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Feasibility study for an Estonian Materials Technology Programme

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2011

Feasibility study for an Estonian Materials Technology Programme

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Foreword

Over the last few decades breakthrough technologies in materials science have triggered a wave of innovation and growth in a wide range of economic sectors while also playing an important role in addressing global challenges, such as energy, climate change and health care. Materials technologies can not only help the traditional industry achieve efficiency gains and climb the value chain through product and process innovation but as enabling technologies they also support other high-tech sectors, for instance ICT, biotechnology or space technologies.

In the Estonian research, development and innovation strategy ''Knowledge-Based Estonia 2007–2013", materials technology has been identified as a key technology that has the potential to significantly contribute to long-term economic growth of the country. Consequently, in the framework of implementing the strategy, the Ministry of Economic Affairs and Communications commissioned a feasibility study, financed from the EU structural funds. The purpose of the study was to map the competences and identify gaps and potential areas for growth in the field of materials technologies and materials science, taking into account both development and application, private sector and academia. Furthermore, drawn from the conclusions of the analysis, the study proposes various possible courses of action in the context of materials technology to help transform Estonian economy and encourage Estonian industry to become more innovative.

The study focuses on the analysis of high impact industries, such as metals and machinery, chemicals, textiles, forestry, plastics and construction materials, which are all simultaneously also of great importance to the Estonian economy both in terms of GDP and employment. Therefore, the sustainability of Estonia's economy, considering the current economic structure, will in large part depend on the competitiveness of these industries. The results of the study indicate that the aforementioned industries and the related high-tech sector are facing significant barriers to growth and may need additional efforts of support from the state to not only prosper but survive. The Ministry of Economic Affairs and Communications will tackle these issues in the upcoming years through the creation of a national programme, the content of which will be derived from the analysis and conclusions of the study and further dialogue with stakeholders.

Technology and Innovation Division
Ministry of Economic Affairs and Communications

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Introduction

The purpose of this study is to perform a thorough mapping of competences and opinions in the field of Estonian materials technology. The study was ordered by the Estonian Ministry of Economic Affairs and Communications and conducted by Spinverse Oy.

Previously, the public sector has lacked information to assess the level of competitiveness of the materials technology related industries and the relevance of current research and development to market needs. This has hindered the public sector from gaining a better understanding of the obstacles, challenges and opportunities that both public and private sector face.

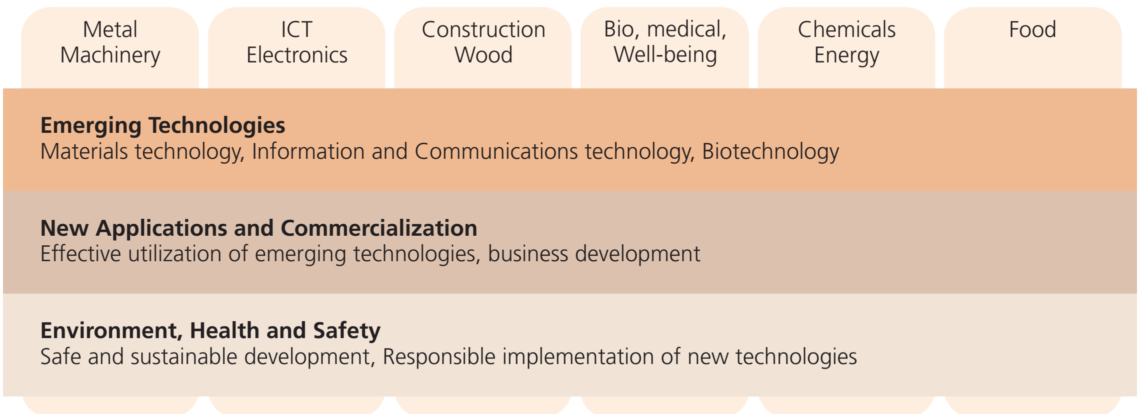
The main driver for studying the field of materials technology and national competences is the national "Knowledge-based Estonia" strategy, which aims to improve the national research environment, building a modern research and development infrastructure and supporting the environment of high-tech entrepreneurship in Estonia. As a concrete goal of the strategy, Estonian government aims to raise the total expenditure on research and development to 3% of GDP by 2014. It is obvious that the goal cannot only be met by means of money and therefore extensive measures must be taken in order to reach the goal.

This study takes a broad approach for finding out and mapping the key competences and success factors in Estonian materials science and technology. Relevant stakeholders to the study include universities and research organisations, well established private companies in manufacturing industries, small start-up companies and various public organisations supporting innovation activities in Estonia. The results of this study are based on extensive desk research (statistics, market studies, technology roadmaps etc.), patent and publication study of materials related research, interviews of key stakeholders in industry and academia as well as a questionnaire targeted at all materials technology research groups in Estonia.

Materials technology is by nature an enabling and interdisciplinary field of technology. It provides significant added value to different fields of industry enabling renewal and increased productivity of existing industrial sectors as well as development of new business areas based on high added value products and services. Materials technology is also strongly interlinked with the development of other strategic key technologies, information and communications technology and biotechnology, also named in the Estonian innovation strategy.

The focus of traditional materials science has long been different structural materials, e.g. metals, coatings, ceramics, plastics and composite structures. During the last few decades a vast number of new advanced materials and applications with extensively tailored material properties have gained ground. Examples include nanoparticles and nanostructured materials, supramolecular materials, bioactive and biocompatible materials, optically active materials and magnetic materials. In the future, it will become possible to manufacture a wide variety of intelligent materials that can, for instance, react to changes in the environment, be responsive and communicative.

Materials technology is an interdisciplinary cross-industry cutting enabling field



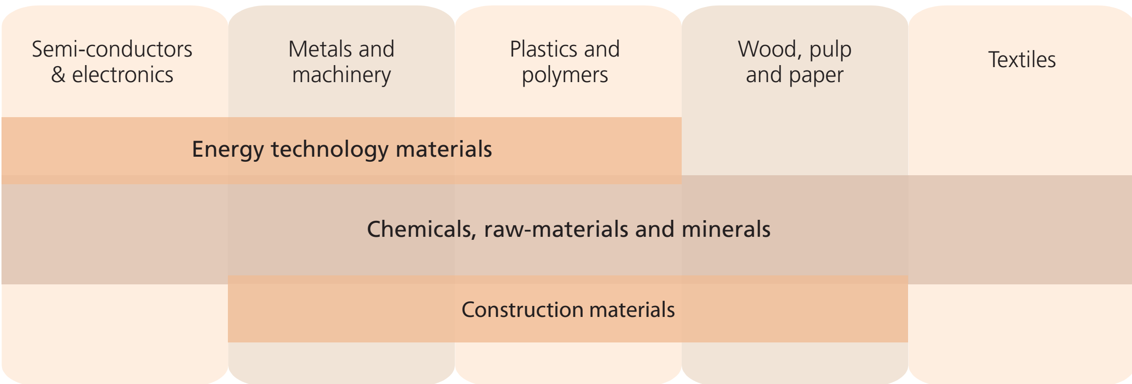
Benefits to society and environment

Materials technology in Estonia: private and public sector

Materials technologies are by nature very closely linked to almost all areas of industry, especially the manufacturing industry. Moreover, materials technologies are major application areas for natural sciences such as physics and chemistry as well as key areas in engineering disciplines such as machine building and civil engineering. The manufacturing industry in Estonia is in a very important position as it corresponds to more than 10% of the country's GDP[1] and most of its exports.

Six industry areas have been identified as most relevant in the context of the study and materials technology in general. The study is therefore focusing on metals and machinery, forest, chemicals, textiles and plastics industries as well as on construction materials. The selected industries can be briefly characterised as follows:

Advanced materials technologies, nanomaterials and functional materials



The manufacturing industry in Estonia consists mostly of small and medium size companies and focuses on subcontracting work even though a few larger companies with own product portfolio and R&D department exist in almost all industries.

The most important research and development institutions related to materials technology are University of Tartu and Tallinn University of Technology, both of which have very broad activities in e.g. physics, chemistry, materials sciences and biotechnology. Other players in the field include the National Institute of Chemical Physics and Biophysics, Estonian University of Life Sciences, Tallinn University, Tallinn University of Applied Sciences and Võrumaa Kutsehariduskeskus. Based on extensive desk research of patents, scientific publications and research projects as well as a number of interviews with university research group leaders and a research group questionnaire, the following key areas of Estonian research related to materials sciences can be identified:

- Advanced materials (e.g. photovoltaic materials, nanomaterials, rare-earth metals)
- Energy technologies (e.g. solar cells, supercapacitors, fuel cells, oil shale)
- Micro and nanoelectronics (solid state physics, ALD)
- Coatings and surface treatment (e.g. advanced coatings for metals industry)
- Measurement, modeling and processing technologies (e.g. computational chemistry, laser technology)

Materials technology education is mainly offered by University of Tartu and Tallinn University of Technology that also have a joint Graduate School of Materials Technology. The biggest challenge related to materials technology education is that there is still a very small amount of highly educated workforce in the manufacturing industries indicated by the table 1.

Table 1. Amount of Highly educated workforce in industry 2009

	Total	*Doctor's*	*Master's*	*Other*
Total	3122	274	688	2160
Manufacturing total	663	32	101	530
Scientific R&D	643	161	221	261

1 Estonian Statistical Yearbook 2010, http://www.stat.ee/publication-download-pdf?publication_id=19991

Advanced materials and technology transfer

An estimate of advanced materials technologies development stage and potential for Estonia is given in the Figure 1 along with relevant global market size estimates in 2015. Technologies mentioned on the right side of the figure under market maturation, market entry and prototype are the ones where quick wins and relatively rapid commercialization can be possible. This includes technologies such as:

- Market maturation
  - Rare-earth metals (Silmet), oil shale technology (VKG and others) and laser technology (laser companies), Atomic Force Microscopy (MikroMasch)
- Market entry
  - Non-woven filter media (EsfilTehno), fuel cells (Elcogen), high temperature power semiconductors (Clifton), supercapacitors (Skeleton Technologies), thin film solar cells (Crystalsol), electroactive polymers (fits.me), electro-optical coatings (AndreseKlaas), industrial biotechnology (NordBioChem), e-paper (Visitret Displays)

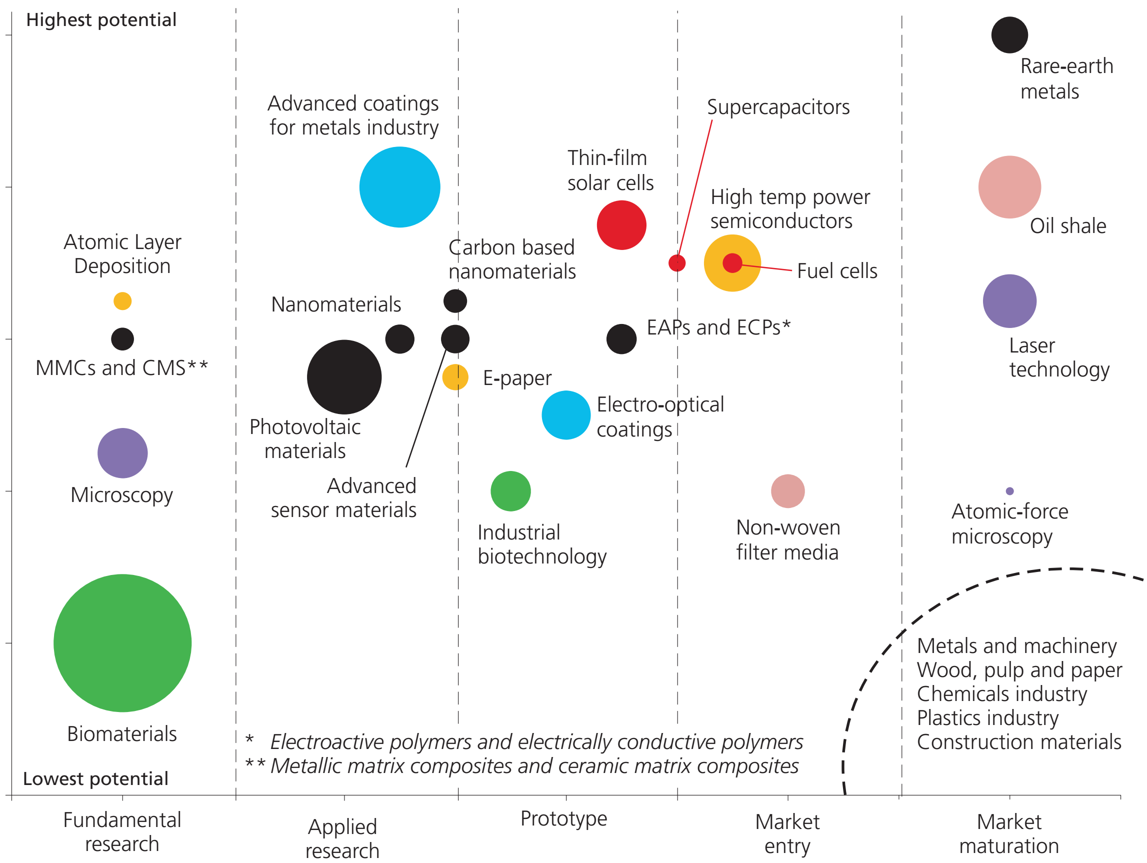


Figure 1. Characterisation of the selected industry areas in relation to materials technology

The circle size indicates the estimated global market size around 2015. The y-axis represents a relative technological and business potential of selected technologies. Technologies with highest estimated potential have both strong university and industry support (e.g. rare-earth metals and oil shale). Technologies in the middle section typically lack industry support (e.g. thin film solar cells where only one Estonian company exists). Technologies in the lower section lack Estonian wide R&D activities and typically only one party capable of developing the technology exists. Colors in the figure symbolise those areas shown in Figure 12.

