation for PINTA, but FM included a much wider scope of technologies and a sharper focus on commercialization of results when compared with the older programmes.

Each project is obliged to answer to a set of follow-up questions when the project is closed. Hence, the steering group of each research project will give its evaluation of the results of the project. Fig. 3-3 shows the summary of the Steering groups' evaluation of the results of their projects in FM. Steering groups seem to have had a very positive view about project success. One might ask, whether the level of risk and challenge is properly set, or are the steering groups just overly optimistic? In a more detailed question about

Fig. 3-3. FM research project Steering groups' evaluation of the results of their projects in final reports.

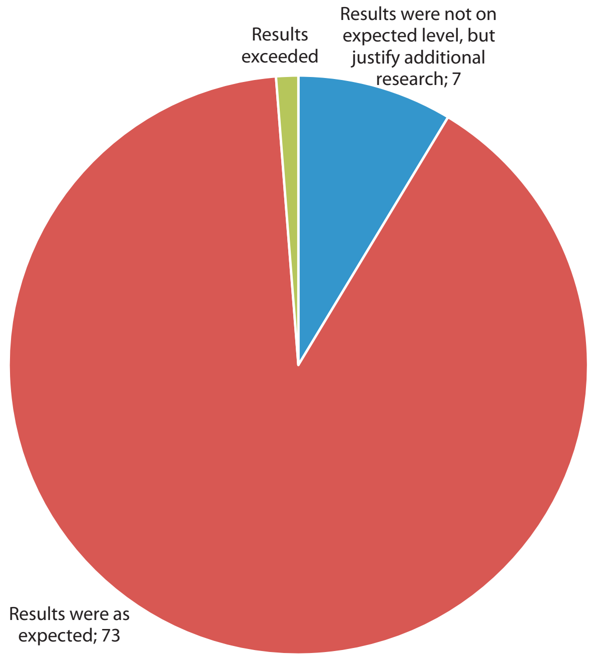


Fig. 3-4. FM research projects' success according to the final reports (n=98).

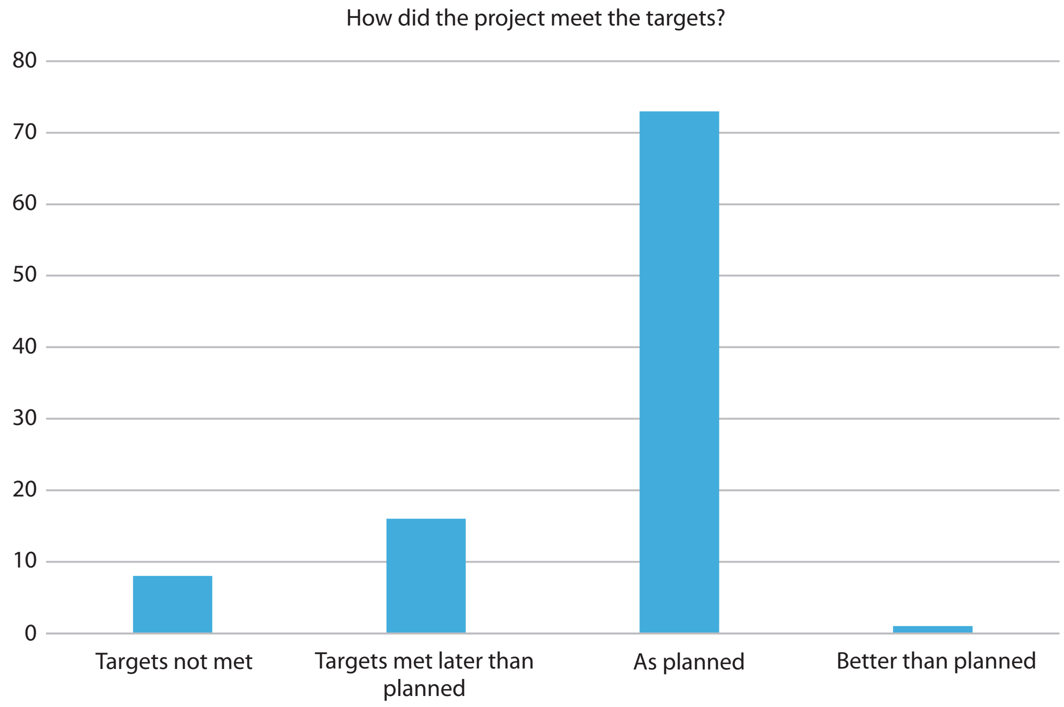
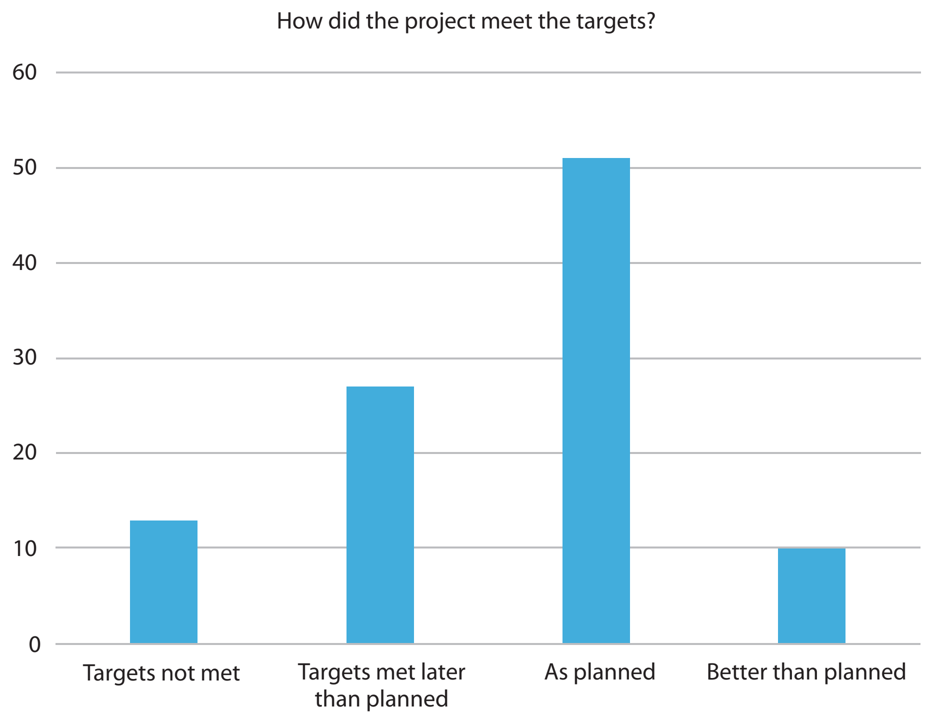


Fig. 3-5. FM enterprise projects' success according to final reports (n=101).



the success of the projects, the research projects reported a pattern displayed in Fig. 3-4.

Project steering groups' evaluations for enterprise projects are not available, but the final reports of enterprise projects gave the profile of their success as depicted in Fig. 3-5. In general, also the enterprise project targets were met quite well.

When asked, what will happen after the project within the programme has ended, the future of FM research projects looks like in Fig. 3-6. The majority of the research projects will continue in one form or another. Ca. 18% of the projects expect at the end of the project that the results will be commercialized, and only a few projects end genuinely.

Fig 3-7 shows the similar picture about the enterprise projects. The patterns are amazingly similar, although the proportion of the project results planned for commercialization is somewhat larger, as could be expected.

Fig. 3-8 shows the opinion distribution of the survey respondents about the achieving of the targets. As always, some projects failed to reach their target, but generally, the objectives were achieved well during FM. The pattern is quite similar between enterprise representatives and researchers. According to the interviews, some of the failed targets have a solution nowadays

In the adjusted strategic framework (Fig. 3-1) the objectives set for the programme were *to create globally competitive commercial value chains (or part of the chain), and competence networks in specific technology areas.* Our experience is that a couple of years is a short time to evaluate success in ambitious objectives like the ones above, but examples of progress – in addition to the ones given in programme's comprehensive final report – can be observed in the following web survey and interview responses:

- The programme has systematically brought different parties together in a new way to do need oriented RDI work.
- A Finnish-Japanese joint project about nanotubes on graphite electrode of Li-ion batteries was launched.
- As a result, hybrid materials are produced for customers in Finland and abroad, and majority of global battery manufacturers collaborate with the company.
- Akron cooperation created a biomedical technology bridge.
- Academic projects were created on the basis of researchers' visit to Japan.
- In its part, the programme contributed to the success of Tekes' sustainable development programmes.
- Collaboration with materials and nano technology competence centres was launched.
- Collaboration with different networks was sought purposely.
- The programme was also a good home base for networks.

Fig. 3-6. The evaluation of the projects on what will happen after their FM project reaches the end according to Tekes follow-up data (n=83).

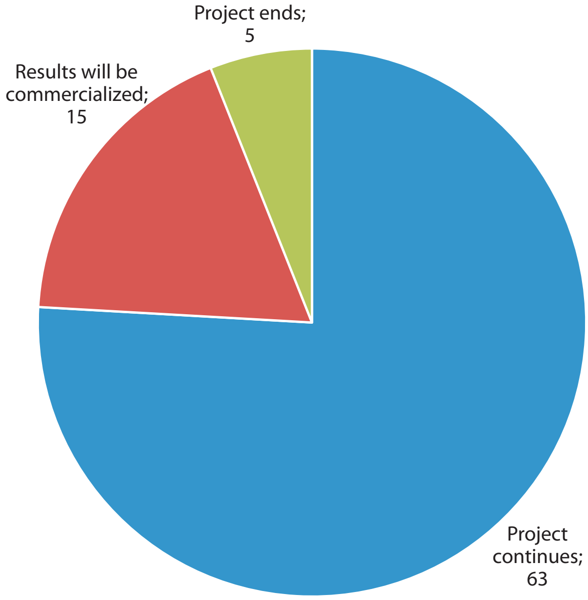


Fig. 3-7. The evaluation of the enterprise projects on what will happen after their FM project reaches the end according to Tekes follow-up data (n=75).

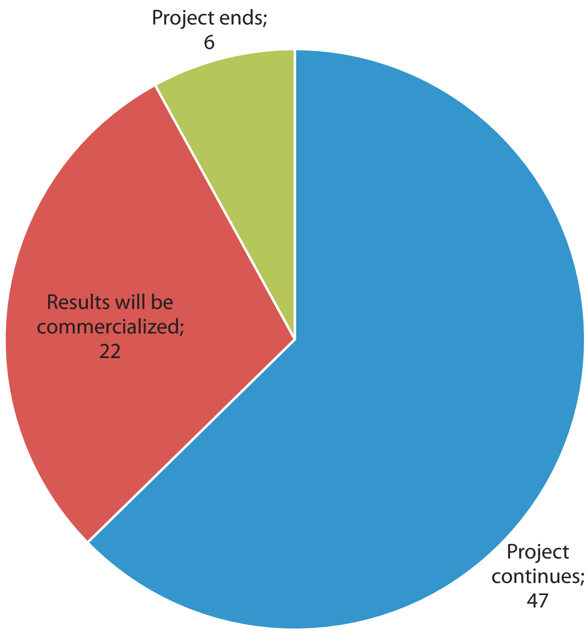


Fig. 3-8. The view of survey respondents about reaching the targets. (n=98).