Other identified technologies are mostly being developed by universities and they are more heavily materials oriented. Interesting materials technologies in this sense include advanced coatings for metals industry, photovoltaics materials in general, carbon based nanomaterials and other nanomaterials as well as materials for sensors, atomic layer deposition and various new composites for metals industry use. This group of technologies is the main target for technology transfer activities towards both Estonian companies and global players.

International comparison

As the field of materials technology is very vast, it is difficult to give an exact assessment about the international competitiveness of Estonian research and development in specific fields. All technologies identified in Figure 1 may very well turn out to be commercial successes and the deciding factor is most likely something other than pure technological excellence.

Estonian researchers at universities as well as many companies have good international connections. The largest area that needs to be developed is international technology transfer and scouting, meaning in practice communicating about Estonian innovations more effectively abroad as well as searching more actively for the best available technologies from foreign countries to be implemented in the Estonian industry.

As the connections of top Estonian researchers to top researchers internationally in countries such as the USA and Germany are already very good, this study includes a brief overview of national materials technology programmes and other activities in the Baltic Sea area and the rest of Europe. Based on the findings, all Nordic and Baltic countries have already established a "programme" or similar actions in materials technology and the focus areas are very similar between different countries. Therefore, Estonia should at first focus on increasing collaboration with the neighboring countries and other European partners (by e.g. FP7 projects) in order to benefit from similar research initiatives being already done.

Conclusions

In summary, the study maps the field of Estonian materials technologies including key players among universities, financiers, industrial companies etc. A notable share of Estonian university research and development work in physics, chemistry and materials sciences is related to materials technologies applicable in various industries. The most relevant industries identified by this study are metals and machinery, forest, chemical, plastics, construction materials and textiles industries.

Based on the findings in the study, the following conclusions and recommendations can be made:

- There is a good set of materials technologies in Estonia in all phases of the commercialization pipeline. The different phases face very different challenges and thus need very different support actions
  - Technologies in mature markets need a more educated workforce in companies and more risk taking attitude in starting R&D projects and increasing the added value of products
  - Technologies close to market entry need public or private funding for establishing production as well as business knowledge to enter the global market
  - Technologies in R&D phase, typically at universities, need to be developed in collaboration with industrial players to guarantee practical relevance and future commercialization capabilities

- In most cases, there is a large gap between industry needs and university research and education
  - Universities should listen to industry more when planning research and education
  - Students should be encouraged more to take practical training in the industry during their studies (B.Sc., M.Sc. and D.Sc/Ph.D.)
  - Industry should hire more educated workforce, increase the amount of R&D and start doing more risky research projects in collaboration with universities

- All in all, target-oriented collaboration needs to be increased on all levels both nationally and internationally
  - Companies & companies
  - Universities & universities (including development centres)
  - Companies & universities with EU and international projects

- Different kind of materials technology programmes and support actions that could best support the competitiveness and economic growth in Estonia are discussed
  - There are already many initiatives ongoing in Estonia: 1) technology programmes in energy technologies and biotechnology, 2) competence centres, especially the Estonian Nanotechnology Competence Centre, 3) the cluster development programme
  - All of the abovementioned work in highly intersecting areas is also related to materials technologies

- Four different options for a programme are discussed in the recommendations section
  - Industry driven small R&D programme on materials technology with 5-10 key players.
  - Applied research Materials Technology programme (where each project has to have industrial partners)
  - Programme to distribute all funding given to both fundamental research and applied research in materials technology development
  - Supporting actions but no programme to distribute funding

- We recommend a combination of the above mentioned examples: A Programme with strong support actions to prepare for future funding "Materials R&D to business"

1 Introduction

1.1 Background

The purpose of this study and report is to perform a thorough mapping of competences and opinions in the field of Estonian materials technology. The work was ordered by the Estonian Ministry of Economic Affairs and Communication and the study was conducted by Spinverse Oy.

The main driver for studying the field of materials technology and national competences is the national "Knowledge-based Estonia" strategy, which aims to improve the national research environment, building a modern research and development infrastructure and supporting the environment of high-tech entrepreneurship in Estonia. As a concrete goal of the strategy, Estonian government targets to raise the total expenditure on research and development to 3% of GDP by 2014. It is obvious that the goal cannot only be met by means of money and therefore extensive measures must be taken in order to reach the goal.

Among other measures, Estonia has been and is bringing up national research and technology programmes for 1) developing key technologies, 2) for solving socio-economic problems and 3) ensuring and promoting the sustainability of research related to Estonian national culture, language, history etc. As part of the "Knowledge-based Estonia" strategy, three key technology areas have been selected: 1) information and communication technologies, 2) biotechnologies and 3) materials technologies. At the time of writing this report, two technology programmes in the areas of energy technologies and biotechnology have already been established.

This study takes a broad approach to find out and map the key competences and success factors in Estonian materials science and technology. Relevant stakeholders to the study include universities and research organisations, well established private companies in manufacturing industries, small start-up companies and various public organisations supporting innovation activities in Estonia. The results of this study are based on extensive desk research (statistics, market studies, technology roadmaps etc.), patent and publication study of materials related research, interviews of key stakeholders in industry and academia as well as a questionnaire targeted at all materials technology research groups in Estonia.

The study describes all materials technology research conducted in Estonian universities, public support e.g. in terms of funding of materials technology, national programmes related to materials technology, venture capital status in the area, different fields of industry related to materials technologies including an analysis of Estonian strengths and weaknesses as well as case studies of 8 interesting Estonian companies. The company cases where chosen based on the frequency that they were mentioned in earlier interviews and/or the number of patents they have. Companies were selected from different industry sectors with an emphasis on young innovative companies. Additionally, collaboration between universities and companies will be discussed in terms of technology transfer and education.

The status of Estonian materials technologies and advanced materials is compared to the leading international players and countries in a similar position. Finally, several scenarios of establishing a Materials technology programme in Estonia are considered along with concrete suggestions of what kind of actions would best improve the country's competitive position globally.

1.2 Applied methodology

Due to the big size of the field of materials technology and advanced materials, the selection of the research methodology for this study is very broad. It is essential to capture relevant information from various stakeholders including leaders in universities, industry and public sector. Materials technology is somewhat present in the majority of university level research of physics, chemistry and engineering and materials play a key role in all manufacturing industries.

In order to capture all key opportunities and challenges for Estonia in the field of materials technology and advanced materials, the study was divided into three phases: 1) preliminary research, 2) main study and 3) reporting and dissemination. The study was conducted between October 2010 and March 2011. For assessment and comparison of different fields of research and industry, an extensive amount of both quantitative and qualitative data was collected during the process.

Methodology for data collection included:

- Interviews with key people in industry, academia and public sector (Table 2)
- Extensive desk research on global trends in materials technology and advanced materials in various sectors
- Patent, publication and research project analysis of research results published by Estonian authors
  - Patent data provided by the European Patent Office (EPO)
  - Publication data provided by Archimedes Foundation and Estonian Research Information System (ETIS)
  - Project data provided by Archimedes Foundation and Estonian Research Information System (ETIS)
- A questionnaire sent to university research group leaders in materials science and technology and related fields
- A workshop for disseminating preliminary results and discussion of the future of Estonian materials technology

Timeline for the study:

- Preliminary research (October-November 2010)
  - Desk research, patent analysis, project analysis and publication analysis
  - 5 preliminary interviews
- Main study (November 2010 – March 2011)
  - Desk research and analysis continued
  - Questionnaire to university research group leaders in materials technology and similar
  - Several interviews in industry and academia
  - Intermediate report in December
- Reporting and dissemination
  - Workshop for preliminary dissemination, validation and discussion in March 2011. Report was sent to 202 emails for review. Responses were got from 15 persons.
  - Final report
  - Dissemination

Table 2. List of interviewed people during the study

Name	*Position*	*Date*
Olavi Otepalu	Manager, National Biotechnology Programme, Enterprise Estonia	October 2010
Runar Törnqvist	Director, UMK Centre for New Materials, Aalto University	October 2010
Priit Kulu	Professor, Department of Materials Engineering, Tallinn University of Technology	October 2010
Pille-Liis Kello	Director, Enterprise Capability Division, Enterprise Estonia	October 2010
Enn Lust	Professor, Institute of Chemistry, University of Tartu	October 2010
Erik Puura	Director, Institute of Technology, University of Tartu	October 2010
Ilmar Kink	Director, Estonian Nanotechnology Competence Centre	October 2010
Jari Mieskonen	Managing Partner, Conor Venture Partners / Member of the supervisory board, Connect Estonia	October 2010
Jüri Riives	Chairman of the board, Innovative Manufacturing Engineering Systems Competence Centre (IMECC)	November 2010
Enn Õunpuu	CEO, Elcogen	November 2010
Anti Viikna, Andres Krumme	Professor, Department of Polymer Materials, Tallinn University of Technology	November 2010
Margus Lopp	Professor, Department of Chemistry, Tallinn University of Technology	November 2010
Enn Mellikov	Professor, Department of Materials Science, Tallinn University of Technology	November 2010
Metals industry representatives	Estonian Metals Industry Roundtable, Enterprise Estonia	December 2010
Mihkel Susi	Managing director, Estonian Plastics Association	December 2010

Name	*Position*	*Date*
Jaanus Sahk	Manager, National Energytechnology Programme, Enterprise Estonia	January 2011
Andres Soojarv	Owner and CEO, Eksamo (Pioneer Engineering Group)	January 2011
Pavel Kudinsky	CEO, MikroMasch	January 2011
Gerd Veelma	CEO, Andrese Klaas	January 2011
Ott Otsmann	Managing Director, Estonian Forest and Wood Industries Association	January 2011
Märt Riistop	Deputy Managing Director, Estonian Forest and Wood Industries Association	January 2011
David O'Brock	CEO, Silmet	February 2011
Araik Karapetjan	CEO, Esfil Tehno	February 2011
Lauri Leitorp	R&D Manager, Krimelte	February 2011
Alvo Aabloo	Professor, Insititute of Technology, University of Tartu	February 2011
Anti Perkson,Mati Arulepp,Vello Madiberk,Jaan Leis,Taavi Madiberk	Skeleton Technologies	February 2011
Mati Karelson	Professor, Institute of Chemistry, University of Tartu	February 2011
Sven Lange	R&D Project Manager, Estiko Plastar	February 2011
Vambola Kolbakov	Chairman of the Supervisory Board, NordBioChem	February 2011
Pille Meier	Professor, Tallinn University of Technology	February 2011

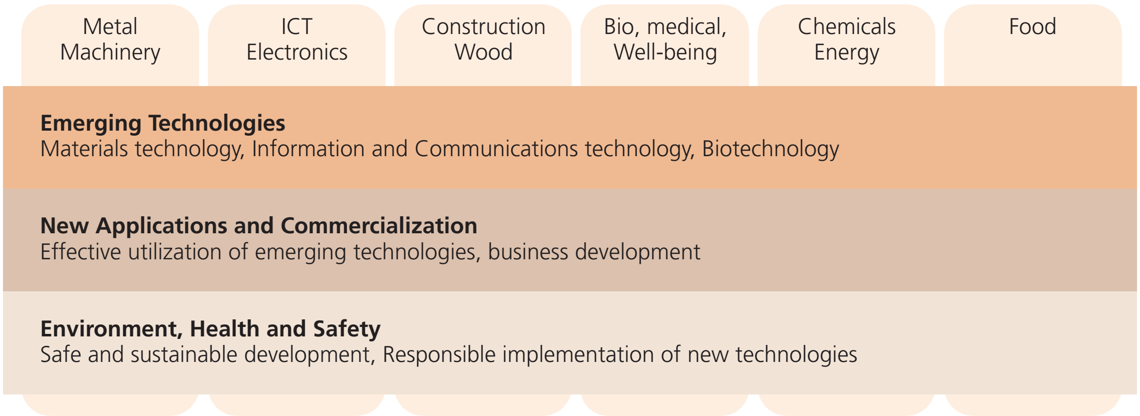
In addition to the interviews, a workshop for preliminary presentation and discussion of the results was held in March with the following participants:

Name	*Position*
Laura Kauhanen	Consultant, Project Manager, Spinverse
Tommi Ristinen	Analyst, Spinverse
Taavi Madiberk	CEO, Skeleton Technologies
Araik Karapetjan	CEO, Esfil Tehno
Vambola Kisand	University of Tartu
Ilmar Kink	Director, Estonian Nanotechnology Competence Centre
Sven Lange	R&D Manager, Estiko Plastar
Renno Veinthal	Director, Department of Materials Engineering, Tallinn University of Technology
Indrek Reimand	Ministry of Education and Research
Tarvo Tamm	Connect Estonia
Aarne Leisalu	Laser Diagnostic Instruments
Priit Tamm	SA Archimedes
Madli Kaju	Ministry of Economic Affairs and Communication
Kaie Nurmik	Ministry of Economic Affairs and Communication
Tea Danilov	Ministry of Economic Affairs and Communication
Jarmo Tuisk	Ministry of Economic Affairs and Communication
Jane Paju	R&D Manager, Silmet

1.3 What is Materials Technology

Materials technology is by nature an enabling and interdisciplinary field of technology. It provides significant added value to different fields of industry enabling renewal and increased productivity of existing industrial fields as well as development of new business areas based on high added value products and services. Materials technology is also strongly interlinked with the development of the other strategic key technologies, information and communications technology and biotechnology, also named in the Estonian innovation strategy.

Materials technology is an interdisciplinary cross-industry cutting enabling field



Benefits to society and environment

The field of materials science and technology has become extremely large and diverse during the last few decades. The new concepts gaining ground require novel interdisciplinary approaches which combine knowledge from many different fields of science and develop new methods in order to understand and create new business opportunities.

Due to its interdisciplinary nature, it is difficult to define materials science and technology precisely. Key factors in the definition are the micro- and nanostructure of the material. Other important elements include the composition of the material, its fabrication and processing, as well as its properties and performance. These factors are closely interlinked and changing one of them always affects some of the others. The purpose of materials science is to understand and control these factors and interactions between them and ultimately apply this knowledge.

The focus of traditional materials science has long been different construction materials, e.g. metals, coatings, ceramics, plastics and composite structures. During the last few decades a vast number of new advanced materials and applications with extensively tailored material properties have gained ground. Examples include nanoparticles and nanostructured materials, supramolecular materials, bioactive and biocompatible materials, optically active materials and magnetic materials. In the future, it will become possible to manufacture a wide variety of intelligent materials that can, for instance, react to changes in the environment, be responsive and communicative.

There are several different approaches for classifying the field of materials science and technology. A suitable classification methodology was developed for the purposes of this study. In this approach, we identified the key Estonian industry sectors from the viewpoint of materials technology and linked these with the classification of materials, as well as different processing and manufacturing methods.

In the analysis, it is crucial to understand the whole value chain linking the properties and composition of the materials, fabrication and manufacturing methods to applications of materials technology and their markets. In addition to the national competence strongholds, the analysis has to identify parts of the value chain. This information is essential for defining the focus areas and structure of the national research and development programme.

To conclude, the study looks mostly at materials technology from the industry point of view. World-wide materials technology trends have also been mapped based on industry sectors. One additional industry has been added in addition to the traditional ones: high-tech industry in the technology transfer section. With this addition we address the new opportunities that materials technology could enable.

2 Materials technology in Estonia

2.1 Overview

Materials technologies are by nature very closely linked to almost all areas of industry, especially the manufacturing industry. Moreover, materials technologies are major application areas for natural sciences such as physics and chemistry as well as a key area in engineering disciplines such as machine building and civil engineering. The manufacturing industry in Estonia is in a very important position as it corresponds to more than 10% of the country's GDP[2] and a major share of its exports. The most important areas of Estonian manufacturing industry include:

- Food and beverages
- Metal products, basic metals, machinery and production of transportation equipment
- Wood, wood products, pulp and paper
- Electrical equipment
- Chemicals and chemical products
- Textiles and leather
- Non-metallic mineral products
- Furniture
- Plastics and rubber

Six of the listed industry areas have been identified as most relevant regarding the study and materials technology in general. The study is therefore focusing on metals and machinery, forest, chemicals, textiles and plastics industries as well as on construction materials. Other sectors including food, electrical equipment and furniture industries are utilising materials and materials technologies but their main products are not materials. The electrical equipment industry is very strongly focused on subcontracted manufacturing of electrical equipment and the effect of materials technology is small. A couple of interesting small companies in the area have been included under the sector on high-tech companies. The selected industries can be briefly characterised as follows:

- Metals and machinery industry
  - Consists mainly of small subcontracting companies, a few larger companies exist
- Forest industry
  - Largest companies are typically subsidiaries of Nordic and other foreign corporations
- Chemicals industry
  - Large emphasis on production of oil shale and rare earth metals and their compounds
- Textiles and leather
  - Very SME oriented, mostly clothing production
- Construction materials
  - Wide variety of producers for several sectors (cement and concrete, glass, etc.)
- Plastics industry
  - Mainly subcontracting companies

Figure 2 demonstrates how materials technology relates to all the different sections discussed. Section 2.4 discusses in more detail each industry sector.

2 Estonian Statistical Yearbook 2010, http://www.stat.ee/publication-download-pdf?publication_id=19991

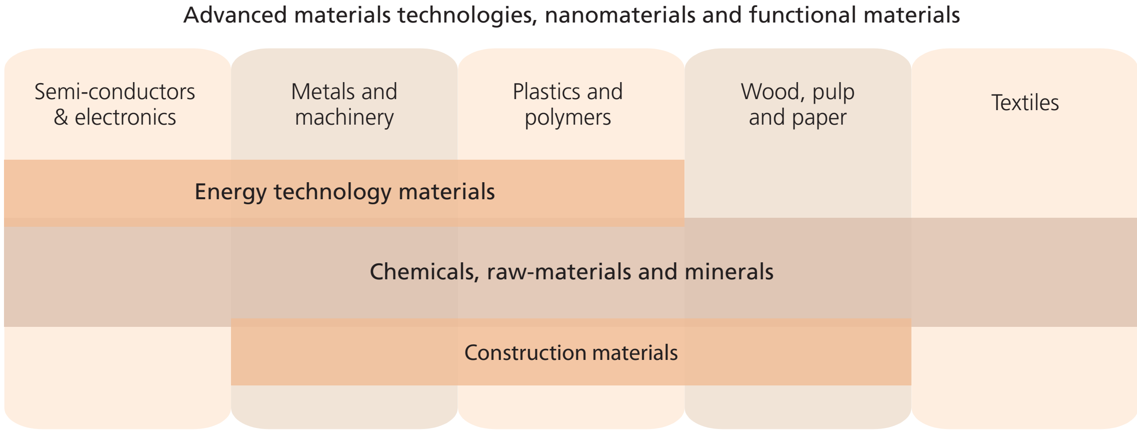


Figure 2. How materials technology relates to all the industry sectors discussed in the report

Materials technologies value chain and research can be divided in a few main parts with close linkage to industry (See Figure 3). The value chain starts with raw materials and their production, continues then to production of intermediate materials and finally their applications to various real world problems. From raw materials point of view, Estonia has several important natural resources locally available but on the other hand lacks natural resources and production of many other important resources. Mineral resources in Estonia include oil shale and various minerals suitable for construction materials use (such as clay, limestone, dolomite and sand). In the Estonian crust, significant mineral occurrences of Uranium and rare earth elements have been discovered. Similarly to other Northern European countries, a large area of Estonia is covered by forest and therefore, there is plenty of wood to be utilised by the forest industry.

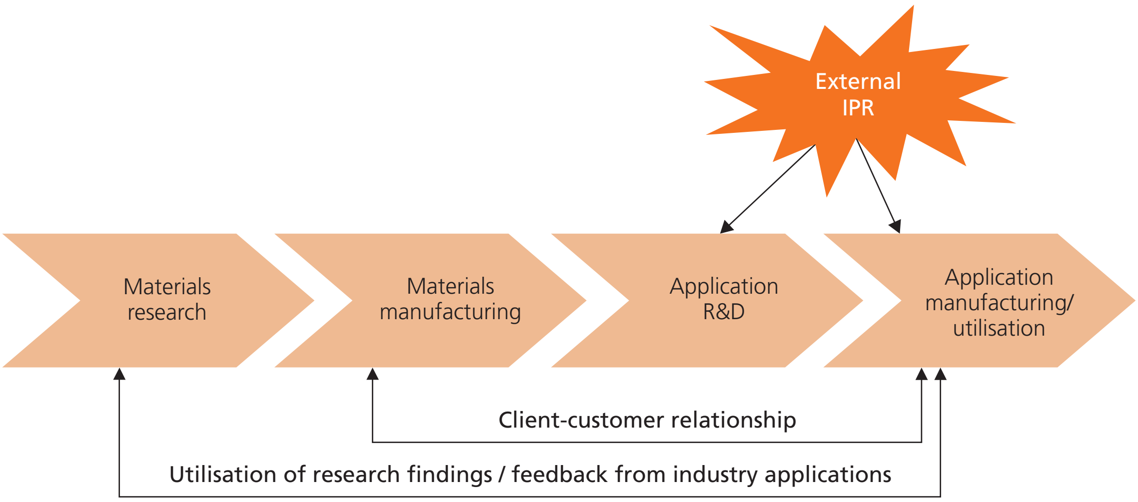


Figure 3. Materials technology value chain can be roughly divided in four phases

The chain starts in materials research and manufacturing. Application oriented R&D takes benefit of novel advanced materials either from local R&D work or by obtaining IPR from third parties. In application oriented business, it is crucial to have feedback from application manufacturers to researchers in order to get good and practical use cases for researchers to solve.

To large extent, the Estonian industry is currently utilising the abovementioned natural resources. There is significant production of oil shale and construction materials and the forest industry is utilising their natural resources. Rare earth elements are being produced by the company Silmet AS. Apart from these, raw materials needed for other applications need to be imported. Most notably this includes metals, chemicals and plastics.

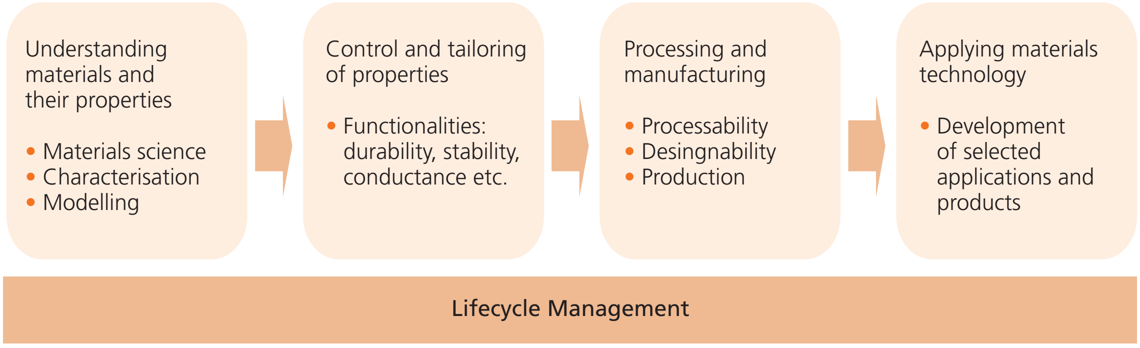


Figure 4. Materials technology and development

Materials Technology and development can be divided into four sectors according to Figure 4. Life-cycle management of both the material itself and the products being developed is an important factor that has to be taken into account throughout the development process.

The end-of-life products and materials recycling sector is very well developed in Estonia. Estonia has well functioning collection systems for different type of wastes, which are organized by producers' responsibility organizations. Interesting organizations in this area include:

- **Eesti Pandipakend OÜ:** The collected packaging materials: aluminum cans, glass and plastic bottles are sold as secondary raw material back to recycling industry.
- **Pakendiringlus MTÜ (non-profit):** Mixed packaging waste collection. The collected material is sold as a secondary raw material back to recycling industry
- **Eesti Taaskasutusorganisatsioon MTÜ (non-profit)** is representing the „green dot" packaging collection system in Estonia and mainly collects mixed packaging waste.
- **MTÜ Eesti Rehviliit** is responsible for tires collection.
- **Kuusakoski OY (Finnish):** End-of-life vehicles collection and electronics recycling.
- **AS Ecometal** retreatment of used car batteries with lead, 20 000 tons annually. Rotating furnace for 20 tons of waste is for lead melting and gives a product – lead.
- **Plastitehase AS (bankrupt):** The company collected metallic and plastic scrap and sold them to metals and plastics industry, respectively.

From the university side, the Department of Materials Engineering at the Tallinn University of Technology has several cooperation projects with recycling industry such as:

- Recycling of composite plastics
  - Acrylic plastics with fiberglass scrap from bathtub and shower cabin producers (AS Balteco, OÜ Aquator, OÜ Wellspa). These companies have done cooperation projects on recycling of composite plastics.
- Desintegrator technology that enables to produce powders from cermets and hardmetals, whish are the wastes from tooling industry, with partners such as Sumar AS.
- PCB (printed circuit board) recycling in cooperation with Weerec AS.

In general materials technology as can be seen from Figure 5, University of Tartu and Tallinn University of Technology have received most of the project funding directed to materials science and technology research in Estonia[3] and thus, most of the activities of the study have been focused on these two institutes. The project funding, though, represents only a small portion of all funding to the universities but based on extensive desk research, interviews and inspection of scientific publications, the picture remains the same.

3 Natural sciences and engineering project data from Archimedes foundation, filtered by Spinverse

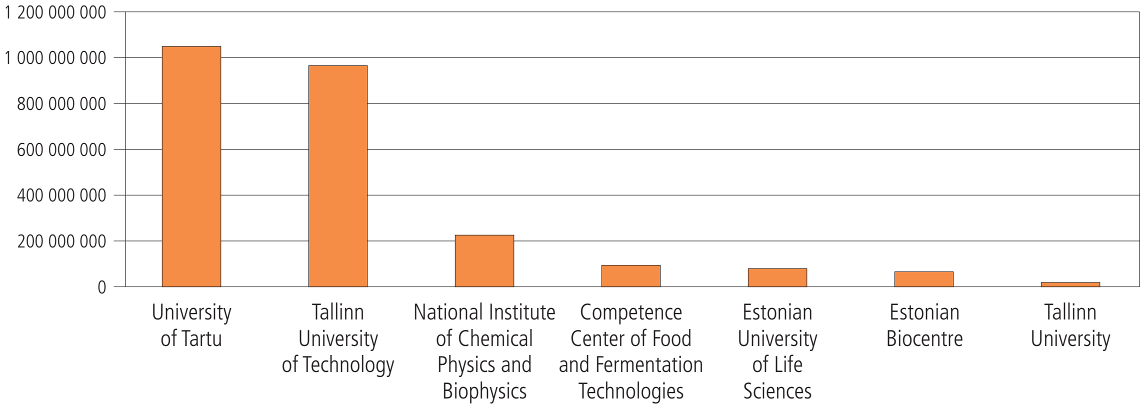


Figure 5. University of Tartu and Tallinn University of Technology are receiving most of the research project funding in materials science and technology (note: relative)

2.2 Key organisations

2.2.1 Universities and research organisations

University of Tartu

University of Tartu (UT) is one of the two large Estonian universities doing materials technology research and teaching. The university has in total 17 500 students in 9 faculties. The materials technology related activities in the University of Tartu are situated in the Faculty of Science and Technology (LOTE), which consists of 6 institutes, approximately 1000 employees and 2000 students[4]. Most relevant institutes of the LOTE faculty regarding materials science and technology are the Institute of Chemistry, Institute of Physics and Institute of Technology.