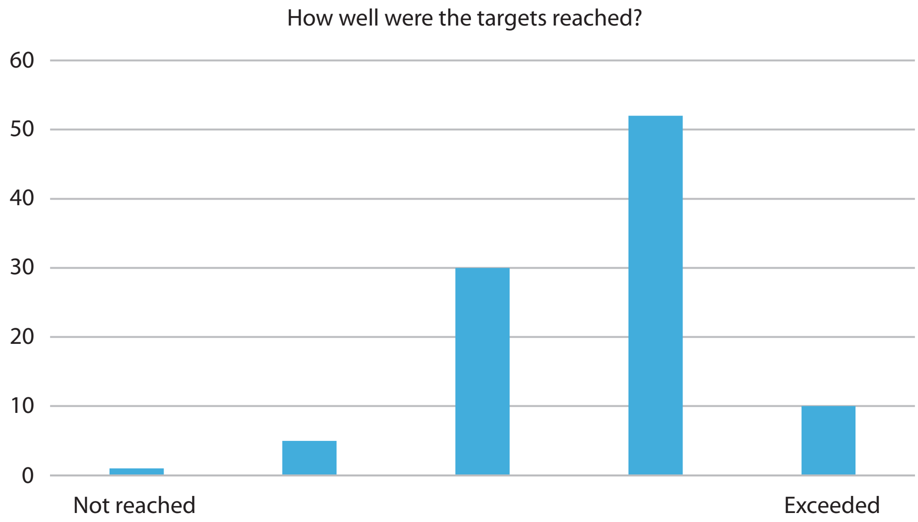


Table 3-1. Key metrics for the results of FM programme.

Metrics	–2010	2011	2012	2013	2014	2015	Total
Patents and patent applications from companies	4	19	33	13	31	15	**115**
Patents and patent applications from research organizations	2	7	13	0	10	2	**34**
Diplomas and theses from research organizations	9	22	37	15	29	38	**150**
Scientific publications from research organizations	11	72	76	34	97	59	**349**

Table 3-1 shows some quantitative indicators of FM results. The numbers for years 2010–2013 are taken from the final report of the programme[12], and the years 2014–2015 from Tekes' project follow-up database. The numbers represent projects that have been finalized in a given year and are formidable as such. The numbers of publications originating from the programme are probably even bigger, because for some projects the number is counted as 10 although the top category in Tekes' follow-up questionnaire was 'ten or more'. Also there are still some ongoing projects, so that there will be results also after the year 2015.

In the programme target setting, *generated new business volume, jobs and new start-up companies* are mentioned as quantitative indicators of the success of the programme. However, we do not see any meaningful way to measure and report these numbers in this context. Reasons for this are:

- The changes in general business environment override any measurable impacts during the period of the programme
- New start-up businesses are not fruits of a R&D programme alone, but results of earlier and subsequent actions of entrepreneurs, investors and inventors, and it may take many years for a start-up to grow to a profitable volume.
- The impact of R&D programmes in the business of established companies is bigger than the volume of start-ups, but impossible to distinguish within the available business data of the company. In national economic sense product innovations of established businesses may be much more significant than start-ups.

Even though – due to the reasons mentioned above – there is no reliable method available to measure new business volume, the number of jobs or new start-up companies, the interviews and web survey give qualitative information in the matter. The following statements refer to *the creation of new business volume*:

- Several products were developed later based on the material technological property studies in FM.
- The project created basic know-how and IP for a new business unlike anything existing before. The results of the project are the basis of company's present business, which is fast growing, albeit yet small.

12 Tekes Functional Materials Programme 2007-2013 Sustainable material solutions – From Finnish research to global business – Tekes report 2/2014. http://www.tekes.fi/globalassets/julkaisut/functional_materials_programme_final_report.pdf

- Commercialization was a success and export was created, although no breakthroughs were reached.
- Roll-to-roll production of nanocellulose film has been developed and promoted commercially with demos and identification of potential product applications.
- The whole business of the company is based on new kind of materials which are currently commercialized and taken to customer applications.

On the basis of the web survey results, new jobs and competence can be assumed to have been born during the programme:

- Rather many young people were hired during the project.
- Even if there would be no direct business results, working with material research creates competence.
- Professional development is more important than theses.
- Tekes has helped in researcher exchanges, which is very positive.
- The programme has been able to educate the operators in the industry to the right direction.

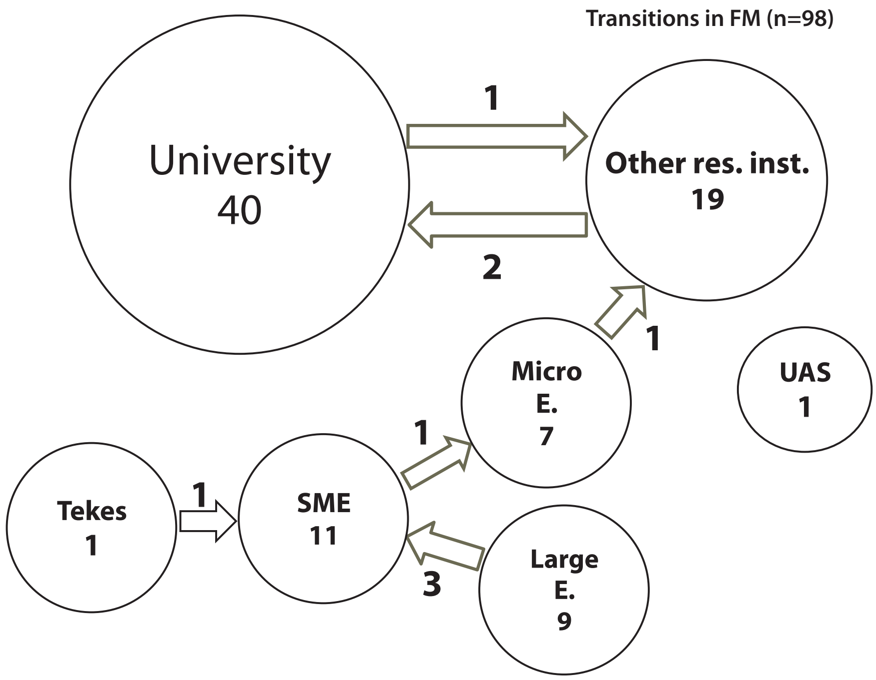
One evaluation target was to examine, to what extent the know-how created in the projects of the programme has spread and moved through the change of experts from one employer to another. Fig 3-9 shows the transitions among the respondents of the web survey. Since only three years have passed from the end of the programme, it is understandable that no big movements of experts are seen. Also, web survey invitations included mainly projects' official contact persons, who are professors and senior researchers who have more stable positions in their institutions than younger emplyees. Junior researchers have not been reached for the survey as extensively and may also have had a lower response rate.

Generally, the flow of academic researchers to the R&D jobs in the industry would be advantageous for the capability of the enterprises to adopt and apply scientific results. Among the professors this creates some controversy: some professors are commonly credited about educating scientifically competent experts for the industry, but naturally from the academic point of view losing good researchers to industry is not welcomed, team leaders would rather keep the best ones.

Even though there seems to be only a little movement from universities to industry, in individual interviews several examples of person changing jobs were reported. The challenge in the mapping of employee movement is that only doctors seem to be "visible" in statistics leaving other degrees hidden.

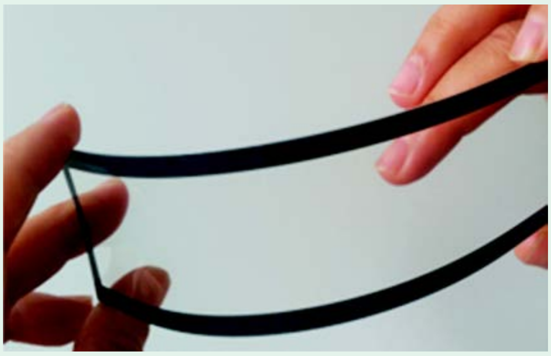
One of the metrics of the strategic framework was Direct Foreign Investment, which turned out to be significant: FM enterprises (Canatu, Beneq, Picodeon, Carbodeon, Savosolar) have succeeded in collecting more than 60 M€ direct investments[3] benefitting also Finnish national economy. Investment risk was realized with the bankruptcy of European Batteries having joined the programme in 2007. The life of the technology still continues within European Battery Technologies Ltd.

Fig 3-9. Web survey respondents' movements between the employers after the programme. (n=98).



CASE: Canatu Oy

Canatu Oy, established in 2004 as a spin-off of Helsinki University of Technology (now Aalto University) developed a novel way to produce transparent, conductive films from carbon gases in a single process step. The products are based on a novel patented hybrid material combining carbon nanotubes and fullerenes, called CarbonNanoBud® (CNB™).



CNB™ One-Plastic Solution

Participating in the FM programme was an essential part of Canatu's technology development and scaling up of the production. In 2013 Canatu opened a pilot plant in Helsinki, and in 2014 Canatu launched CNB™ In-Mold Film optimized for 3D formed capacitive touch displays, CNB™ Flex Film for products requiring extreme flexibility and CNB™ Hi-Contrast Film for first-class optical displays. In the same year Canatu entered commercialization stage by delivering its first order of CNB™ (Carbon NanoBud®) Film in roll format to an Asian touch module manufacturer. The company's projections for growth are aggressive as there is significant interest especially from the automotive and wearable markets due to the unique flexible, 3D formable, ultra-thin properties of their films as well as their all-in-one film and touch sensor solutions.

Recent developments

2015:

- Design win for a first-to-market fully flexible product – Polyera's Wove http://www.wove.com/
- Volume order for *CNB™ Touch Sensors* for a new automotive model for a North American customer
- Canatu, jointly with Schuster Group and Display Solution AG, create *multitouch, button-free 3D shaped panel for automotives* being the first to bring touch applications to dashboards
- Canatu reaches Global Cleantech 100 list 2015 after being shortlisted from the 6,900 companies that were nominated worldwide
- Canatu launches its One-Plastic-Solution, OPS, incorporating display window, touch sensor and decoration, all in an ultra-thin, robust and durable package, namely targeted to the wearable market.

2016:

- Canatu expands product portfolio with the On-cell, moisture barrier integrated touch solution and a record breaking ultra-thin 12 µm film, one of the thinnest conductive transparent films on the market.
- Second wearable win from major, well-known global sports brand.
- Canatu and E Ink Holdings start unified project in which they partner to offer a line of flexible touch displays for the wearable market.

Roll-to-roll machine

3.3 Results

"There has been unusual needs, for which unusual materials have been developed, and later applied for other uses."

Final reports of the individual projects give information about the results. Different types of results reported by enterprise projects are shown in Fig. 3-10. It must be noted that a project may have reported more than one result.

For research projects, a variety of different results were indicated, among them:

- fundamental know-how on the research subject
- technology or know-how that has many potential applications
- internationally top level knowledge
- technology transfer to Finland from abroad
- identifying new business opprtunities
- demonstration equipments/plants
- organisatoric or methodological innovations
- new service products

Besides the strategic objectives of the programme and the objectives of individual projects, it can be assumed that additional value has been created within the programme. The final report[13] of the programme includes comprehensive descriptions of individual results of the projects, so they are not repeated here. Below, however, some examples in different focus areas of the programme reported in the survey and interviews.