- Institute of Chemistry[5]
  - Chair of Applied Electrochemistry
  - Chair of Bioorganic Chemistry
  - Chair of Colloid and Environmental Chemistry
  - Chair of Inorganic Chemistry
  - Chair of Molecular Technology
  - Chair of Organic Chemistry
  - Chair of Physical Chemistry

- Institute of Physics[6]
  - Department of Materials Sciences
    - Laboratory of Physics of Ionic Crystals
    - Laboratory of Thin Film Technology
    - Laboratory of Physics of Nanostructures
    - Laboratory of X-Ray Spectroscopy
    - Laboratory of Laser Spectroscopy
  - Department of Experimental Physics
    - Laboratory of Laser Techniques
  - Department of Theoretical Physics
    - Laboratory of Solid State Physics
  - Department of Bio- and Environmental Physics
    - Laboratory of Biophysics

- Institute of Technology[7]
  - Material and chemical technology
    - Section of Organic Chemistry
    - Intelligent Materials and Systems Lab

4 http://www.ut.ee/804172
5 http://www.chem.ut.ee/index.aw/set_lang_id=2
6 http://www.fi.ut.ee/292586
7 http://www.tuit.ut.ee/index.aw/set_lang_id=2

Tallinn University of Technology

Tallinn University of Technology (TUT) is the other large Estonian university doing materials technology research and teaching. The university is organized into 8 faculties with 33 departments, 9 faculty research centres, and 10 affiliated institutions. In total, TUT employs a staff of approximately 2000 people, half of which belong to the academic staff. The university gives teaching to almost 14000 students (6500 bachelor level, 1300 engineering, 3250 masters, 700 doctoral, plus applied sciences and Open University students).[8] The three faculties most relevant for materials science and technology are the Faculty of Civil Engineering, Faculty of Chemical and Materials Technology and Faculty of Mechanical Engineering. Some materials related activities are also present in the Faculty of Power Engineering, Faculty of Information Technology and the Faculty of Science.[9]

- Faculty of Civil Engineering
  - Department of Structural Design
  - Department of Building Production
  - Department of Mechanics

- Faculty of Chemical and Materials Technology
  - Department of Chemical Engineering
  - Department of Materials Science
  - Department of Polymer Materials
  - Department of Food Processing
  - Centre for Materials Research
  - Laboratory of Inorganic Materials

- Faculty of Mechanical Engineering
  - Department of Machinery
  - Department of Materials Engineering
  - Department of Mechatronics
  - Laboratory of Mechanical Testing and Metrology

- Faculty of Power Engineering
  - Department of Mining

- Faculty of Information Technology
  - Department of Electronics
  - Centre for Biorobotics

- Faculty of Science
  - Department of Physics
  - Department of Chemistry
  - Centre for Biology of Integrated Systems

- Institute of Cybernetics

National Institute of Chemical Physics and Biophysics

The National Institute of Chemical Physics and Biophysics (KBFI) is a research institution that carries out fundamental and applied research in materials science, gene- and biotechnology, environmental technology and computer science[10]. The institute is organized under sections of Chemical Physics, Molecular Genetics, Bioorganic Chemistry and Bioenergetics.

The institute employs an academic staff of approximately 100 people with an annual budget of 51,5 M EEK (3,2 €) in 2009. Majority of the staff (~60) is working under the chemical physics laboratory.

8 http://www.ttu.ee/tallinn-university-of-technology/about-tut/facts-and-figures/
9 http://www.ttu.ee/faculties-institutes-colleges
10 http://www.kbfi.ee/?id=56&lang=eng

Estonian University of Life Sciences

The Estonian University of Life Sciences, located in Tartu, is the main university in the country focusing on sustainable development of natural resources as well as preservation of heritage and habitat.[11] The university is conducting research and development in fields such as agriculture, forestry, animal science, veterinary science, rural life and economy, food science and environmentally friendly technologies.

The research areas related to materials technology include forest and wood processing technology, energetic and rural building, which are performed in the Institute of Forestry and Rural Engineering, Institute of Technology and College of Technology.

Most of the projects of the Estonian University of Life Sciences considered for this study were dealing with biotechnology, energetics and food sciences and thus the university's role in the field of materials science in the country is rather small.

- Institute of Forestry and Rural Engineering
  - Department of Rural Building
  - Department of Forest Industry

- Institute of Technology
  - Farm and Production Engineering Division
  - Department of Applied Physics
  - Department of Energy

- Tartu Technical College
  - Biotechnical systems
  - Technotronics

Tallinn University

Tallinn University is mostly related to other subjects than materials technology. Some relevant activities can be found in the Department of Natural Sciences under the Institute of Mathematical and Natural Sciences. Materials science related research deals with stochastic processes at dense plasma interaction with materials.

Tallinn University of Applied Sciences

Tallinn University of Applied sciences is a higher educational institution providing professional higher educational studies in the field of engineering.[12] The university consists of five faculties that offer education in several different fields. The most relevant activities regarding materials technology are in the Faculty of Clothing and Textile, Faculty of Construction and Faculty of Mechanics.

- Faculty of Clothing and Textile
  - Technical Design and Technology of Apparel
  - Resource Management in the Field of Clothing and Textiles

- Faculty of Construction
  - Civil Engineering
  - Road Construction

- Faculty of Mechanics
  - Mechanical Engineering
  - Engineering Materials and Marketing

11 http://www.emu.ee/en/general-information/concept/
12 http://www.tktk.ee/?id=1693

2.2.2 Funding organisations

Three key funding agencies can be identified. **Enterprise Estonia (EAS)** is one of the largest institutions in Estonia supporting entrepreneurship and technological innovation. Its total budget for 2010 was 3500 million EEK which is more than 210 million EUR. Enterprise Estonia supports technology companies by giving e.g. guidance and support and project funding and hosting several different programmes to support innovation activities on different fronts. A major share of EAS innovation programmes are currently being co-financed through the European Regional Development Funds: e.g. the competence centre programme and the cluster development programme.

The Estonian Science Foundation (ETF), was established in 1990 by the Estonian Government. It is an expert research-funding organisation and its main goal is to support the most promising research initiatives in all fields of basic and applied research. It awards peer-reviewed research grants to individuals and research groups on a competitive basis from state budget appropriations.

The Archimedes Foundation is an independent body established in 1997 by the Estonian government. The task of the foundation is to coordinate and implement different international and national programmes and projects in the field of training, education, research, technological development and innovation.

2.2.3 Relevant Programmes, competence centres and cluster programmes

Technology programmes

Initiated by the Ministry of Economic Affairs and Communication and the Ministry of education in cooperation with other ministries, Estonia is establishing national research and development programmes. The "Knowledge-based Estonia" strategy identified three key technologies for Estonia 1) information and communications technologies, 2) biotechnologies and 3) materials technologies. At the time of writing this report, two technology programmes in the areas of energy technologies and biotechnology have already been established. Several others are in preparation. All programs are tailor-made to the needs of the sectors in question. The two existing programmes are run by managers employed by Enterprise Estonia. Both programmes are cross-cutting with materials technology.

The **Estonian Energy technology** programme is the first national R&D programme initiated in Estonia. It was started in 2007. According to the programme manager, the programme was originally intended as a separate unit but this turned out to be impossible to implement. The change in plan postponed the real starting date of the programme. Today the programme is run under a steering committee of related ministries and implementing agencies. The programme manager works at Enterprise Estonia, which also takes part in the steering committee. According to the Programme document[13] the programme has four tasks:

- Select priority areas for science and development
- Put up an innovation system in the area
- Manage international relations
- Manage state, university and company relations

The programme acts as an umbrella organisation for all funding institutions giving money to energy technology development in Estonia and helps select funding distributions. In total the programme is to distribute 500Mekr over a seven year period. The programme has three focus areas: oil shale, renewable energy and nuclear energy. Nuclear energy does not involve research and development but dissemination of future activities in the country. So far the programme has focused on distributing funding with its first funding round opening in 2010. The programme has also built the programme's managerial structure, with a steering group, advisory committee and 14 technology focus areas. In 2011 the programme opens another funding call, conducts a study in collaboration with Eesti Elektritööstuse Liit on the workforce in the energy sector (because so many are retiring), and a future market analysis which was deemed necessary due to changing markets. The programme manager believes that the success of a technology program in Estonia comes from the extent of involvement of the industry.

The programme has strong connections to materials technology as very many of the materials technologies developed in Estonia are related to the clean-tech energy industry.

13 EESTI ENERGIATEHNOLOOGIA PROGRAMM plan/Jaanus Sahk Program Manager, EAS

The **Estonian Biotechnology programme** is the other of the two cross cutting programmes. The programme plan identifies key areas of interest in the country. The biotechnology industry sector in Estonia is the youngest and consists of a large amount of innovative small enterprises. Most of them are not self-sufficient yet but rely on governmental and investment funding. Due to this fact the programme focuses on helping the enterprises and researchers understand business models better.

The biotechnology programme has connections to materials technology in the areas of biomaterials and computational chemistry.

Competence Centres

The competence centres are aimed to be structured, long term RTDI collaborations in strategic important areas between academia, industry and the public sector. They are meant to bridge the gap between scientific and economic innovation by providing a collective environment for key stakeholders and creating a sufficient critical mass for innovation. Currently there are 8 competence centres established in Estonia of which two have larger relevance for materials technology: Estonian Nanotechnology Competence Centre (ENCC) and Innovative Manufacturing Engineering Systems Competence Centre (IMECC). The competence centre programme was initiated in 2004 and current centres are receiving public support at least until 2013. A feasibility study conducted for the preparation of the competence centres and their mid-term evaluation has also been finished.[14] According to the evaluation, the programme has already been running for a few years and some results have been created by different partners. Nevertheless, most of the competence centres are working with very science intensive fields and thus, it will still take time before their real success in increasing innovation can be assessed.

Estonian Nanotechnology Competence Centre is a consortium of industrial and science partners established to conduct common research in the field of nanotechnology, results of which will be bases for development of new products and/or new research of consortium partners[15]. It has currently 6 shareholders and in total 13 partners, including Tartu University Institute of Physics which is a key stakeholder concerning nanotechnology research in Estonia. The centre has two target research areas: 1) functional nanomaterials for industry use, where the research findings of Tartu University and the competence centre are being transferred to the industry and 2) nanosensors, where the aim is to develop new nanostructural sensor materials and layers to enable higher sensitivity sensors.[16]

Objectives of the Innovative Manufacturing Engineering Systems Competence Centre include improving the competitiveness of Estonian engineering industry and developing cultural, ethical, and social values based on increasing integrated industrial use of new technologies. The technologies include optimal product life-cycle management, e- Manufacturing, emerging manufacturing technologies and process automation techniques. In one program, also new forms of self-organizing systems with online monitoring and diagnostics are tested to gain a competitive advantage. IMECC aims to ensure economic success in the global economy, to raise the effective use of knowledge in product engineering and manufacturing planning for small series production in distributed and networked organizations of Estonian engineering industry. [17] Currently IMECC runs three programmes. IMECC consists of 14 industrial partners and one university partner. Most of the research is done at the university. During the time of writing the report IMECC has a focus group of projects in robot welding, which has some materials technology relevance but the centre has not yet funded any pure materials technology projects.

Cluster development programme

The cluster development programme is aimed at Estonian company consortia to increase the added value of cluster companies, their sales and exports as well as to promote cooperation between the stakeholders of the cluster: companies in the sector, with different sectors and also research establishments. Three of the existing clusters have been identified as somewhat relevant to materials technology: the timber construction cluster[18], the Estonian ECO Cluster[19] and the Estonian wind power cluster[20]. The programme is in a very early stage of development and thus there is no clear implication of its impact on creating more value for the economy.

14 http://www.eas.ee/index.php/for-the-entrepreneur/innovation/competence-centre-programme
15 http://encc.ee/about/
16 Estonian Nanotechnology Competence Centre Annual Report 2009-2010
17 www.imecc.ee
18 http://www.estoniantimber.ee/en/facts/timber-construction-cluster
19 http://www.solarbase.ee/index.php?main=1
20 http://www.tuuleenergia.ee/en/wind-power-cluster/

The timber construction cluster aims to increase the global competitiveness of the Estonian timber industry by creating a partner network inside the industry as well as beyond industry boundaries. This includes, in addition to cluster members, building technology and education establishments, building design consultancies, equipment and technology suppliers, timber building manufacturers and sales companies.

The Estonian ECO cluster unites Estonian entrepreneurs that are focused on increasing their products' value by making them more economical and ecological. Cluster participants are planning to develop a common passive house product that will potentially decrease heating expenses by 10 times. General goals of the cluster include increasing collaboration between companies and scientific institutions as well as sharing knowledge related to economical and ecological houses. The activities of the cluster deal with planning and managing economical and ecological houses, materials, cleaning products, maintenance products, etc.

The Estonian wind power cluster is running under the umbrella organisation Estonian Wind Power Association. There are currently 11 members in the cluster including companies in metal industry, ICT industry, energy industry as well as educational and research institutions. The planned activities of the cluster until 2013 include e.g. linking the cluster to the supply chains of international wind power companies, launching of manufacturing of compact wind generators as well as launching of manufacturing of wind generator parts in Estonia.

2.2.4 Industry, associations and companies

There are several industry associations in Estonia representing industries having relevance from the materials technology point of view. The following table gives an overview of these associations; individual industries are discussed in more detail in section 2.3.

Table 3. Industry associations in Estonia representing industries having relevance from the materials

Association	*Members*	Web
Estonian Constructional Steelwork Association	15	http://www.teras.ee/
Estonian Waste Management Association	40	http://www.ejkl.ee/
Estonian Association of Chemical Industry	32	http://www.keemia.ee/
Federation of Estonian Engineering Industry	>100	http://www.emliit.ee/
Estonian Association of Information Technology and Telecommunications	64	http://www.itl.ee/
Association of Estonian Printing Industry	100	http://www.trykiliit.ee/
Estonian Biotechnology Association	15	http://www.biotech.ee/
Estonian Forest Industries Association	57	http://www.emtl.ee/
Estonian Clothing and Textile Association	76	http://www.textile.ee/
Association of Construction Material Producers of Estonia	57	http://www.hot.ee/eetl/
Estonian Plastics Industries Federation	31	http://www.plast.ee/
Estonian Woodworking Federation	55	http://www.furnitureindustry.ee/
Association of Estonian Food Industry	41	http://toiduliit.ee/
Estonian Association of Engineers		http://www.insener.ee/
Estonian Association of Construction Entrepreneurs	100	http://www.eeel.ee/
Estonian Association of Electrical Enterprises	108	http://www.eetel.ee/
Estonian Oil Association	12	http://www.oilunion.ee/

2.2.5 Venture capital

The Estonian venture capital business is yet in a very early stage of development. According to a study by the European Private Equity & Venture Capital Association (2009), peak for venture capital investments in Estonia was before the economic downturn in 2007 when in total 36 million Euros was invested in Estonian companies.[21] Since then, the volume of investments has declined, at least in 2008 and 2009. However, the amount of deals has remained on a constant level of 10 deals per year.

In addition to the low volumes of private equity deals, materials technology has a relatively small share of the deals (Figure 5). According to Estonian Venture Capital Association's members, only a fifth of investments are directed to sectors where materials technology could play a larger role. Many of the companies are financed by private business angel type persons and the founders themselves but these investments are not present in any statistics.

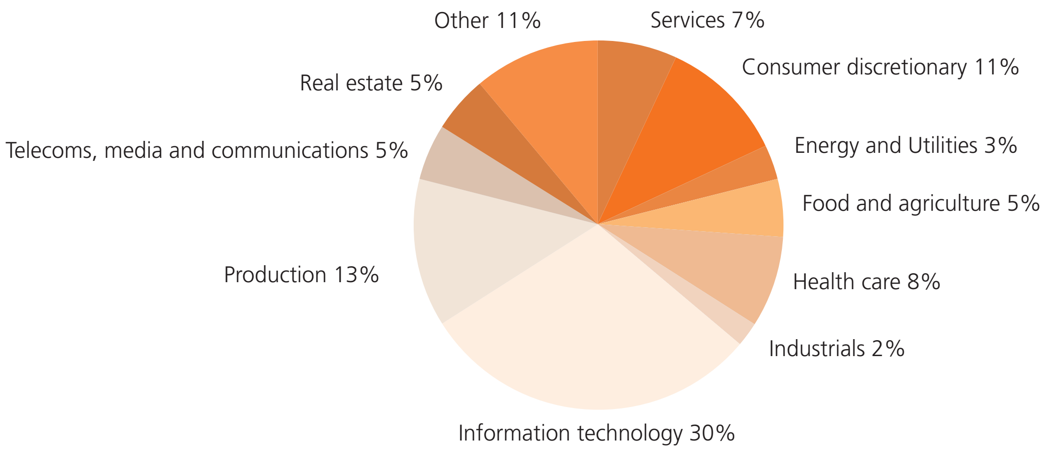


Figure 6. Venture capital investments by sector according to EVCA

Approximately 20% of the investment of Estonian venture capital are directed to sectors related to materials technology (Production, Energy, Industrials).

A handful of the members of the Estonian Venture Capital Association have invested in materials technology related companies or have an investment strategy directed to high technology startup companies. These include Ambient Sound Investment (invested in Celecure, Clifton, Evikon MCI), Askembla Asset Management (Aeroc), Astrect Invest (invests in early stage technology and life sciences), Estonian development fund (Massi Milliano (fits.me) and Goliath Wind), Hanseatic capital (Favor, Boxer Timber Group, Marepleks, Eskaro, Sunorek) and wnb (Goliath, Sorbent company, Ilmarine).

In addition to the national investment companies, most notable venture capital investments by foreign investors have been made into Crystalsol that has investors from Austria, Finland and Norway as well as significant support from the EAS. The fuel cell company Elcogen has received 2,5 million Euros from the Power Fund II LP managed by a Finnish venture capital company VNT Management Oy.

In conclusion, the field of private equity and venture capital is still very immature in Estonia. The country, similarly to other small countries, suffers from having only a small number of potential companies in which to invest and thus the volume of venture capital deals will remain very low. In order to improve the situation, foreign venture capitalists with good contacts to other international partners, especially in the field of materials science, would need to be attracted to look into investment opportunities in Estonia.

21 http://www.estvca.ee/files/VC%20CEE2009.pdf

2.3 Academic research and development

2.3.1 Scientific publications

The academic research in Estonia was inspected by a general review of scientific publications in the field of materials science and technology. For the inspection, a set of high impact materials technology journals was identified through scientific metric databases[22]. The basis of the set of high impact journals is the SCImago Journal Rank[23] category "Materials Science" that ranks materials science journals in the following subcategories: 1) Biomaterials, 2) Ceramics and Composites, 3) Electronic, Optical and Magnetic Materials, 4) Materials Chemistry, 5) Materials Science (miscellaneous), 6) Metals and Alloys, 7) Polymers and Plastics, 8) Surfaces, Coatings and Films. The database consists of 600 individual journals and the top quarter of each category was selected for the publication analysis. This journal data was augmented by data from another free journal ranking database eigenfactor.org[24] and finally compared to publicly available information on ISI materials science journals impact factor ranking. As a result, altogether 119 top quarter materials science journals with Estonian publications were identified and the list includes all the highest impact materials science journals by the ISI impact factor measure.

This review consists of roughly 1000 articles; a more thorough description of the data collection procedure is available in the introduction section of the study. For comparison, Tallinn University of Technology and Faculty of Science and Technology in University of Tartu have produced altogether approximately 11000 articles during the same period.

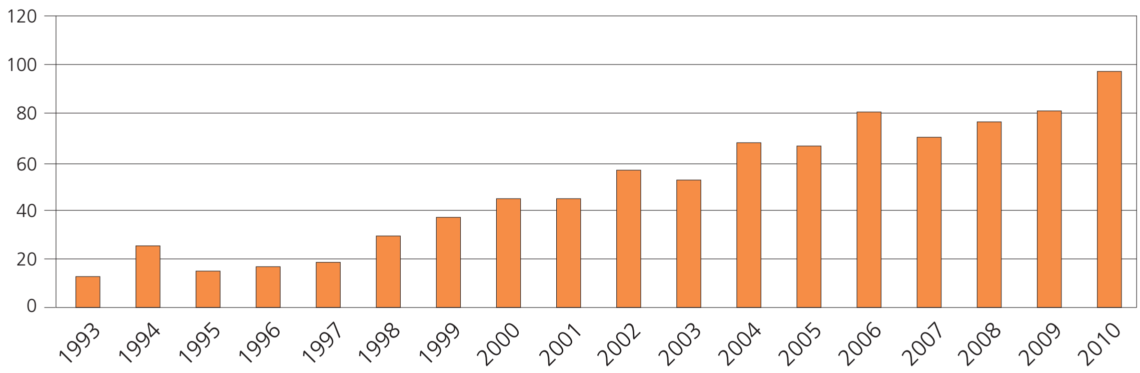


Figure 7. Annual number of Estonian materials technology publications in high impact magazines

According to Figure 7, the amount of high impact materials technology publications has been steadily growing almost every year. This is most probably due to the increased funding directed to universities but is clearly a positive sign of the state of academic research.

A list of top materials technology related journals where Estonian authors have most publications are listed in Table 8 in the Appendix A. Along with the journal name and count, a short description and latest impact factor information given by the journal has been given. Together, these 31 journals contain almost 80% of all high impact materials technology publications in Estonia and thus, they are a good indicator of the focus of academic research in the field.

Based on the publication data, several key areas of research can be identified:

- Solid state and condensed matter physics (>300 publications)
- Thin films and surfaces (> 150 publications)
- Electrochemistry, materials chemistry and organometallic chemistry (> 100 publications)

22 Eigenfactor.org, which is based on ISI publication data (category Material Engineering) and SCImago Journal Rank, which is based on Scopus publication data. These are free alternatives for commercial journal rank databases such as ISI.
23 www.scimagojr.com
24 www.eigenfactor.org

In total there are almost 1700 different people that have been listed as authors of these publications. A small group of authors (30), however, are closely related to majority of the publications as they are mentioned as one of the authors in more than 2/3 of all the listed publications. Based on inspection of these key authors, it can be concluded that the strongest areas of materials science in Estonia are dealing with the following three areas:

- Fundamental physics: Solid state and condensed matter physics (Tartu University Institute of Physics)
- Solar cells and related materials research (Tallinn University of Technology)
- Electrochemistry (Tartu University Institute of Chemistry)

However, it must be noted that in general impact factor is a better measure for fundamental research than for applied research, as applied research articles usually do not get as many citations. Measuring the excellence of applied research is more difficult and should be looked at from technology transfer and industry perspective. Broadly speaking, the impact factor is a good measure for journals in highly and frequently cited areas. It is also not wise to compare journals across science areas (such as e.g. medicine and economics), as the citation activity may differ. Also the length of the journal review process affects the impact factor: if the review process is long, taking up to years, the impact factor will be lower as it takes time for the references to occur.

2.3.2 Research project funding data

In addition to scientific publications, a large amount of materials technology university level research projects was inspected. A set of more than 550 projects was collected from the Estonian Research Information System (ETIS) with the help of Archimedes Foundation. The set includes all projects starting from 1995 in the areas of chemistry, physics, materials technologies, biotechnology and other fields closely related to materials. By far the most active universities in these projects were the University of Tartu and Tallinn University of Technology which corresponded to approximately 80% of all project volume.[25]

Table 4. Characterisation of research projects in Estonia

Field of research	*Total project volume*	Largest contributors
Biotechnology	24€€	TUT (38%), UT (25%), EBC (17%), TFTAK (13%)
Condensed matter physics	24€€	TU (65%), KBFI (30%)
Materials technology	23€€	TUT (51%), UT (45%)
Biochemical technology	8€€	UT (66%), TUT (19%), KBFI (12%)
Energy research	7€€	TUT (80%), UT (15%)
Physical chemistry	6€€	UT (58%), KBFI (31%)
Organic chemistry	5€€	TUT (56%), UT (46%)
Coatings and surface treatment	4€€	UT (57%), TUT (43%)
Analytical chemistry	4€€	UT (58%), TUT (42%)
Food and drink technology	4€€	TFTAK (72%), TUT (17%), UT (12%)
Technology of other products	4€€	TUT (77%), UT (23%)
Semiconductor physics	3€€	TUT (67%), UT (28%)
Bioenergetics	3€€	UT (92%)
Electronics	3€€	TUT (100%)
Microelectronics	3€€	TUT (100%)

25 Note: due to the database structure, no exact monetary volumes of projects can be given and thus all estimates in this section are indicative only. All projects are assigned under one or more codes, which results in duplicate data entries.

Together the listed fields of research account for more than 80% of all research projects in the database by funding volume. The numbers indicate that the university research in Estonia is roughly divided according the following guidelines:

<table>
<tr>
<td>
University of Tartu

Physics
Condensed matter physics
Metrology, physical instrumentation
Gases, fluid dynamics, plasmas
Laser technology
Atomic and molecular physics
Elementary particle physics
Materials technologies
Materials technology
Coatings and surface treatment
Composite materials
Chemistry
Physical chemistry
Organic chemistry
Analytical chemistry
Surface and boundary layer chemistry
Electrochemistry
Theoretical chemistry, quantum chemistry
Petrology, mineralogy, geochemistry
Biotechnology
Biotechnology
Biochemical technology
Bioenergetics

</td>
<td>
Tallinn University of Technology

Physics
Semiconductor physics
Electronics
Microelectronics
Gases, fluid dynamics, plasmas
Materials technology
Materials technology
Coatings and surface treatment
Composite materials
Optical materials
Ceramic materials
Chemistry
Organic chemistry
Analytical chemistry
Inorganic chemistry
Chemical technology and engineering
Theoretical chemistry, quantum chemistry
Carbochemistry
Biotechnology
Biotechnology
Lipids, steroids, membranes
Other
Energy research
Technology of other products
Instrumentation technology

</td>
</tr>
<tr>
<td>
National Institute of Chemical Physics and Biophysics

Physics
Condensed matter physics
Metrology, physical instrumentation
Atomic and molecular physics
Biotechnology
Biochemical technology
Chemistry
Physical chemistry
Carbochemistry, petrochemistry

</td>
<td>
Competence Centre for Food and Fermentation Technologies

Biotechnology
Food and drink technology

</td>
</tr>
</table>

2.3.3 Patenting

Patenting activity of Estonian companies and universities is currently quite low but has significantly increased during the last years (Figure 8). For this study, patenting activity was studied by comparing patent applications that have global relevance and thus only applications with United States (US), Europe (EP) and Patent Cooperation Treaty (WO) were considered. There are in total ~370 of these applications between 1993 and 2010. Approximately a fifth of these patents deal with materials technologies.

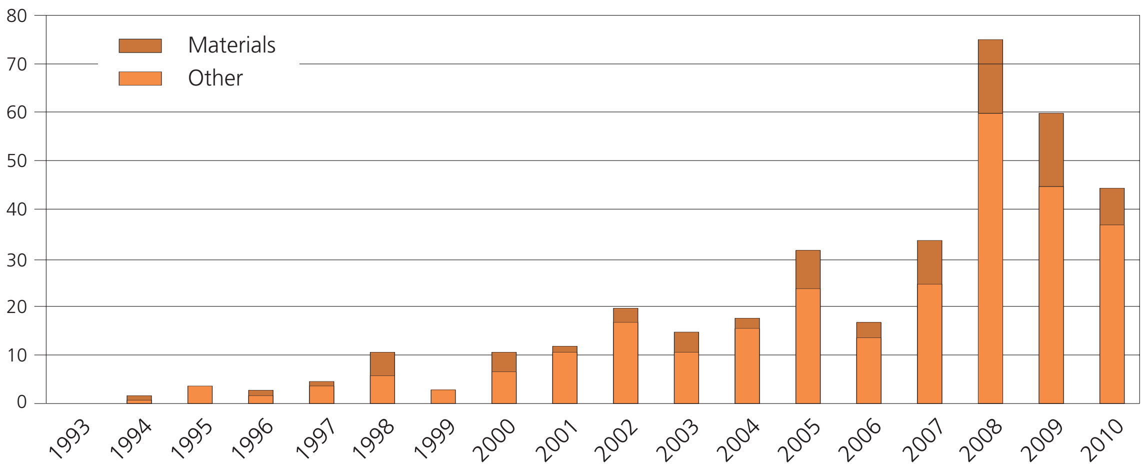


Figure 8. Patenting activity (US/EP/WO) in Estonia between 1993-2010.
The share of materials technology patents highlighted

A handful of high-technology companies and organisations can be identified in the materials technology patent data. Organisations with highest number of patents include NordBioChem (9), University of Tartu (8), Tallinn University of Technology (6), Viru Keemia Grupp (5), Visitret Displays (3), Estonian Nanotechnology Competence Centre (3), Skeleton Technologies (2), National Institute of Chemical Physics and Biophysics (2). A few interesting companies having only one patent can also be pointed out: Elcogen, Esfil Tehno, Molcode and ProSyntest. For Skeleton Technologies the actual number of patents is somewhat higher but these have been registered for the company's employees and not the company itself.