In biomaterials:

- innovative new production methods for ceramic materials and study of their biological responses
- discovery of biomarkers in bone resorption areas and ossification signal molecules
- understanding of relationships between technical properties, raw materials and processing of wood product

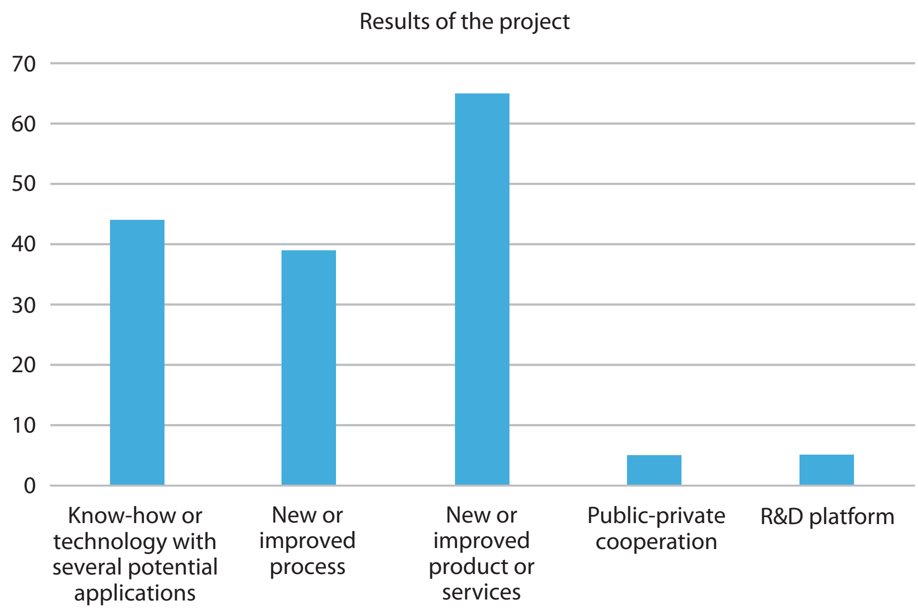
In low-cost manufacturing of intelligent structures:

- manufacturing of supercapacitors by printing
- development of an industrial scale ALD method
- understanding of the manufacturing of functional nano carbon materials
- elimination of gluing, taping and welding as joining methods in an application

In active materials and structures:

- development of technology and methods to integrate different functionalities into surface materials
- verification of the functionality and cost factors of nanocoating technologies
- improved understanding of the influence of environmental conditions to the aging of plastic composites
- development of new micro robotics utilizing method for the research of individual fibres
- development of a better ski surface coating

Fig 3-10. Reported results of FM enterprise projects (n=158).



13 Tekes Functional Materials Programme 2007-2013 Sustainable material solutions – From Finnish research to global business – Tekes report 2/2014. http://www.tekes.fi/globalassets/julkaisut/functional_materials_programme_final_report.pdf

In new energy technology materials:

- development of solar cell materials
- development and commercialization of a solar heating solution architecturally integrated into copper based façade of a building

The outcome of projects and applications was understandably not always positive as seen in the following examples:

- The product developed in the programme reached its customers well in domestic market, but the producers failed in export marketing and sales.
- M-Eranet would have required company driven projects which has not succeeded.
- The project aimed at creation of a wide research network. However, the commercialization has taken so much resources that the long term research has suffered.
- More enterprises in material R&D activities were wished to participate.

The evaluation of what would have happened/not happened without the programme is obviously not undisputable but potential specific value achieved due the programme may be seen in statements like the following:

- The programme has enhanced remarkably the national competence level in material technology. It has created new scientific basis as well as fast applicable material solutions for the industry.
- A lot of new and valid information was gained during FM. For example, basic research in the field of polymer science to enable the use of programming tools in the development work.
- The FM projects created a huge information package, which is still in use in the R&D activities.
- Originally the objective was to proceed further in the path of commercialization. However, without the seed planted in the programme, the development would have been slower.
- The project was very ambitious and no significant breakthrough was reached.

FM programme target setting included *new energy technology materials and environmentally sustainable materials* as special points. Tekes follow-up reporting of projects includes questions about new innovative Energy and Environmental products/services the project has created. Table 3-2 shows the results reported by FM projects in their final reports.

Table 3-2. New innovative energy & environment products and services according to Tekes FM projects' follow up data.

	Research	Enterprise
Number of new E&E services created in the project	9	6
Number of new E&E products created in the project	11	24

3.4 Reaching customer groups

Reaching of the customer groups has an obvious connection to the programme's strategic objectives targeting to the creation of value chains and competence networks. Hence, the contents of paragraph 1.2 (Achieving objectives) can also be considered to give enlightment to the matter of reaching customers.

As shown in Fig. 3-11 the web survey respondents held the opinion that the programme reached its customer groups and other stakeholders generally well. The researchers had a slightly more positive opinion on this than enterprises' representatives.

An example of the programme organization's striving to reach its customers is that in 2009–2010 numerous workshops of 300 material technology experts were organized in order to boost the programme forward. Generally, the Tekes events were a platform for the networking of SMEs, and reaching customers.

In many interview and web survey statements the project manager was regarded unusually competent, and his active role in inviting the enterprise representatives to all events was acknowledged. The coordination team and the programme manager were active in contacting and motivating right parties to the events of the programme also in the beginning phase. The participants who considered the programme useful, spread the word. The programme was active not only among material and applications branches, but also towards other Tekes programmes, Academy of Finland and SHOKs (especially FIMECC) in the spirit of open cooperation. Also, representatives of the whole value chain e.g. raw material producers, coating producers, equipment manufacturers and end users participated mutual projects programme.

The programme reached 153 companies, 17 research organizations in 61 research and consortium projects with total of nearly 1 000 research group and company participations. In addition, there was collaboration with organizations in 40 countries, participation in three European cooperation networks (MATERA, MATERA and M-ERA.NET), joint calls and participant visits to several countries. Hence, the reaching of customer groups can be stated to have succeeded.

All in all, the programme seems also to have met the needs of its participants as shown in Fig. 3-12 below. The web survey respondents' opinion follows the general positive line of the answers to other survey questions. The experience of enterprise and research organization participants in the matter were also very similar.

"We broke boundaries beyond the often typical own sandbox view."

Fig. 3-11. Opinion of web survey respondents about reaching programme's stakeholder groups (n=99).

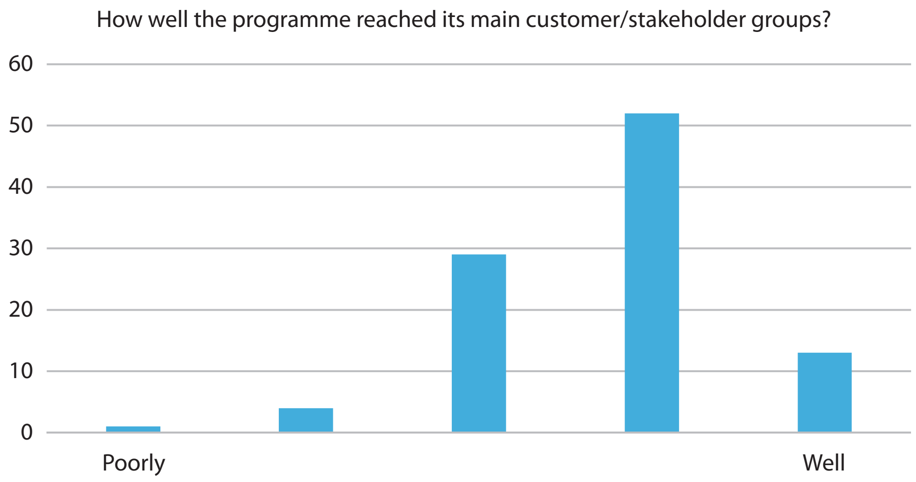
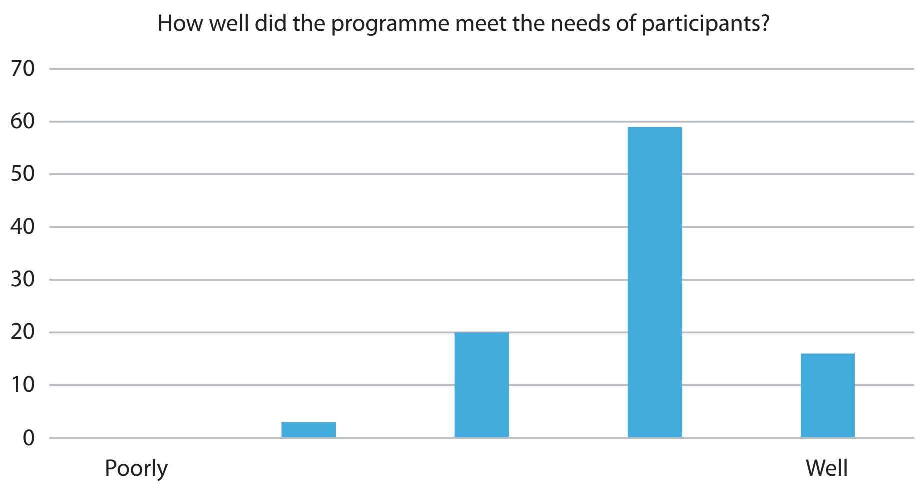


Fig. 3-12. Web survey respondents' view about the level the programme met the needs of the participants. (n=98).



3.5 Resilience in changing operating environment

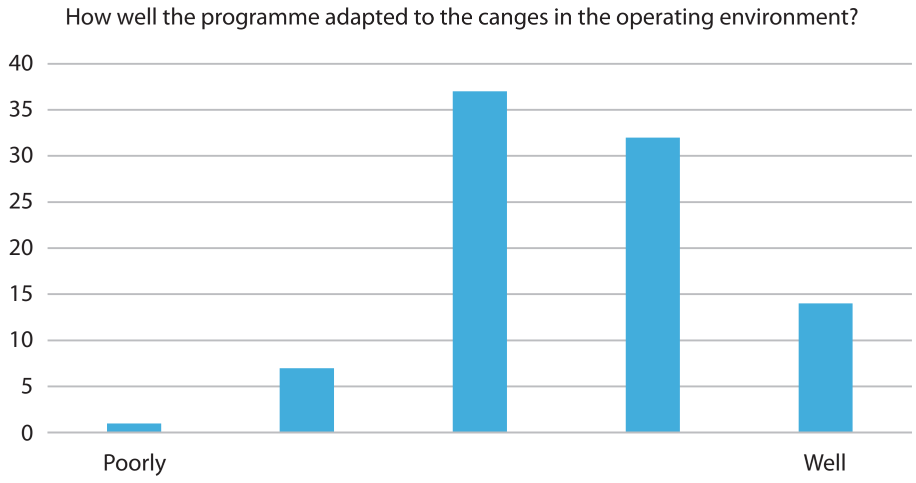
In the beginning of the programme the yearly GDP growth in Finland was five percent and investment in research of phenomena in material technology was remarkable. When the economy crashed and circumstances changed an adaption was a must. The dramatic change in the economy during the programme caused cuts also in R&D spending and jobs in enterprises. At the same time a significant part of Tekes funding was reallocated to SHOKs. Also, the structural changes in the universities were started during the programme, even though no effect on the projects has been reported.

FM programme was refocused in 2009 through a broad strategy work. The original objectives were valid but had to be adjusted. In original preparation before 2007 the path to the now accepted meaning of materials technology was defined, and projects on different research areas were accepted in order to find the right focus areas. The strategy refocusing work brought together over three hundred experts from different involved parties. The strategy was sharpened, biomaterials, solar, energy technology and smart manufacturing were chosen as focus areas. Life Cycle Analysis had to be taken into account in every area, multidisciplinarity was included. Also, the FM objectives had to be directed to prevent overlapping with FIMECC programmes.

Besides the economic crisis and the changes in the Finnish research funding the interviewees and web survey participants held following changes in their operational environment important:

- international development was fast
- the price of competitive technologies fell significantly
- new cheaper materials replaced old ones

Fig. 3-13. Web survey respondents' view of the adaptation to changing environment. (n=91).



- the markets developed continuously and customer needs were changed
- the funding of development of electronics was cut significantly on the national level
- new financers joined company projects
- research results were quickly applied by the industry.

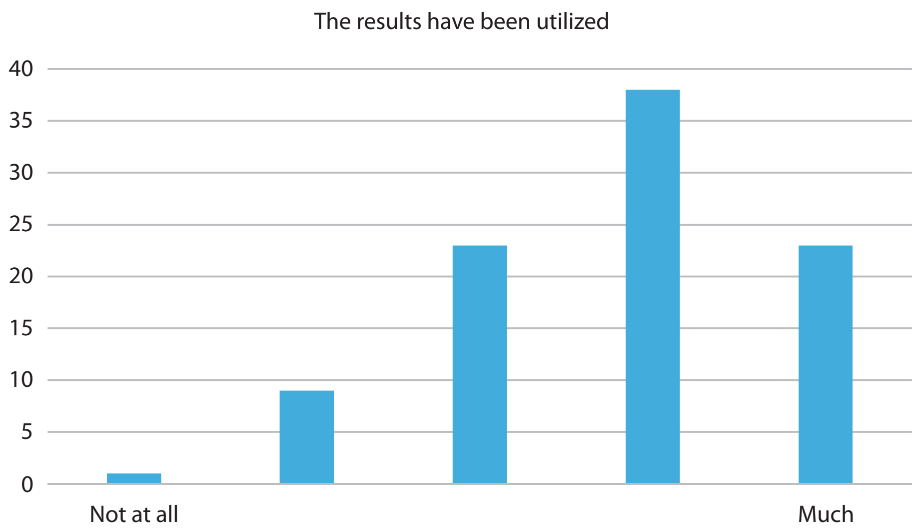
As a whole, the strategy refocusing responded well to the changed circumstances, also according to the opinion of the web survey respondents (Fig. 3-13). The shrinking of Tekes funding of course was a disappointment for several participants. After 2010 no significant changes of the operating environment of the programme were reported.

The operation environment has changed a lot since FM programme. At that time the amount of resources was by programme participants considered much higher which made the research work easier. The quality of the knowledge gained during FM is still regarded as high and up-to-date. The material issue is still of high interest, although now the focus is rather in the energy efficiency. In many cases the work done within FM is said to have continued in FIMECC HYBRIDS.

3.6 Utilization of results and programme services

The utilization of results is estimated to have been on a high level by the web survey participants as seen in Fig. 3-14; enterprise representatives' opinion being even somewhat more positive than that of researchers. Obviously the results of enterprise projects have been well utilized by the enterprises themselves, the results of the research projects are publications presented on different forums. Hence, in the

Fig. 3-14. The view of all FM respondents about the utilization of the results. (n=94).



web survey the enterprise representatives may emphasize commercialization more than researchers and have also better touch to products created.

In dozens of answers of the web survey and interviews, a lot of progress in research, education, product development, commercialization, collaboration, internationalization, marketing and business in general was reported in all the focus areas of the programme. Several Tekes TUTLI projects were launched. On the other hand, some answerers complained that commercialization has not succeeded or there is no feedback of commercialization results. Multidisciplinarity seems to have become a more everyday matter. In the following some qualitative statements of the web survey respondents:

The results are still relevant and used in the R&D processes. Thus it is the basis also for new innovations and solutions in the future.

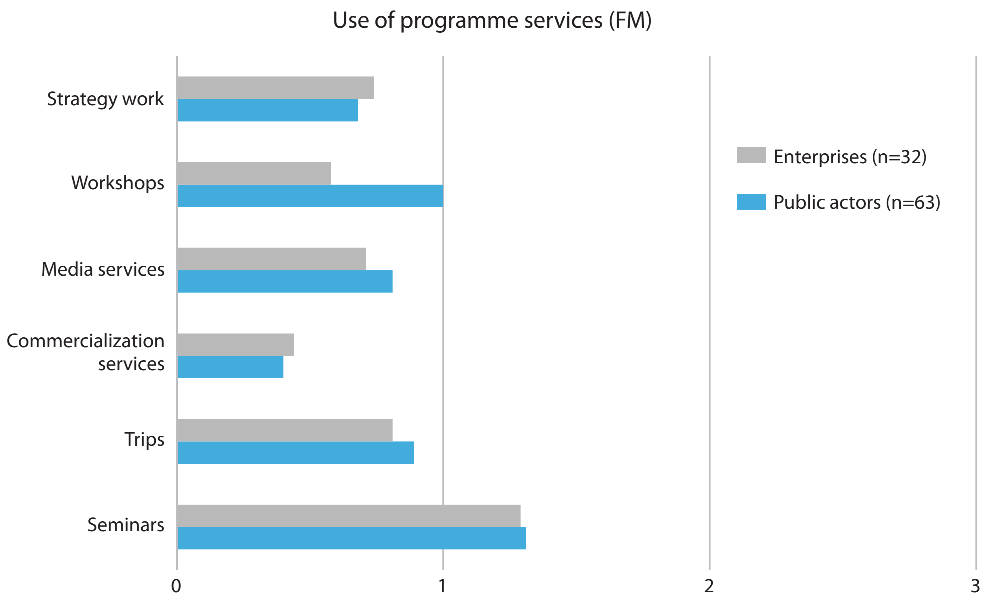
- The mechanism preventing the functionality is known and will be utilized in new coatings.
- New component solutions have been created and published.
- H2020 applications are being prepared.
- First international contracts for the export of the technology have been signed.
- An entirely new business area is being established based on the know-how created in the project. Fast volume growth in 2016-2017 is expected.

Fig. 3-15 shows the comparison of the use of programme services by public sector and enterprise respondents. The results shown are indexes calculated as an average of weighted responses to the statement: *I/our team used programme services (Not at all=0 points; Somewhat=1 point; Substantially=2 points; A lot=3 points)*. The results show that the respondents used in general the programme service only "somewhat". Seminars were the most popular form of participation, and more than one third of the respondents reported having attended seminars "A lot" or "Substantially", over 40% "Somewhat". About 20% had participated "Much" or "Substantially" in workshops and trips. In spite of the diminutive popularity the launching of commercialization services can be considered a bold try, even though – in a few statements – the acceptance of the services by researchers and the quality of the services were reported to be insufficient. According to the experience of the evaluators, the popularity of different FM services is very much on conventional level compared to respective Tekes programmes. The only significant difference between public sector and enterprise representatives in utilization of services within the programme is in the participation in workshops, where researchers have been clearly more active.

However, the popularity of the programme services does not necessarily give a reliable picture of their quality. In the statements of the interviewees and web survey respondents, the programme events were generally considered to be well and efficiently organized, and their outcome seen as satisfactory for the participants. Some examples of the respondent feedback are presented in the following:

- People could be gathered to several different forums (kick off day, impact day, scientific day for young scientists etc.).
- The creation of a materials community was a targeted by-product of the events.
- The coordination of the programme worked well, also on changing situations.
- FM programme was efficient, it worked well and a lot of relevant results were achieved.

Fig. 3-15. Comparison of the use of programme services by public sector and enterprise respondents. (n=95).



- Work being done by contacts to international research teams for state of the art view in Germany, Sweden USA, Japan etc.
- Wide scope of international collaboration (a review made) was launched.
- Good points for programme coordinator, marketed the results well, contacting him was easy.

The last statement shares the opinion of many respondents that the role of programme coordinator was decisive for the general success of the programme. It was also suggested that the experienced functioning cooperation culture may have originated from earlier PINTA material technology Tekes programme, since many of the FM participants had also background in PINTA.

On the basis of the outcome of FM, important issues that seem to help successful utilization of the results of a programme are e.g.

- a novel subject with sufficient business potential to exploit
- a subject with weight enough to interest also bigger companies
- an emphasis set very much in the commercialization of the results
- multidisciplinary approach for a sufficient turbulence in R&D
- participation of the whole value chain from research, valuable for all parties of the chain
- an active and competent programme coordination with good international contacts on the subject in question
- wide variety of programme services for different types of customer groups
- carefully planned programme trips with concrete contacts with top companies and experts.

3.7 Efficiency

The evaluation team has not used any defined efficiency metrics, e.g. comparison to the results vs. investment in other comparable Tekes programmes. Qualitatively, however, it can be stated that

- The web survey respondents – whose number was exceptionally high – gave a highly positive feedback in practically all the questions set.
- The numbers of patents, patent applications, publications and theses are convincing.
- The 60 M€ direct investment in start-ups is impressive.
- Collaboration with other material technology networks was actively sought and successfully activated.
- The results of the projects have been successfully utilized commercially and scientifically.
- The results of trips and other events are reported.
- The work of the coordination team was praised in the feedback.

According to evaluation team's own experience of several respective evaluations and considering that it is too early to predict the success of the businesses created within in the programme, the results with respect to used money are well over average as well in published scientific results as reported improvements in products and processes of enterprises.

3.8 Expected future impacts

Programme's final report presents a comprehensive overview of the steering group of the expected next steps on material technology. The steering group's approach is based on the current need on a different technology areas including solar, photonics, manufacturing, energy efficiency, biomaterials and packaging. The overview also gives recommendation of development measures on a general level. The evaluation group has no specific wisdom to add on this.

However, the matter of future was also addressed in the interviews and free comments of the web survey. The respondents pointed out that many application fields in the focus of the programme are just in the process of developing into large scale industries. However, it can already be seen that the investments to the programme have improved the competence base and the Finnish players are ready to compete on world markets when they open and the industries develop to mainstream. It was even predicted that business based on the know-how created in the programme will grow to hundreds of millions euros in ten years. In its part FM has also influenced on the contents of Tekes Green Growth programme and enterprise driven materials research in the programmes of FIMECC, Fibic and Cleen (which later merged to form CLIC Innovation). Specific future development was covered in the web survey and interviews followingly:

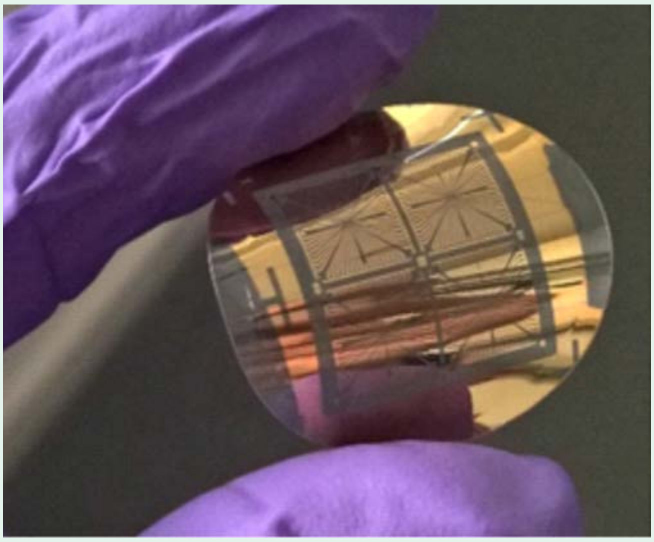
- New alternative coatings will come to market and replace the traditional ones.
- The results can be applied especially in IoT and wearable applications.
- Next step will be applications, scaling up of the developed materials and their manufacturing, and interface with IoT.
- Materials will be more part of the whole; not only development of technology.
- The four corner stones of FM – international cooperation, commercialization of research results, environmental issues and life cycle analysis and value chains - should be taken into account in the future in every programme.