2.3.4 Summary

Research developments will be discussed in more detail under the corresponding industry sectors in section 2.4 as well as in the section dedicated to technology transfer in section 2.5. To conclude here, based on exhaustive data collection of the Estonian research and development work done at universities including scientific publications, patents, university research questionnaire and numerous interviews, the following strong areas of Estonian materials technology can be identified:

- Advanced materials
  - Photovoltaic materials
  - Nanomaterials
  - Carbon based nanomaterials
  - Electroactive polymers and electrically conductive polymers
  - Rare-earth metals
  - Advanced sensor materials
  - Metal-matrix composites

- Energy technologies
  - Thin film solar cell technology
  - Supercapacitors
  - Fuel cells

- Micro and nanoelectronics
  - E-paper
  - Atomic Layer Deposition

- Coatings technologies
  - Advanced coatings for metals industry
  - Electro-optical coatings

- Biotechnology and biomaterials (e.g. biopolymers)

- Measurement, modelling and processing technologies
  - Computational chemistry
  - Measurement technology in general
  - Laser technology
  - Atomic Force Microscopy

2.4 Industry status and technology transfer potential

2.4.1 Metals and machinery

Industry overview

Metals and machinery is one of the largest industry in Estonia by revenue and exports. The whole sector makes up approximately one fourth of manufacturing enterprises but contributes 42% in total exports and 43% in total imports (2008). The sector consists of various subsectors including fabricated metal products, machinery and equipment, transportation equipment and manufacturing of basic metals. One of the notable subsectors of metals and machinery industry in Estonia is also tool-making. The whole industry employs more than 25000 people, more than half of which are in manufacturing of metals and fabricated metals products, nearly 6000 in the manufacturing of machinery and equipment and about 5000 in manufacturing of transportation equipment. [26]

The largest industry association representing metals and machinery industry is the Federation of Estonian Engineering industry, which represents over 100 companies in metalworking, machine building and manufacturing of electrical equipment. Most of the companies in the industry are located in the Tallinn region.[27] The Estonian Constructional Steelwork Association is also related to the industry representing a few companies manufacturing steel and steel products.

The metals and machinery industry in Estonia mainly consists of subcontracting companies were little or no long-term R&D development is done.

Universities: R&D, education and collaboration

The most important university partner for metals and machinery industry is the Tallinn University of Technology and primarily the Faculty of Mechanical Engineering. Tallinn University of Applied Sciences is also active in the field as well as some research groups in the University of Tartu. A large part of the university level research in Estonia regarding metals and machinery sector in materials technology is concentrated on films and coatings and improving characteristics of metal materials by nanotechnology. Different composites and novel materials for replacing metals in applications altogether were also emphasized by the researchers. Most of the research aimed for metals and machinery sector in Estonia, therefore, deals with improving characteristics of metals and metal products by introducing more durable, wear resistant and anti-corrosive materials or by developing novel light weight materials to replace metal components in different applications.

Tartu University has participated in an EU FP7 project CORRAL, which aims to develop corrosion protection in applications such as high precision mechanical parts (bearings), aerospace components (break systems) and gas handling components.

26 http://www.investinestonia.com/en/business-environment/Page-5-1
27 http://www.emliit.ee/index.php?page=3

Technology transfer potential of advanced materials technologies

The core advanced materials technologies for the metals and machinery industry is at Tallinn University of Technology in the Faculty of Mechanical Engineering. Most of the research work is conducted in the Department of Materials Engineering, which conducts research in the fields of powder technology and tribology having specific laboratories for these fields. The laboratory also studies surface technologies, disintegrator technology and nanotechnology as well as welding technologies. One area of work is also the study of TiC and Cr2C3 cermets, which is unique even in global terms. Research work is also conducted in the Department of Mechanics where composites and especially their quality control with non-destructive evaluation (NDE) methods are being studied. The Tallinn University of Applied Sciences is also active in the same areas and they are closely co-operating with the Tallinn University of Technology.

Other Estonian universities in the area are more fundamental research oriented. Relevant research is conducted at the University of Tartu and Tallinn University but these are more related to fundamental physics than to e.g. machinery applications. The University of Tartu, Institute of Physics is conducting large amounts of research in areas such as sol-gel technologies, nanofilms, measurement methods (AFM, SPM), nanomaterials and coatings and these can also be applied in the metals and machinery sector. In summary, advanced materials research in Estonia in the field of metals and machinery sector can be described as follows:

- Metal coatings and surfaces
  - Tribological coatings
  - Wear reduction

- Composites for replacing metals in various applications
  - Cermets (TiC, Cr2C3)
  - Use of other advanced materials to replace metals

- Modelling and measurement
  - Non-destructive evaluation and testing
  - Atomic Force Microscopy, Surface Probe Microscopy, other measurements

Majority of the high quality publications identified in the sector (33) were published in *Wear*, which currently has the impact factor of 1.7 and ranks among top journals in mechanical engineering as well as surfaces, coatings and films.

International markets and assessment of Estonian potential

The global market for the abovementioned technologies, including metals coatings and surface for wear reduction, corrosion resistance and composites for replacing metals in various applications, is huge. Rough estimations in the area suggest[28] that direct costs of friction and wear in an industrialized country are 7% of the Gross National Product (similar to GDP) and as a result up to 1% of GNP can be saved by developing and utilizing better tribological solutions. The impacts of corrosion for industry and economies are also significant. It has been calculated that the costs in the U.S. and Europe amount to 3% of GDP and 70% of these costs could be avoided. A concrete example by Battelle Institute reports that corrosion damages correspond to $300 billion per year in the U.S alone.

In addition to manufacturing industry and machinery, one large application area for tribological coatings is transportation. Tribological coatings used and developed for transportation include single phase, multi-phase or composite coatings of materials such as carbides (e.g. TiC), nitrides, metals or ceramics.[29] These coatings are used for increasing the performance of e.g. engines and power trains of vehicles. They increase lifetime and decrease energy consumption and dissipation of heat by reducing wear and friction. As a result, the efficiency of vehicle (and machinery) is improved, maintenance costs and the need for lubricants are reduced. The current market of coatings in the automotive industry is estimated to around $133 million and is expected to reach $330 million in 2015 (ReportLinker). Similarly, the coatings market for the aerospace sector was estimated at $215 million in 2001 with expected increase of the figure by 50% by 2010.

28 Roadmap of the European Technology Platform for Advanced Engineering Materials and Technologies (2006)
29 ObservatoryNANO: Coatings, adhesives and sealants for the transport industry

Nanotechnology is very closely involved in novel innovations of advanced materials for metals and machinery sector. Several general market estimations for nanotechnology applications for coatings in general and nanotechnology in the automotive industry in general has been given as follows:

- Nanocoatings (BCC Research)
  - $3000 million in 2010
  - $18000 million in 2015

- Nanotechnology in automotive (43% of nanotechnology for automotives were paints and coatings in 2008)
  - $6460 million in 2015 (Institute of Nanotechnology, 2007)
  - $7000 million in 2015 (RNCOS, 2006)
  - $6460 million in 2015 (Frost & Sullivan 2005)

Undoubtedly high competition already exists in the area of tribological and wear resistant coatings both in Europe and globally. However, the huge market size means that there is plenty of room for novel innovations and a huge number of potential partners exists e.g. in Europe thanks to the strong automotive and machinery industry. Main drivers for applying novel coatings and surface technologies for machine building include:

- Reducing environmental footprint
  - Fuel efficiency, weight reduction, new powertrain systems

- Maintaining and increasing competitiveness
  - Innovativeness
  - New products, e.g. electric vehicles
  - Cost reduction

Despite clear key drivers, large barriers also exist in the application of new technologies. One of the identified barriers is the lack of understanding between the industrial and scientific communities, which has also been identified as a challenge for Estonia in general. Coatings can typically be applied in various fields of industry and researchers tend to try to find out what is technologically possible instead of trying to solve more applied industrial problems (for e.g. tool-making). Thus there is a large gap between research findings and market applications. Another notable barrier that needs to be taken into account is the lack of nanomaterials availability to the extent of mass industrialisation as well as various environment, health and safety concerns related to nanomaterials.[30]

Summary and conclusions

- In conclusion, there is very high potential in the Estonian metals and machinery sector
  - Large company base, high net sales and high export rates
  - Some companies with good potential to adopt novel materials technologies due to their large size (e.g. BLRT and Norma)
  - Long traditions in specific fields such as tool-making, which requires high quality coatings

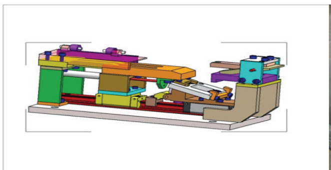
- Broad R&D support from the university sector
  - Core at the Tallinn University of Technology, Faculty of Mechanical Engineering
    - Both materials research and machine building expertise
  - Support from University of Tartu, Estonian Nanotechnology Competence Centre and Tallinn University of Applied Sciences

- Huge global market and big possibilities for increasing collaboration
  - Huge market potential for novel coatings in machinery and transportation
  - Already existing international collaboration with e.g. EU projects and Finland

- Key challenges for Estonia
  - Need to build more complete value chains including large companies, smaller subcontractors and universities
  - Need to decrease the gap between universities and companies – this is an important challenge also globally

30 ObservatoryNANO: Coatings, adhesives and sealants for the transport industry

Case: Pioneer Engineering Group



Background

The Pioneer Engineering Group (P.E.G) is the representative marketing organization for the connected supply network for the subcontracting output of Estonia's metal and machine building industry. They find export orders for cluster members and offer consolidated services to members as well as the parties who order. The members are companies with a specific distinct resource matrix which covers the technical capacity of all machine construction and metalworking machine parks available. There are plans to include Finnish companies in the PEG network, P.E.G. employs 3 persons focusing on financing, legal and operational activities. They also do some joint R&D projects.

Aim is to grow bigger, create more partnerships, expand the network of companies to provide better supply chain and to get higher level machine building cases to Estonia. Their business potential is bigger (abroad), but local presence takes resources. Target markets include Finland, Sweden, Germany. Export ranges from 0 to 100% depending on the case.

The companies make contract type manufacturing for machine building customers. P.E.G. provides customers as wide a selection of their own production components as possible, with the opportunity to order everything from one location.

Target **customers** are active in fields like:

- Design and building of various industrial machinery and equipment (mining, construction, material processing, automotive, energetics, lifting-conveying)
- Furniture and interior, with the top quality steel, plastic and wooden component
- Manufacturing of products requiring automated machinery and production lines, quality assurance equipment, jigs and fixtures.

R&D

R&D now < 1% of turnover. They would like to make more R&D (to lower the risks, "fail quick & learn"). Examples of some small-scale R&D made: To find correct materials for specific purposes (case: plastics comparable to aluminum); Fixture for military application, replacing a part which is imported; Plastics for mining industry (wear, chemical resistance, machining) – Eksamo company made the mold, another company a specific polyurethane material, customer ready.

University-Company collaboration

Some co-operation with Tampere University of Technology/Plastics, Finland. Tallinn TU is known, but it is a bit distant. It seems that the needs and offering from universities do not match at the moment. The companies have ideas and would be ready to participate. "The economy needs scientists who can jump from one project to another". P.E.G. has applied EAS funding but were rejected.

Lessons learned/key success factors from the interview

- small companies have resource problems (competence, equipment, scale/big machining cases), together the P.E.G. group can take bigger cases, provide a wider offering and find customers
- contract manufacturing often making only components; wish towards higher level assemblies
- needs of these companies and the offering of universities do not match – also faster, more solution oriented R&D projects should be done and tunded

Contact and more information: Andres Soojärv, CEO, asoojarv@peg.ee

2.4.2 Wood, pulp and paper / Forest industry

Industry overview

The forest industry is one of the most important industries in Estonia. The sector (forestry, forest and wood industry) produces 4.4% of the GDP of Estonia. Forest and wood industry corresponds to fifth of the total industry GDP. It is also very important for exports because forest industry products account for 16% of total exports from Estonia. It is also the only manufacturing industry that has a positive trade balance, i.e. having more exports than imports.

Estonia, similarly to other Northern European countries is very rich in supplies of wood and timber and a significant area of the country is covered by forest. The annual usage of roundwood in Estonia today is approximately 9 million m^3, which is mainly distributed within sawmills and other mechanical production (~30%), energy use (~20%) and pulpwood export (~25%). Other areas include pulp and paper production (~7%), chipboard production (~2%), pellet production (~4%), and plywood, veneer and glue laminated wood production.

The total export of wood products in 2010 was almost 1 243 million Euros. The three most important areas responsible for approximately 50% of the sales were wooden furniture and parts, sawn and planed wood and builders' joinery and carpentry. Smaller areas include, ordered by the value of exports, prefabricated buildings of wood, pellets briquettes & fuel wood, thermomechanical pulp and roundwood.

Due to the vast local resources, Estonia has long traditions in forest industry and therefore a lot of know-how in the industry. During the recent years, there have also been a lot of Greenfield investments, which means that the industry is currently well developed and has good capabilities to further increase production. Estonia's market share in the global market is still relatively low and with more value added products, the country has a good chance of increasing the market share. The largest challenges of forest industry are related to the operating environment of companies. Compared to Scandinavia, forest industry companies in Estonia are quite small, which is an obstacle to growth in the highly competitive industry. Moreover, due to local legislation, Estonian companies have a significant disadvantage in the efficiency of logistics as they are allowed to carry only 44 tons load per truck whereas the limit is 60 tons per truck in e.g. Finland.

Largest companies in the sector include Stora Enso (mechanical production), Graanul Invest (bioenergetics and renewable energy), Lemeks (timber processing), Estonian Cell (pulp) and Horizon Tselluloosi ja Paberi (paper).

R&D potential, education and collaboration

Currently, the amount of R&D in Estonian forest industry companies has remained rather low. Most of the development done in the industry is closely related to daily activities of production and product improvement and therefore is not visible in the official statistics. However, there is a high determination in the industry to develop more value added products, which requires more research and development work for the companies. To achieve this, the industry tries to collaborate actively with universities and find funding for R&D projects. So far, there have been challenges in getting EAS support to industry initiatives. For the industry association one of the main themes of 2011 is R&D. They aim to raise awareness of R&D by inviting industry representatives to meet the biggest research center that is involved in wood development: Estonian University of Life Sciences, Tartu, Eastern-Estonian Vocational Education Centre, Jõhvi, and Võrumaa Vocational Education Centre, Võru (Southern Estonia).

Most of the current innovations have been on mechanical production such as prefabricated houses. The industry would, however, like to go into bio refinery and start generating more innovations from the chemical production which is actually more related to modern materials technology.

Despite the large importance of the forest industry for the country, there is little high technology oriented research being done at Estonian universities. Relevant activities are ongoing in the Tallinn University of Technology Department of Polymer Materials and at the Estonian University of Life Sciences. The Tallinn University of Technology is mostly responsible for the scientific research in the area, which consists of two main focus areas: 1) improving properties of wood products and 2) the use of wood in composite materials. The research group is currently very small, consisting of 6 people doing both education and research work. Estonian University of Life Sciences is more focused in mechanical processing of wood and production of wood based products as well as education and research in forestry.

A lot of collaboration is already done in the forest industry with good links among and between universities and companies. A good share of international collaboration also exists with the Nordic – Baltic Network of Wood Material Science and Engineering.[31] The network consists of key Nordic and Baltic players in the field and provides Estonian students possibilities to do part of their studies abroad. Education in the field is offered in close co-operation with companies and most of the students are already working in the industry during their studies. Typically the master's theses are also related to practical problems defined by the industry. However, only a few theses are produced yearly.

The biggest challenges in the forest industry today are related to very limited funding from the public sector. Currently, a minimal amount of basic funding is given to the research group at the Tallinn University of Technology, which means that it is nearly impossible to conduct scientific research. The research group conducts research only in collaboration with the industry. However, there are no large projects currently underway, and it will take some time before new projects can be established. As a result of limited funding and research capabilities, there was no wood related research identified among the high class Estonian scientific publications.

Summary and conclusions

Despite the high importance of forest industries, the funding and volume of scientific research related to wood materials is very low. There is also a very small amount of people with either Doctor's or Master's degree working in the industry, which makes it difficult to implement advanced materials technologies. However, thanks to strong chemistry education and chemical industry as well as other polymers research conducted at the universities, it would be possible to increase the amount of research applicable in forest industries. A Wood Materials Centre of Excellence is also being planned in Estonia but the final funding decision had not yet been madew at the time of writing this study. The centre would hopefully improve the situation regarding transfer of new technologies to the industry.

- Despite the high importance of the industry, there is practically no advanced materials research in Estonia regarding wood based materials
- There is only one small research group conducting research in wood chemistry (in TUT), which does mostly applied research to meet company needs
- Large majority of the teaching and development is related to mechanical processing
- Developing high quality research in advanced wood based materials requires a lot of time and effort
  - Does Estonia want to invest in this or is wood chemistry research required at all?

Case: Forest industry

The industry includes several interesting companies which could possibly play a key role in the future of development of materials technology in the forest sector. However, most of these are foreign owned. Some of these companies are:

- **Raitwood AS** (Estonian capital based ownership, one of the leaders in sawmilling and specially further processing and developing products in this field)
- **UPM Otepää AS** (daughter company of UPM, only Estonian plywood producer, focused last times on coating of the plywood making some new products)
- **Stora Enso Eesti AS** (daughter company of StoraEnso, leader of the sawmiling and having at Imavere also big mill for gluelam beams, most of these beams sold to the Japanese market)
- **Estonian Cell AS** (Austrian capital based ownership, only Estonian termomechanical pulp producer, produces high quality Bleached-Chemi-Thermo-Mechanical aspen pulp (Aspen BCTMP), using Estonian aspen)

31 www.wse.no

2.4.3 Chemical industry

Industry overview

The chemical industry in Estonia accounts for approximately 1% of all sales revenues of the economy and a little over 5% of the manufacturing industry (5.3% or 5B EEK in 2009). The industry is therefore similar in size compared e.g. to the plastics industry.[32] The chemical industry consists of two important subsectors that are oil shale chemistry and rare earth metals and oxides production. The industry is very export oriented as 85% of the production is exported. Oil shale exports made up 1.7% of the country's exports in 2009.

According to the Federation of Estonian Chemical Industries, there have been a lot of efforts in recent years to improve the efficiency and environmental friendliness of the industry. However, the federation states that the development should still continue and needs more financial capital, skilled labour and product development to succeed.

The majority of Estonian chemical industry related to materials technology is closely linked to construction materials, including companies such as Henkel Makroflex, Krimelte, Akzo Nobel, ES Sadolin, Tikkurila and Eskaro. The oil shale production is somewhat related to materials technologies as some university research groups are studying the utilisation of oil shale waste and fly ash for construction materials production. Major companies involved in oil shale production in Estonia include Eesti Energia Õlitööstus, VKG Oil and Kiviõli Keemiatööstus. Materials technology is not, however, a core business of these companies and therefore, it is unlikely that they would be willing to invest heavily in the development of the field.

A single company with relatively high importance for the country is Silmet, which has a unique position in the whole Europe being one of the largest rare earth metals and oxides producers. The metals are of high strategic importance globally as they are needed in various high technology applications and are difficult or impossible to replace by other means. Some large companies also exist in agricultural chemical and fertiliser production including Baltic Agro, Farm Plant Eesti, Agrochema Eesti and Nitrofert.

Chemical industry has undoubtedly a key role in developing materials technologies in Estonia. It corresponds to a very large share of total production of the economy, it is very export intensive and chemistry is widely taught at Estonian universities. Still, the role of chemical industry in Estonia is relatively small when compared to the rest of Europe as the European chemical industry has traditionally produced twice as much chemicals as it consumes. This is a completely opposite case in Estonia, as the country consumes twice as much chemicals as it produces.

Unfortunately for Estonia, its chemical industry is very much SME oriented: 85% of the member companies of the Federation of Estonian Chemical Industries are SMEs (2009) and there are only 6 companies employing more than 100 people and 5 companies employing 50-99 people. In the chemical industry, larger companies have a natural cost advantage gained from high volume production and therefore increasing competitiveness of the industry requires very large investments. The REACH regulations are also a tough challenge for Estonian chemical industry because companies need to register their products, which costs a significant amount of money and requires an extensive amount of work. There is currently a lack of know-how in both companies and public sector and therefore, the country needs to rely on foreign expertise regarding the REACH regulation.

R&D and education

Chemistry is widely taught at Estonian universities. Main contributors include Tartu University, Institute of Chemistry and Tallinn University of Technology, Faculty of Chemical and Materials Technology. Other notable players include Faculty of Science at Tallinn University of Technology, Institute of Technology in Tartu University and Institute of Mathematics and Natural Sciences at Tallinn University. The National Institute of Chemical Physics and Biophysics is conducting research in chemistry. The areas of chemistry education and research include: Chemical engineering (TUT), Environmental Chemistry (TUT, TU, KBFI), Analytical Chemistry (TUT, TU), Inorganic Chemistry (TUT, TU), Bioorganic chemistry (TUT, TU, KBFI), Biotechnology (TUT), Molecular technology (TUT, TU), Organic chemistry (TUT, TU), Materials chemistry (TUT, TU), Electrochemistry (TU) and Physical chemistry (TU, TUT).

32 www.keemia.ee

Technology transfer potential

The spearheads of Estonian chemistry research are related to four key areas: 1) research and development of oil shale production and processing technologies, 2) developing materials technologies for high technology applications and 3) computational modelling and measurement. Most of oil shale related research is not directly related to materials technologies and thus it will not be discussed any further in this study. The other key areas of materials research are mostly related to advanced materials technologies and not directly to the traditional chemical industry producing different kinds of chemicals for e.g. agricultural purposes. Therefore, the most relevant chemical industry company for materials technologies is the rare earth metal producer Silmet, which has some collaboration with Estonian universities. According to Silmet's R&D manager, the company is looking for new projects to add value to their products.

Global status, trends and connection to Estonian chemicals industry

Chemicals industry plays a very important role in the development of the European economy. It corresponds to 1.1% of GDP (2009) and comes second in added value among industries after pharmaceuticals. The total sales of the chemicals industry in Europe was 450 billion Euros in 2009 consisting of petrochemicals (25%), polymers (23%), basic inorganics (12%), specialities (26%) and consumer chemicals (14%). Similarly to Estonia, most chemical industry companies in Europe are SMEs (61%), but most of the sales and employment originates from large corporations (72% and 65% respectively).

The American Chemical Society has identified five major areas crucial to the future development of chemical industry from materials technology view point[33]. These areas are:

- New materials
  - New concepts in catalysis for polymers
  - Polymer-structure property relationships
  - Colloid/interface science (especially polymers and thin films)
  - Polymer composites
  - Continued development of new materials
- Materials characterisation
  - R&D tools
  - Real-time measurements
- Materials modelling and prediction
  - Methods development for interfaces, biomaterials, surface chemistry and catalysis
  - Modelling theory
- Additives
  - Prediction/modelling
  - Understanding of surface chemistry and interactions of additives
  - Nanoparticles
- Disassembly, recovery and recycling
  - Collection of raw materials
  - Deriving pure monomers and intermediates from polymers
  - Chemistry for mixed polymers streams and polymers modification
  - High yield separation process

The roadmap and technology trends are very much related to polymer materials, which is mostly lacking in Estonian chemicals industry. Another huge technology trend for chemicals industry is the importance of modelling and prediction methodologies, which is already studied to large extent at Estonian universities and spin-off companies (especially Molcode and Baltic Technology Development).

The development of novel materials is also seen as very important in the chemicals industry and there are important initiatives at Estonian universities and companies related to new nanomaterials, carbon based materials, rare-earth metals and biomaterials.

33 Vision 2020 Chemical Industry of The Future – Technology Roadmaps for Materials (2000)

Summary and conclusions

- In conclusion, the Estonian chemicals industry is mostly focused on activities that are not directly relevant to materials technologies. However, there are several important areas in both industry and universities that form the basis for very much of the materials technology activities in the country.

- Altogether, Estonian chemical industry consists of two very interesting niche areas related to advanced materials and chemicals industry is also an important enabler in triggering research and development
  1. Oil shale industry
     - Utilisation of oil shale in petrochemicals production
     - Utilisation of oil shale waste in various materials production
  2. Rare-earth metals and oxides: Taking full advantage of rare earth metals expertise
     - Used in various advanced materials based solutions
  3. Utilizing chemistry innovations in other industries
     - Construction materials, modelling

- In addition, Chemical industry is an important raw materials producer for other industries

- R&D work is strong
  - Very strong R&D base in universities in fundamental research: TUT, TU, KBFI, etc.
  - Also in modeling and measurement (e.g. research that led to the establishment of Molcode)

- Education has also an important place in educating workforce for different industries: plastics, textiles, construction materials, etc.

Case: AS Silmet

Background

Silmet, which is located in the north-eastern part of Estonia in Sillamäe, is one of largest rare earth metal and rare earth metal oxides producers in Europe. The company has annual production of up to 3000 tonnes of rare earth products and up to 700 tonnes of rare earth metals. The company employs more than 500 people in three factories for rare earth metal separation, production and metallurgy. The company was originally established in the Soviet Union era for processing of uranium and it started the rare earth metal production in the 1970s. The company was privatised in 1997 and since then it has been constantly developing its processes for the production of high quality rare earth metals.

Materials technology

The metals produced by Silmet are of high strategic importance globally as they are the key ingredients in many high technology applications such as Tantalum, which is mostly used in electrolytic capacitors, and Niobium, which can be applied e.g. in superconductive magnets. The rare earth metals produced by Silmet include Lanthanum, Cerium, Praseodymium, Neodymium and they are extracted from the mineral Loparite.

Being an established company with a long history, Silmet is currently mostly focused on the success of its day-to-day activities. The price pressure coming from the Chinese rare earth metal producers is severe and largely affects the capabilities of western countries of establishing their own rare earth metal production. The largest challenge for the industry today is the demand for rare earth metals and their price volatility mainly due to changes in world politics and economic growth. The most important factors for Silmet's success so far has been its good market knowledge, qualified employees and good management which are considered the key success factors also in the future.

The importance of materials technology and advanced materials are a twofold issue for a rare earth metal producer such as Silmet. On one hand, novel materials technology and other technological inventions can greatly increase the demand for rare earth metals if they are required for producing these new inventions. On the other hand, there is great determination globally to develop artificial materials (e.g. carbon based materials) and solutions that could replace rare earth metals completely for environmental reasons – to save these scarce natural resources.