CASE: Maturing graphene-based sensor technology from lab samples into new business

Nokia has invested in R&D work on graphene-based technologies for over a decade. Research activities started at Nokia Research Center (NRC) Finland in 2006 in collaboration with Aalto University. This was soon followed by the establishment of a dedicated nanotechnology research laboratory and collaboration with the University of Cambridge in the UK. The primary focus of the research work was to develop components and materials for electrical devices – in particular for consumer electronics and emerging IoT technologies – with truly disruptive physical properties such as transparency, deformability, self-cleaning ability, printability, and superior electrical performance and sensitivity compared to conventional material technologies. Perhaps the most visible outcome of the NRC research work was the Morph concept device, illustrated on the left in the figure below, which was honoured with The Red Dot: Best of the Best award in 2008.

When Nokia sold its mobile phone business to Microsoft in 2014, the mode of operation for graphene-related activities transformed from research into product development and business incubation, now carried out in the Nokia Technologies business unit. The objective of the Graphene team was to mature selected material and sensor technologies for commercial application and technology licensing. In 2016, the focus was further narrowed to the development of graphene-based photodetectors (see a sample device on the right in the figure below) and their various applications in the areas of wide-spectrum imaging and industrial and scientific measurements. These commercialization activities have now been spun out from Nokia and will be continued with venture capital funding in a new company, Emberion, having operations both in Finland and in the UK.

The successful transformation from experimental research laboratory work into a new business has been possible due to an excellent collaboration network and public funding. In addition to Tekes' Functional Materials program, Nokia has received significant Tekes funding for FLINT (2013), Eskin1 (2014) and Eskin2 (2015–2016) projects. Also, Nokia is a founder member of EU FET Graphene Flagship project.



Experimental deformable product concept ideas (left), functional photodetector device designs manufactured on a flexible substrate (right).

4 Conclusions and Recommendations

4.1 Conclusions for the R&D and innovation activities

The field of material technology generally includes future growth opportunities. Fast growth is possible in a niche that is in a suitably mature state for the growth. Many niches in material technology are yet to come to that. This is one reason why often persistency and predictability of development funding are more important than the big amount of money. Thus the results of the research and development work has to be seen and evaluated in this light.

The long-time funding of course underlines the importance of the selection early in the process. Selection of long-term supported projects should go hand in hand with fast failure- approach, where a large number of ideas and initiatives are funded until a phase, where an evaluation of the feasibility can be made, and a bulk of not so promising initiatives are terminated for the benefit of the chosen ones, whose continuity is secured.

In the evaluation of the FM programme, the diversity of the expressed opinions was large, ranging from the technological solution needs of strong industrial enterprises to views emphasizing broader networking and free idea creation. The well-known fact that researchers are worried about basic research funding was often discussed.

Cooperation has changed from what it was 10-15 years ago so that the leaner financial resources force tighter co-operation. Multidisciplinary competences are needed and training of people for multidisciplinary R&D development in research institutes and enterprises is important. The evaluated programmes had a great impact in multiskills. Renewal of industries requires joint input of enterprises and research institutions. Finland can be an applier, but applying of new technologies can be difficult without domestic research.

For a research and development project, belonging to a larger programme is valuable as such. The projects belonging to a larger entity get contacts and learnings that a separate project might never find. The role of the programme (officers) is to continuously challenge the participants to strive towards better, developing goals. It might be beneficial to include in programmes even such projects that get their entire funding from outside. This could strengthen the programme community and be useful to all participants.

Programmes and the funding obtained from them are important especially for the development by combining knowledge form different industries and disciplines. Perseverance and long term thinking are needed. Thousands of new jobs are not created at once, but the developed competences can be utilized, even on new fields of application.

Creating new business activity in material technology requires attention of Tekes and other public actors, because the time-to-market is typically long and the work requires substantial investments. Risk level is in the beginning phase high, and the public funding has an even more important role than e.g. in software technologies.

Working together with enterprises motivates researchers, and participating in research motivates industry experts. The path from research to practice is not a one-way road, but a process of interaction. Feedback gives motivation! It would be good to have some mechanism to give feedback about the utilization of project results to the researchers also after the project. It was complained that when the financing runs out, there is no way to get the information.

A shared problem and common language create multidisciplinary solutions. The volume is decisive: when the group of people is big enough, solutions can be created. However, they may become concrete elsewhere and after some time.

The alternatives for financing internationally competitive innovations: big company/corporation money, venture capital, foreign investor and public money either nationally or from EU. The inclusion of EU funding has to be taken into account already in early stages, EU networks and connection have to be taken care in advance. Tekes programmes emphasize the benefits of Finnish companies, inclusion of foreign partners may be considered risky.

When the national R&D funding has been shrinking and the preferences have shifted towards industrial applications, some research funding clients have noticed that the targets of the main funding providers are moving closer to each other. The roles of Academy of Finland and Tekes seem to need some clarification. When similar projects can apply funding from any of the two main funding providers, also the differences of their approach become visible. Tekes with its own substance expertise is seen as easy and supportive from applicant's point of view. The Academy of

Finland, however, gives less advice on the substance of the research and is therefore sometimes perceived not to know what kind of research they want to finance. The applicants may feel frustrated when they try to guess what kind of application would be favourably received by the funder. The reasons for this are in the different missions of the Academy and Tekes. Academy has been funding free basic research, where the researchers chose the subject freely and the evaluation is only about the expected scientific level of the work, whereas Tekes has always been funding projects with defined objectives or at least on a nationally prioritized subject area. However, nowadays the focus of Tekes and Academy seem to have become closer to each other, even overlapping, which seems to be confusing.

The R&D process in material science tends to be long (10–15 years). Development from PINTA through FM to FIMECC HYBRIDS program exhibits a good trend towards faster R&D cycles. As an example parallel modelling and experimental work has contributed to this.

The opinions towards PINTA and FM programmes were mostly positive amongst participants whereas opinions towards SHOKs were more controversial. SHOKs were criticized both for being too much driven by academia and for concentrating to the specific problems of the industry instead of the conditions of science. On the other hand, FIMECCs HYBRIDS was regarded successful in many statements.

Participating enterprises should put special emphasis on resources; the representing persons should be genuinely committed to achieve concrete results. Participants of consortia should be selected based on best available competence.

Education of doctors should enable adaptation to different operational environments, since only small fraction of the doctors can be employed by the academia. This requires also cultural change in enterprises.

Important issues that seem to help successful utilization of the results of a programme are e.g.

- a novel subject with sufficient business potential to exploit
- a subject with weight enough to interest also bigger companies
- an emphasis set very much in the commercialization of the results
- multidisciplinary approach for a sufficient turbulence in R&D
- participation of the whole value chain from research, valuable for all parties of the chain
- an active and competent programme coordination with good international contacts on the subject in question
- wide variety of programme services for different types of customer groups
- carefully planned programme trips with concrete contacts with top companies and experts..

4.2 Conclusions for Tekes

Tekes was criticized of tendency to abruptly change the focus of interest. Sometimes it is better to grant less money and more time for a business to develop. According to a MIT research[14] the success of a project correlated best with a sufficient time frame and enterprise's own hunter-gatherer bringing research results into the company.

The trend during e.g. PINTA was to make a general concept of a general mutual problem whereas nowadays the trend is more to concretize a small specific problem. Tekes has a role as an orchestrator in this.

Fragmentation of funding periods and programmes and sometimes very short time funding decisions towards the end of a programme cause problems in organizations and with the participating enterprises, especially if project plan has been prepared with the enterprises to cover several years. More flexibility was wished and the project should be allowed to continue also after the end of the programme, if the original plan was such. One idea presented in the evaluation was that Tekes programmes could be implemented in batches so that after the termination of a programme and a pause of e.g. two years the funding of the subject could be started again.

Communication with Tekes was mostly seen to be very easy and fluent. It is very good that there is an own contact person who knows the client and maintains contact. Tekes is in this respect much better than Academy of Finland. The handling of project plans in an early phase together with Tekes representative was especially fruitful. The dialogue with Tekes has improved the project plans greatly. Discussions with Tekes have also been an effective way for the enterprises to test ideas and streamline the forming of R&D projects.

Some opinions were presented suggesting that Tekes should shift emphasis from funding of projects of large corporations towards stronger support of export and innovation of SMEs. This is also frequently repeated in the public discussion. It is possible that the popular public discussion is not always recognizing the fact that the funding addressed to the projects driven by large enterprises flows to SMEs and research parties through subcontracting, which is a prerequisite in the funding of large enterprise R&D. Large enterprises have the capacity to direct and coordinate the work. Although the business created by start-ups and in-

[14] Pertuzé, J.A., Calder E.S., Greitzer E.M., Lucas, W.A: Best Practices for Industry-University Collaboration. MIT Sloan Management Review Summer 2010 Vol 51 No. 4

novation based SMEs is in the focus of the discussion and expectations, the major business volume created by publicly funded research projects probably comes through the improvement of products and processes of large enterprises. This impact is hard to measure and cannot always be distinguished from other business growth of the enterprise.

Evaluated programmes created a vast network of connections, wide circle of scientists; Tekes research projects are public, people dare to talk with each other; network is a resource for company. The national R&D funding system is necessary for securing the operating possibilities and competitiveness of SMEs and micro enterprises. Technology strategic choices need at least 5 years of time to prove the validity.

Support should be focused to the own projects of the companies and such research projects that have genuinely good consortium and target setting. Central challenges for Tekes are

1. Balance between development of solutions to specific problems vs. the money invested in inventing entirely new things that cannot be specified in advance.
2. Balance between the bigger amount of initial ideas of which many will die after closer scrutiny and the long term funding needs of those fewer projects that really promise value adding results provided that their funding is not discontinued too early.

It was frequently noted that companies are not capable, at least not yet, to handle the loans in their financial statements. The trend of Tekes to provide more loans instead of grants was criticized.

PINTA and FM were good programmes in which a lot of important knowledge was created. Now the next step should be announced. Multidisciplinary programmes are needed also in the field of materials science. There is a need for ambitious programs in materials science with well thought out scale and the needs. Tekes' role to ensure continuation, long term research, needs perseverance.

Tekes' efforts to get companies committed early in the projects in order to facilitate information transfer are essential. This improves the possibilities to reach the goals of targeted and applied research. It also ensures better baseline for mutual understanding of the goals of the research and the realistic possibilities to reach them. Close collaboration between the programme management, companies and research institutes in the programme planning phase also speeds up the first phases of the projects.

It was not clear to all respondents, that the role of Tekes is to fund RDI projects that are targeting to applications in selected industries, technologies and concepts instead of supporting academic research that selects its subjects more freely guided only by the advancement of science.

In its beginning, FM programme used outsourced service for commercialization. This did not work out well, and was replaced by Tekes own service. The development of these to meet the requirements of the clients is being developed.

4.3 Conclusions for research and innovation policy

Following two views about the role of SHOKs were recorded during the evaluation. They illustrate the central challenge of linking scientific research and development of marketable innovations:

"The academic world does not understand the basis of SHOKS. The SHOKS do not function because the academic world is driving the work in SHOKs. If the academic world leads something, it has to be done in a more need-oriented way."

"Programmes were better than SHOKs, because in the programmes the cooperation between academia and industry was taking place under conditions that were acceptable for both sides. In SHOKs industry has sometimes been pushing for solutions of their specific problems instead of the conditions of science."

The companies have a vast number of problems that might be solvable by research and development efforts and by applying scientific knowledge. On the other hand, research funding should be directed boldly to areas not well known in advance, since safe choices bring expected results but no new unforeseen solutions.

All publicly funded research and development is subject of fundamental political priority settings:

1. How much public funds are allocated to scientific work where the researchers set the goals and academic freedom is prevalent?
2. How much funds are allocated to the development of solutions to such problems that are recognized as essential for the welfare and prosperity of the nation?

After the division of available funds between 1 and 2, the main question is how the funds allocated to point 2 are spent, i.e. which are the essential subjects of research and development. This requires a well thought and adequate national vision that is both up-to- date and stable enough to allow for long terms actions. Lack of vision causes too bouncing and hasty decision making.

Does Tekes have an adequate national vision to support the work? Are the roles of Tekes and Academy of Finland clear and adequate?

It was commented both pros and cons that current research strategy is aiming for fast wins with good margins with little or no funding on long term development of established branches of technology.

Transfer of knowledge between industries is essential, and in the forming of national strategies and in the development of the innovation system some thought should be given to who shall take care of this transfer and how.

Education is of central importance for the success of the innovation system and industries. To grow to be a researcher requires participation in research work. It should be kept in mind that the doctoral students in the universities are a research engine creating benefits but also needing long term research funds.

The SHOK model is being reformulated. In spite of the shortcomings, the SHOKs have been a good platform for networking. "New SHOKs" could e.g. start more demos with industry and research. Industry knows best its own challenges; academia sees things more globally. Mutual operations and a good combination of industry and academia are needed.

4.4 Key recommendations

According to the evaluation of PINTA and FM programmes, the following key conclusions and recommendations are given:

- Many niches in material technology are only slowly developing towards a level of maturity where major breakthroughs can be expected. This is a reason why often persistency and predictability of development funding are more important than the big amount of money.
- Selection of long-term supported projects should be balanced with fast failure- approach, where a large number of ideas and initiatives are funded until a phase, where an evaluation of the feasibility can be made, and a bulk of not so promising initiatives are terminated for the benefit of the chosen ones, whose continuity is secured.
- Programmes like PINTA and Functional Materials have been crucial for the development of industry-university cooperation and for the development of multidisciplinary competence base in Finland. The future of this kind of activity needs to be secured.
- Working together with enterprises motivates researchers, and participating in research motivates industry experts. Feedback gives motivation! It would be good to have some mechanism to give feedback about the utilization to the researchers after the project.
- The roles and strategies of the Academy of Finland and Tekes should be clarified and documented. Communication of Tekes' operating principles and target setting as supporter of applied research should be improved.
- The dedicated client contact persons and coaching approach of Tekes in preparation of project plans is valuable and should be maintained and strengthened.
- Tekes' efforts to get companies committed early in the projects in order to facilitate information transfer are essential. In the communication with the companies, Tekes could emphasize the deciding importance of the commitment and activity of company contact person for the success of the project.
- Transfer of knowledge between industries is essential, and this should be taken into account in the forming of national strategies and in the development of the innovation system.

Appendix 1. Evaluation project

Target of the project

The target of the project was to produce
- The final evaluation of Tekes programme Functional materials (Toiminnalliset materiaalit, 2007-2013)
- An ex post evaluation of Clean surfaces programme PINTA (2002-2006).

The emphasis of the final evaluation of Functional Materials was in results and operational issues, while also adequacy of the objectives and the observed or expected impacts were addressed.

The ex post evaluation of PINTA concentrated on the impact of the programme in Finnish society, environment and industries and on the creation of skills, competences and networks.

In addition to the evaluations of the two programmes the project produced a literature study on relevant developments in research and innovation in the field of materials, including international benchmarking.

The project looked for answers to the following Evaluation Questions

Work package 1: Literature review of operating environment

1. What are the major changes in the operation environment?
2. International benchmarking: insights of RDI in the in some comparable countries (Sweden; Denmark etc.)

Work package 2: Results achieved, relevance and efficiency - Functional materials (Toiminnalliset materiaalit)

1. How relevant and challenging are the programme's objectives? To what extent have they helped to implement Finland's strategic choices, and Tekes own strategies?
2. To what extent have the objectives set for the programme been achieved? What are the important results supporting the main objectives of the programme?
3. What other programme results can be found that were not listed as programme objectives? Which of the results would not have been achieved without the programme?
4. How well were the most important customer groups reached?
5. How resilient was the programme concerning the changes in operating environment? How well did the programme, its services and administration meet the needs of the participants? How well did the interaction with FIMECC and its material programmes (or other SHOK programmes) work?
6. How should the results and programme services of the programme be utilised so that performance can be improved and more impacts generated after the programme and in future programmes?
7. How efficient has the programme been?

Work package 3: Impacts achieved and expected, effectiveness and utility – Clean Surfaces (PINTA)

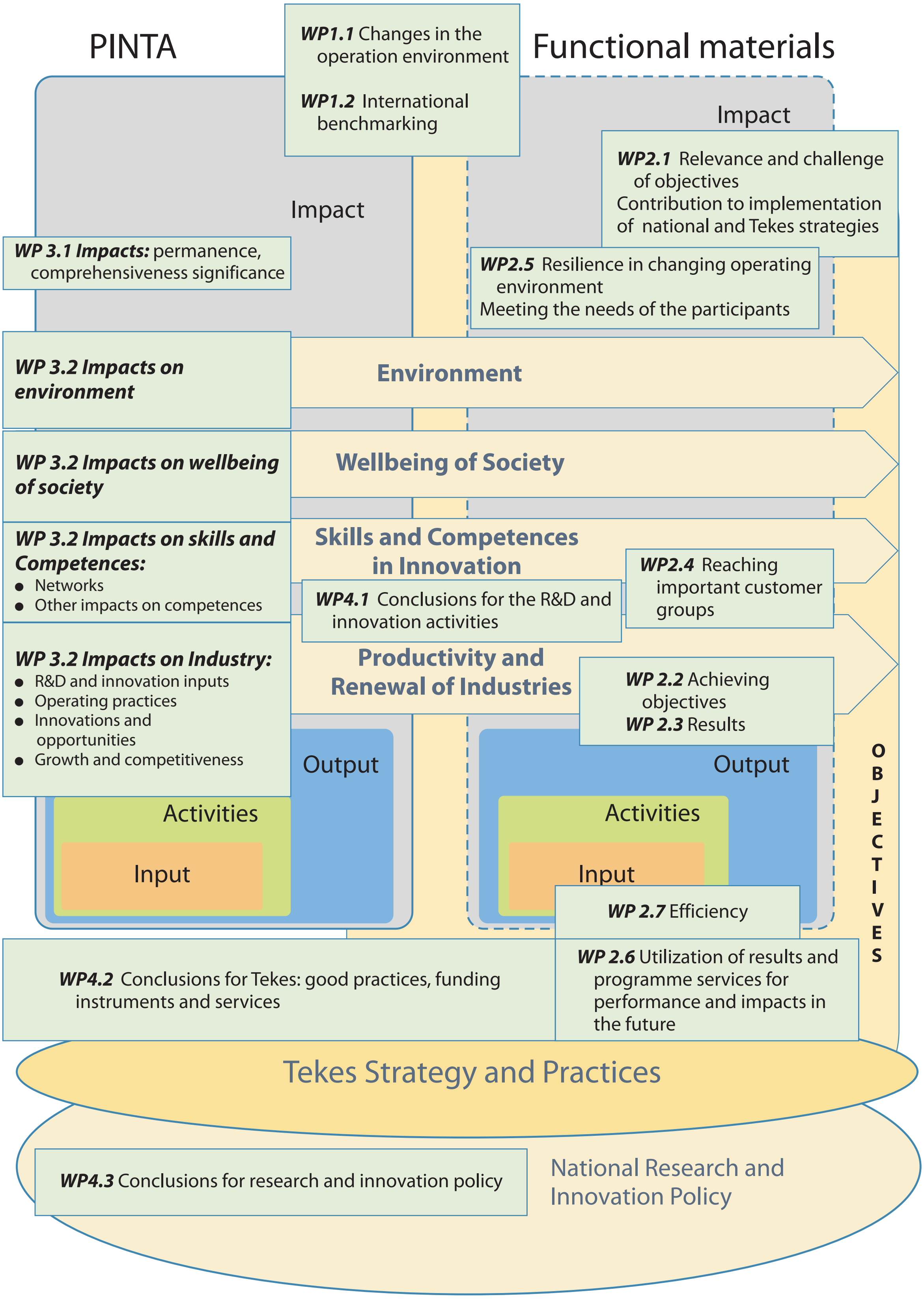
1. What are the impacts of the programme? How permanent, comprehensive and significant can the impacts be considered?
2. To what extent and in what ways has the programme impacted the following areas (give indicators or case examples):

- R&D and innovation inputs in the sector
- establishment of domestic and international networks
- changes in companies' operating practices
- important innovations and business opportunities
- growth (especially international) of participating companies
- competitiveness of the industrial sector
- Finnish industry and society more generally

Work package 4: Conclusions

1. For the R&D and innovation activities: How should the material technology R&D and innovation activities be developed in the future?
2. For Tekes: Give the good practices that are concrete and workable and that can be used in the development of programme services and the programmes themselves. What kind of funding instruments or services should be included in order to improve the impact?
3. For research and innovation policy: What do the findings imply for innovation policy? What other research and innovation policy measures, in addition to the measures taken by Tekes, should be applied so that impacts can be strengthened?

Evaluation framework



The above figure presents the framework for the project, where the work packages and evaluation questions have been positioned. The green boxes in the image represent the different working packages and evaluation questions as defined in the invitation to tender. The framework is built on the familiar impact analysis model of Tekes. The programmes to be evaluated contain the Activities. Funding and programme services provided by Tekes represent the Inputs in this analysis. The direct results of the programmes are the Output. In the Impact field the focus will be in those impact areas, where Tekes has defined its objectives.

Project Team

The evaluation project was carried out by an evaluation team consisting of Lic.Tech. Juhani Timonen and M.Sc. Markku Antikainen of Virebit Oy, professor Jyrki Vuorinen, Dr. Essi Sarlin and Dr. Amit Das. Project Manager was Juhani Timonen.

Project Steering Group consisted of Pekka Pesonen, Kimmo Kanto and Kari Keskinen from Tekes.

Phases and Schedule

The project was implemented in the following phases:

Project start (kick-off meeting)	9.2.2016
Literature review	February 2016
Interviews	11.2.–12.5. 2016
Web survey	12.4.–4.5. 2016
PINTA Workshop	3.5.2016
Functional Materials Workshop	2.6.2016
Draft report	29.4.2016
Final report	30.6.2016
Steering Group Meetings	21.3.2016
	25.4.2016
	15.6.2016

Appendix 2. Methods and materials

Project phases vs. work packages

Work package structure presented in the invitation to tender has been the basis for structuring the targeted result of the evaluation project. Project phase structure and division of work between the team members did not fully correspond to the work packages, because some work phases served data collection, analysis or administration of more than one work package, and also took place parallelly. Figure 1 depicts the relationship between project tasks and resulting report (work package) structure. The tasks and methods used in the project are described in the following chapters.

Literature Study

The trends and development in materials research globally and in the selected countries were analysed by materials scientists based on their experience, contacts and available public sources. The source for the publication activity statistics was the Scopus database for peer-reviewed international publications.

Key Person Interviews

Both evaluated programmes were covered by key person interviews. Programme managers and coordinators were interviewed to get an overview about the programme and useful contact information. Based on these discussions and contact lists obtained from Tekes, the interviews were planned to cover the different projects and subject areas in the programmes. The number of persons interviewed was 36. Many of them had been participating both programmes. The list of names is given in App. 4.

The interviews were semi-structured theme discussions, where, instead of rigid question-and-answer schema, a written guideline, based on the evaluation questions (see App. 1) was loosely applied to steer the discussion around relevant topics.

Network Analysis and LinkedIn Group

Special attention was given to the emergence of networks due to the programmes. The objective was to chart the networks of persons that have been utilizing or processing the knowledge from the programmes. Both the interviews and web survey tried to identify the movements of programme participants between different employers and so to build an idea about the dissemination of knowledge in this way.

A theme group was opened in the social networking tool LinkedIn, but it did not attract participants and remained inactive.

Web survey and complementing interviews

A web survey was carried out, based on the email addresses of persons who were on the list of project contact persons or whose name was mentioned in the final reports of the programmes. The address list was checked and new names added during the survey time, and several reminders were sent. For 392 person names identified, 354 valid email addresses were finally found, and 152 persons (43%) completed the survey. The survey was implemented using Survette tool, developed and maintained by Fountain Park Oy. The questions of the survey are in App. 5. Some complementing interviews were performed during the survey, and assistance about the use was given. Looking at the address list, it appeared that surprisingly few of the persons reached for the survey were not Finnish. That's why the survey was implemented only in Finnish, and some persons who asked for English questions, were interviewed by phone using the same questions.

Workshops

During the project two half-day workshops were arranged, one for each of the programmes. Invited experts (name lists in App. 4) discussed the preliminary findings, conclusions and question settings. The material created in the workshops is used in the report.

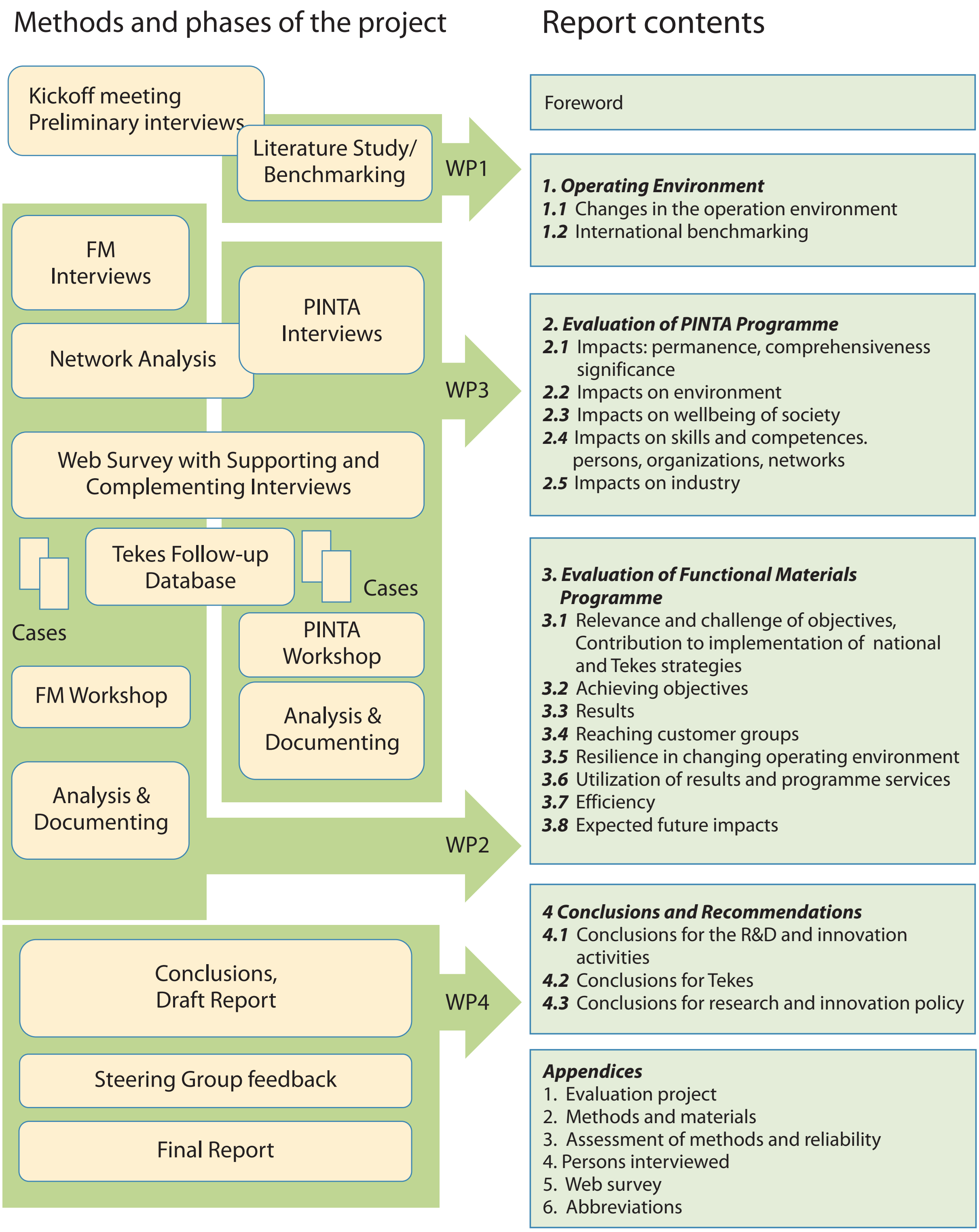
Tekes programme follow-up data

The administrative material (meeting memos, publications, funding decisions, planning documents etc.) of Tekes about the programmes has been available and used for the report, as well as follow-up database based on the final reports of the individual projects.

Steering Group feedback

Preliminary findings and draft reports were presented to the steering group in 3 meetings. The comments and feedback has shaped the report.

Methods and materials and their contribution to the final report



Appendix 3. Assessment of methods and reliability

Key Person Interviews

We think that the interviews cover fairly well both programmes within the limits of the time and resources available. Especially Functional Materials included a vast number of different R&D subjects, and it was possible to cover only a thin sample of them by interviews. An attempt was made to select a representative set of different projects and areas for the interviews of key persons.

The long time since PINTA programme may have caused some difficulties. Two key persons of programme preparation phase were not available for the interview. Also it was not easy to distinguish the impacts of PINTA from everything else that has happened in the field during ten years.

Network Analysis

Special attention was given to the emergence of networks due to the programmes. The objective was to chart the networks of persons that have been ulilizing or processing the knowledge from the programmes. The results of the network analysis remained leaner than expected. The data obtained from interviews and web survey about the links between teams and persons was not sufficient to draw any larger scale maps about the professional networks in materials science. A theme group opened in the social networking tool LinkedIn, but it did not attract participants and remained inactive.

The maps drawn about the movements of persons between different types of employers indicated surprisingly little mobility of the professionals. We think that there is a bias here caused by the fact that the survey that was the basis of this mapping was built on the project contact person data, which is biased towards senior researchers and managers. These tend to have more permanent positions in their organizations than the junior members of the teams.

Web survey

The web survey was based on the email addresses of persons who were on the list of project contact persons or whose name was mentioned in the final reports of the programmes. The address list was checked and new names added during the survey time. For 392 person names identified, 354 valid email addresses were finally found, and 152 persons (43%) completed the survey. We think that this is an extremely good response rate. Key success factors here were the compactness of the survey and several reminders. We also promised to send a link to the final report to all persons who finalized the survey.

Workshops

The discussion in both workshops was good and brought the evaluation forward. Traditionally it is difficult to get company representaties into workshops. Researchers seem to be more interested. In this case both workshops had competent representation from both enterprises and research parties.

Appendix 4. Persons interviewed and workshop participants

Persons interviewed

Sisko Sipilä	Tekes
Risto Nieminen	Aalto University
Juha Määttä	Ladec Oy
Jari Koskinen	Aalto University
Markku Leskelä	University of Helsinki
Mikko Ritala	University of Helsinki
Jukka Kolehmainen	DIARC Technology
Sanna Tervakangas	DIARC Technology
Erkki Levänen	Tampere University of Technology
Mika Valden	Tampere University of Technology
Marke Kallio	Metso Oyj
Eini Puhakka	University of Helsinki
Esko Kauppinen	Aalto University
Jari Knuuttila	Millidyne Oy
Mirja Salkinoja-Salonen	University of Helsinki (emerita)
Joe Pimenoff	Beneq Oy
Markku Heino	Spinverse Oy
Markku Lämsä	Tekes
Esa Puukilainen	Vauhti Oy
Jari Liimatainen	Picodeon Oy
Tapani Ryhänen	Nokia Oyj
Erna Storgards	VTT
Viljami Pore	ASM Microchemistry Oy
Maarit Karppinen	Aalto University
Solveig Roschier	University of Helsinki
Riitta Keiski	Oulu University
Hele Savin	Aalto University
Risto Vuohelainen	Canatu Oy
Mikko Kärkkäinen	Canatu Oy
Juha Nikkola	UPM
Kirsi Hirvonen	Metsä Group
Janne Raula	Teicos Pharma Oy
Jari Koskinen	Aalto University
Jukka Heikkinen	Valmet
Jari Keskinen	Tampere University of Technology
Esa Laurinsilta	UPM

PINTA Workshop 3.5.2016

Eini Puhakka	University of Helsinki
Erkki Levänen	TUT
Erna Storgards	VTT
Essi Sarlin	TUT
Jyrki Vuorinen	TUT
Juhani Timonen	Virebit
Markku Antikainen	Virebit
Mirja Salkinoja-Salonen	
Pekka Pesonen	Tekes
Sanna Tervakangas	DIARC Technology
Sisko Sipilä	Tekes

Functional Materials Workshop 2.6.2016

Hele Savin	Aalto University
Jari Liimatainen	Picodeon
Juhani Timonen	Virebit
Jyrki Vuorinen	Tampere University of Technology
Markku Antikainen	Virebit
Markku Heino	Spinverse
Markku Lämsä	Tekes
Pekka Pesonen	Tekes
Sanna Tervakangas	DIARC Technology
Solveig Roschier	University of Helsinki

Appendix 5. Web Survey questions (in Finnish)

Työnantajasi nyt

1: 1. Saat tästä halutessasi näkyviin ohjelmien tutkimus/yritysprojektin listat (valitse yksi vaihtoehto kerrallaan ja paina 'Jatka'). Listan näytön jälkeen palaat listan lopussa olevalla 'Jatka'-painikkeella tälle sivulle ja voit joko valita uuden projektilistan tai jatkaa seuraaviin kysymyksiin valitsemalla 'Jatka eteenpäin'.
7: 1. Osallistumisesi PINTA-ohjelmaan: Osallistuin tutkimusprojektiin
7: 1. Osallistumisesi PINTA-ohjelmaan: Osallistuin yritysprojektiin
7: 1. Osallistumisesi PINTA-ohjelmaan: Osallistuin ohjelman hallintoon
7: 2. Organisaatiosi PINTA-ohjelmaan osallistumisen aikaan
7: 3. Kuinka hyvin muistat PINTA- ohjelmassa tekemääsi työtä/projektia: En muista; Muistan hyvin
7: 4. Onko nykyään tekemälläsi työllä yhteyttä PINTA- ohjelman aihealueeseen: Ei mitään yhteistä; Työskentelen edelleen samojen asioiden parissa
7: 5. Täsmennä
7: 6. Onko PINTA-ohjelmalla ollut mielestäsi vaikutuksia vaikutuksia tiedon ja osaamisen tasoon?: Ei lainkaan; Merkittävästi
7: 7. Millaisia vaikutuksia?
7: 8. Onko PINTA-ohjelmalla ollut mielestäsi vaikutuksia yritystoimintaan?: Ei lainkaan; Merkittävästi
7: 9. Millaisia vaikutuksia?
7: 10. Onko PINTA-ohjelmalla ollut mielestäsi vaikutuksia kansalaisten hyvinvointiin?: Ei lainkaan; Merkittävästi
7: 11. Millaisia vaikutuksia?
7: 12. Onko PINTA-ohjelmalla ollut mielestäsi ympäristövaikutuksia?: Ei lainkaan; Merkittävästi
7: 13. Millaisia vaikutuksia?
7: 14. Onko PINTA-ohjelmalla ollut mielestäsi vaikutuksia verkostoitumiseen asiantuntijoiden ja organisaatioiden kesken?: Ei lainkaan; Merkittävästi
7: 15. Millaisia vaikutuksia?
7: 16. Onko PINTA- ohjelmalla ollut mielestäsi muunlaisia edellä mainitsemattomia vaikutuksia?: Ei lainkaan; Merkittävästi
7: 17. Millaisia vaikutuksia?
7: 18. Onko tiedossasi henkilöitä, tutkimusryhmiä tai yrityksiä, jotka olisivat edelleen kehittäneet tai hyödyntäneet PINTA- ohjelmassa tehtyä työtä? Anna yhteystieto, jos tiedät.
9: 1. Osallistumisesi Toiminnalliset materiaalit- ohjelmaan: Osallistuin tutkimusprojektiin
9: 1. Osallistumisesi Toiminnalliset materiaalit- ohjelmaan: Osallistuin yritysprojektiin
9: 1. Osallistumisesi Toiminnalliset materiaalit- ohjelmaan: Osallistuin ohjelman hallintoon
9: 2. Organisaatiosi Toiminnalliset materiaalit- ohjelmaan osallistumisen aikaan
9: 3. Onko nykyään tekemälläsi työllä yhteyttä Toiminnalliset materiaalit- ohjelman aihealueeseen: Ei mitään yhteistä;Työskentelen edelleen samojen asioiden parissa
9: 4. Täsmennä
9: 5. Ohjelman/projektin tavoitteiden haasteellisuus: Hyvin matala; Hyvin korkea
9: 6. Kuinka hyvin tavoitteet saavutettiin?: Ei saavutettu; Tavoitteet ylitettiin
9: 7. Ohjelman/Projektin tärkeimmät tulokset
9: 8. Tuloksia on hyödynnetty: Ei lainkaan; Paljon
9: 9. Täsmennä
9: 10. Kuinka hyvin ohjelma/projekti tavoitti tärkeimmät asiakas/sidosryhmänsä?: Huonosti; Hyvin
9: 11. Täsmennä

9: 12. Tärkeimmät toimintaympäristön muutokset ohjelman aikana
9: 13. Kuinka hyvin ohjelma/projekti sopeutui toimintaympäristön muutoksiin?: Huonosti; Hyvin
9: 14. Kuinka hyvin ohjelma/projekti täytti osallistujiensa tarpeita?: Huonosti; Hyvin
9: 15. Käytin/ryhmämme käytti ohjelmapalveluita: Seminaarit
9: 15. Käytin/ryhmämme käytti ohjelmapalveluita: Matkat
9: 15. Käytin/ryhmämme käytti ohjelmapalveluita: Kaupallistamispalvelut
9: 15. Käytin/ryhmämme käytti ohjelmapalveluita: Tiedotuspalvelut
9: 15. Käytin/ryhmämme käytti ohjelmapalveluita: Työpajat
9: 15. Käytin/ryhmämme käytti ohjelmapalveluita: Strategiatyö
9: 16. Odotettavissa olevia ohjelman vaikutuksia tulevaisuudessa
10: 1. Vapaita kommentteja, mielipiteitä, terveisiä esim. Tekesille tai muille Suomen innovaatiopolitiikan toimijoille:
10: 2. Muuta palautetta?
10: 3. Tämä kysely oli: huono; hyvä

Appendix 6. Abbreviations

ALD	Atomic Layer Deposition
ALE	Atomic Layer Epitaxy
ERA	European Research Area
ERA-NET	Funding instrument within EU framework prorgammes
ESD	Electrostatic discharge
EU	European Union
FIMECC	Finnish Metals and Engineering Competence Cluster, one of the SHOKs
FM	Functional materials
GDP	Gross Domestic Product
H2020	Horizon 2020 – a 7-year frame programme of EU
HSE	Health, Safety and Environment
ICG	Inorganic Chemistry Group in UH
ICT	Information and Communication Technology
IoT	Internet of Things
LED	Light Emitting Diode
MATERA	Materials project within ERA-NET
MIT	Massachusetts Institute of Technology
MSE	Materials Science and Engineering
OPV	Organic Photovoltaic (Solar cell)
R&D	Research and Development
RDI	Research, Development and Innovation
SHOK	Strategic Centre for Science, Technology and Innovation
SM	Small and Medium
SME	Small and Medium Enterprise
TRL	Technology Readiness Level
TUTLI	Tutkimuksesta Liiketoimintaa; New knowledge and business from research ideas. A funding concept of Tekes
UH	University of Helsinki
UK	United Kingdom
UV	Ultraviolet
VTT	Technical Research Centre of Finland Ltd

Tekes' Reports in English

4/2016	Towards material excellence – Evaluation of Tekes' programmes on materials. Juhani Timonen, Markku Antikainen, Amit Das, Essi Sarlin and Jyrki Vuorinen. Evaluation Report. 59 p.
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4/2011	GIGA – Converging Networks programme 2005–2010. Final Report. 217 p.
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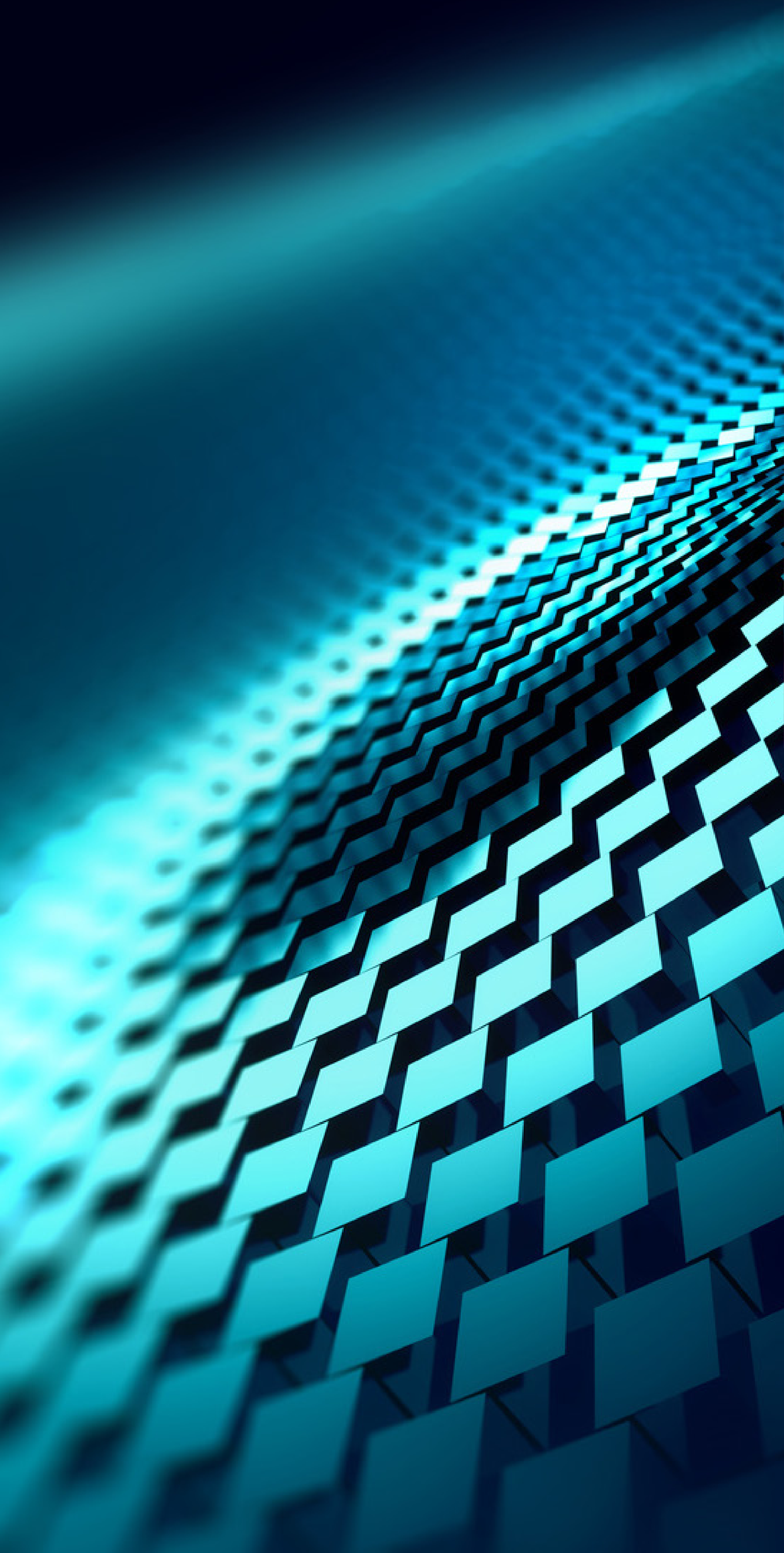

Porkkalankatu 1, P.O.Box 69
FI-00180 Helsinki
Tel. +358 2950 55000
www.tekes.fi

Further Information

Pekka Pesonen
Tekes
pekka.pesonen@tekes.fi