Collaboration and future needs

Silmet has been collaborating actively with universities in training new employees qualified to work for the company as well as running special projects in e.g. improving Silmet's production processes. In long term, the company hopes that the government maintains the level of support from EAS and universities and sees Estonian nanotechnology research as a key to help companies succeed in future.

More information: Jane Paju, R&D manager. Jane@silmet.ee. http://www.silmet.ee/

Case: Krimelte OÜ

Background

Krimelte OÜ is a production company, based on Estonian capital, that is specialized in joint sealants and insulating foams. The company was founded in 1994 and the production in Estonia started in 1998. The company employs approximately 160 employees, of whom about 2/3 are in production. 95% of revenues come from export, of which 75% goes to Russia.

Products and customers: About half of Krimelte's output is sold under the trademarks of their business partners. Krimelte offers full service – from product development to logistics solutions using their laboratory facilities, a highly qualified product development team and international business networks. Their main **products** include gun foams, manual adapter foams, cleaners, adhesives and self-adhesive expanding tapes.

Their competitive advantage includes the rough climatic conditions of Estonia, due to which they have set especially high quality standards to the products. In addition, having been previously a retail company, they have a better understanding of their customers' needs and are able to deliver more quickly than their competitors. They also get information about market needs from their retailers and partners. Krimelte's closest **competitor** is the Estonian Henkel Makroflex. Henkel is the fourth **largest** in the world with Krimelte in fifth place. Other competitors include Den Braven in the Netherlands and Selena in Poland.

R&D

In addition to chemistry R&D projects, the company also develops the containers where their products are stored. One of their best R&D projects is the Golden Gun. Previously there were only two types of tools for applying foam: a straw or a metal gun. The straw foam is not reusable and the metal Gun cost 2-3 times the amount of the whole bottle. Easygun from Krimelte is in between these two, being a combination of cheap and reusable.

The 10 person R&D department at Krimelte works also with Quality checking and design of product labels as these require a lot of expertise. Krimelte has plans to hire a person to do technology scouting.

University-Company collaboration & Materials technology

Krimelte has a joint project with Tartu University, Professor Uno Maeorg. The collaboration started based on the needs of Krimelte, but the university has provided very important insight into the process. The project is aimed to develop a new approach to isocyanate free construction foam; previous approaches cannot be used as they are heavily patented.

Lessons learned/key success factors from the interview

- Difficult to find skilled workforce for the industry in Estonia. It is also difficult to find highly educated R&D personnel with a lot of practical experience
- Currently, there is not enough cooperation between companies and universities. Universities should more actively contact companies. Krimelte would be interested in increasing cooperation.

Contact and more information: Lauri Leitorp, Head of R&D, http://www.krimelte.ee/en

2.4.4 Plastics industry

Industry overview

The plastics industry is the smallest industry discussed in this study. According to the official statistics[34] the whole industrial production (plastics and rubber) was worth approximately 270 million EUR in 2008 and accounted for more than 230 million EUR in exports. There are currently about 100 companies in the Estonian plastics industry that are active and generate revenue.[35] The industry is very diverse and the products are aimed at different industries such as automotive, construction materials and packaging. Most of the companies in the industry are small and only a few are listed among the 500 largest companies in Estonia. Approximately half of the industry's production is exported, mainly to Sweden and Finland.

The plastics industry value chain can be divided into the following broad segments.[36] Majority of the Estonian companies in the industry are plastic converters, which also means that they are mostly running subcontracting business. Most of the materials related innovation happens in earlier parts of the value chain including raw materials, plastics resins and plastics production. The chemical industry in Estonia has some relevance regarding raw material supply for plastics industry, e.g. utilisation of oil shale based products.

- Raw material suppliers (petrochemical and chemical feedstock's and additives)
- Plastics producers (who manufacture plastic resins)
- Plastic compounders (prepare plastic formulations)
- Plastics machinery manufacturers
- Plastic converters (who form the plastic resins and compounds into finished products)
- Plastic product distributors/users (OEM manufacturers, retailers, etc.)
- Plastics end-of-life businesses (waste management, recycling)

The recent recession hit the plastics industry very hard and forced many Estonian plastics producers to change their business model. The changes were largest in construction materials providers, which used to produce decoration materials but are now more focused in producing infrastructure materials for the construction industry. Packaging materials producers did not face such significant damages from the recession.

Key issues for the plastics industry, especially plastics converting, are the price of raw materials and energy. The prices of raw materials are increasing rapidly and the industry has seen up to 40% increases in some raw materials prices. This is seen as especially problematic as the production volumes in the industry are also expected to grow.

Research and development

Similarly to other manufacturing oriented industries in Estonia, plastics industry does not conduct much dedicated research and development. The plastics industry is currently very much focused on subcontracting and companies only have a few products of their own. For that reason, most development in the industry is done in production where the personnel incrementally develop more efficient production methods. The industry is clearly in the very beginning of the process of developing new products and the change will not happen overnight. For many companies, the subcontracting business model is limiting possibilities to develop own products. Many companies also lack the necessary funding to start technology development activities and thus national or EU support would be needed.

Most plastics industry related research is conducted in the Department of Polymer Materials at Tallinn University of Technology. The most important research activities in the department are in novel polymer composites and research of thermoplastic polymers. Based on the publication and project study, a large majority of high impact polymer research in Estonia deals with electrically conductive polymers, polymer thin films and coatings. The research is applied in areas such as solar cells, sensors, and other electronics applications. Printed and plastic electronics, for instance printing of polymer solar cells, is naturally a very potential application area for this fundamental research but it is not directly related to the activities going on in the plastics producing industry.

34 Statistics Estonia
35 Mihkel Susi, Estonian plastics industry association
36 http://www.plasticseurope.org/plastics-industry/value-chain.aspx

Currently, collaboration between companies and universities is not common for the plastics industry. The main challenge for developing co-operation is the fact that universities and companies are focusing on very different actions. University researchers focus very much on fundamental research and materials characteristics whereas the plastics industry would primarily need educated workforce that is able to use and install machinery. People educated at the universities do not have the practical skills required by the industry and they need a lot of preparation before being able to successfully work in the industry. Thus the primary need in the plastics industry is to find a common language between universities and industry before any large scale technology transfer can be carried out in Estonia.

Global perspective and trends

The plastics industry has high significance to the European economy as more than 1.6 million people work in over 50,000 companies that generate in total 300 billion Euros of revenue annually. Largest consumers of plastics in Europe by materials volume include packaging industry (40.1% of the 45Mt consumption), construction industry (20.4%), automotive industry (7.0%) and electrical and electronic equipment manufacturers (5.6%). Similarly to Estonia, the plastics industry suffered globally from the recession but several important trends in innovation mean that especially high value added plastics products will enjoy market growth in the future. The most important industry trends can be found in transportation, construction, electrical equipment, packaging and healthcare.

Plastics have huge potential in the transportation sector, where the key for future development is the reduction of weight of the vehicles. According to the European Plastics Converters, 9.3% of the materials used in cars, by weight, are currently plastic and up to 75% are still different metals[37]. However, plastics already compose more than 50% of the volume of the car. This means that by introducing components based on novel plastics or polymer composites, significant improvements in the fuel economy of cars and airplanes can be achieved. For the transportation industry, plastics also enable manufacturing of novel molded structures that are not possible to achieve with metals.

Another huge market for future will be the quickly emerging plastic electronics. Based on the advances in polymer technology, plastics can be the core material in technologies such as OLED (organic light emitting diode) based displays and lighting, solar photovoltaics (thin film solar cells and organic solar cells) and smart packaging solutions. The plastics electronics enables roll-to-roll mass manufacturing of electrical and electronic structures by printing conducting and semiconducting inks on a thin plastic film. The developments in printed and plastic electronics are closely linked to future packaging technologies, where they enable integration of electronics into packaging resulting in smart packaging products that can e.g. sense if the food in the package is still edible. Printed electronics also play a key role in the development of healthcare technologies, where it will enable e.g. various lab-on-a-chip applications used for constant monitoring of patient health without the need for surgical operations.

In addition to technological trends and development, life cycle management issues are considered of key importance in the plastics sector. This is due to the fact that most plastics are produced from non-renewable raw materials and the properties of the material mean that most of the synthetic plastics currently disposed could be utilised in production of new plastic products or at least in energy use. Another aspect worth mentioning is the continuously increasing use of natural renewable raw materials for plastics.

Summary and conclusions

- In plastics industry, there is a clear mismatch between industry needs and university R&D supply
  - Subcontracting and plastics converting vs. advanced polymer materials

- R&D work
  - Relevant activities at TUT, TU, ENCC
  - Mostly related to very advanced polymer materials, electroactive polymers and electrically conductive polymers, that are not in the interest of bulk industry

37 http://www.plasticsconverters.eu/markets/automotive

- Recommendations for the plastics industry
  - There is a clear need for higher added value products in the Estonian plastic industry
    - This calls for more collaboration between/within companies and universities
    - Current subcontracting business models are making collaboration difficult
  - Plastics are extremely important materials for the future
    - Polymer composites for transportation, construction and machinery
    - Plastic and printed electronics (lighting, packaging, solar cells, ...)
    - Packaging
  - Interesting companies
    - Estiko Plastar, Nordbiochem
  - And more concrete comments:
    - Plastics industry would need an independent development centre.
    - Universities are very much on the chemical side: how to bridge the gap with industry? Give some teaching about practical work and internships
    - The technology investments programme (EAS) was popular among plastic industry. The industry believes it should be restarted.

Case: Estiko Plastar

Background

The company was orginally established already in 1917, being a comb factory at the time. In 1991 the enterprise was registered as a public limited company – Estiko Plastar AS. From that time the enterprise has been operating as one of the leading manufacturers of packaging materials in the Baltic region, also competing successfully in the local markets in Scandinavia, Russia, Ireland and other export markets. The company currently employs around150 people.

Thanks to the modern flexographic printing presses, Estiko Plastar offers high quality solutions printed in up to eight colours for the packages of many food products. Clients include e.g.

- **Milk industries:** Packages for milk, yoghurt, sour cream, mayonnaise, ice-cream, and cheese
- **Meat and fish industries:** Packages for meat, sausage, dumplings, fish and shrimp
- **Confectioneries:** Packages for candy, biscuits, chocolate and bread.

Their **competive advantage** compared to baltic competitors is better technology with its newly upgraded production, and compared to nordic competitors is better price. **Vision:** To be the first choice as a producer of packages and packaging materials in the target market.

R&D

From EstikoPlastar point of view basic R&D means product engineering, i.e. tailoring the products with properties according to customer needs.

Exceptional on Estonian scale, the owners have put effort into renewal of the company through long term development by **hiring an R&D project manager**, Dr Lange, who is an expert in the field of material science. Projects involve EU-projects, contract research from Estonian universities and typically have a time-scale of 2-5 years. Dr Lange does also technology scouting by e.g. attending international conferences in the area he is also responsible for all R&D related contacts and networks in the company. The aim is to increase the use of plastics through e.g. including electronics, and be aware of the newest trends to be able to change production rapidly to answer the demand of the markets.

University-Company collaboration

Estiko Plastar is a partner in the Estonian Nanotechnology Competence Centre, where they are working together with Tartu University on developing plastic film properties, with the main objective to reinforce the plastics with a minor doping of carbon nanomaterials. Collaboration with Tartu University, Physics department is twofold as they do some properties measurements with Estiko Plastar's machines. Estiko Plastar has also done some contract research with Tallinn University of Technology, Department of Polymer Materials.

The company would be interested in hiring university students. However, this could be made more attractive for companies. The supervision of thesis work is a big investment, most of this should still be managed by the university staff.

Lessons learned/key success factors from the interview

- Plastics market is very saturated. To survive in the growing competition you have to do research.
- Estonian companies can provide interesting work places for university graduates.

Contact and more information: Sven Lange, sven@estiko.ee, http://www.plastar.ee/

Case: NordBioChem OÜ

Background

NordBioChem is a private, 10 people R&D Management Company located in Põlva in South Estonia. Technology development started in 1997 and in 2003 NordBioChem was established. The leading idea was originally development of technologies that could replace oil in basic bulk chemistry with renewables and battle the quickly rising oil prices. Eventually Lactic-Acid chemistry was chosen to the main technological focus area of the company.

Most notably, NordBioChem is the owner of most international patents in Estonia with 11 currently published patents and several patent applications. The amount of patents is closely linked with NordBioChem's project based business model of being a R&D management company that aims to transferring the results of their technology development to manufacturing companies by technology licensing deals.

Materials technology

NordBioChem's technology platform for Lactic-acid chemistry is targeted at substituting and replacing petrochemicals in various applications. The technology uses renewable non-food raw materials for production of e.g. lactide, polylactic acid, propylene glycol, propylene oxide and acrylic acid by a fermentation and chemical derivatisation process.

The technology is claimed to be significantly more efficient, cost-effective (on process as well as on investment level), energy effective and environmentally friendly (low CO_2 and waste emission) than any competing technology available – including petrochemistry at the current oil price. In practice this means that there is potentially a multi-billion dollar market annually for the technology in chemistry as well as in agriculture. However, competitors are already in the market including leading chemical producing companies such as Dow Chemicals, BASF and NatureWorks, which is the leading biopolymers manufacturer in the world.

R&D

Similarly to many Estonian technology development companies, NordBioChem operates with a minimal amount of employees coordinating the day-to-day work and R&D activities. This means that NordBioChem owns neither hardware nor employs any researchers itself. Most of the research and development is outsourced to universities and research institutes in Western Europe and Russia. NordBioChem's technology is currently in the final phase of development and ready for industrial implementation.

University-Company collaboration

NordBioChem's business model means that they are closely connected to various universities and research institutes around Europe. However, there is currently poor co-operation with Estonian partners due to a few drawbacks. Firstly, there is a lack of researchers working in biopolymers related technology and secondly, it is very difficult to find competent graduates or students who could be applicable for the company. Moreover, NordBioChem feels it is difficult to co-operate with Estonian universities and public sector organizations due to bureaucracy and their limited ability and willingness to support companies to succeed. To universities, NordBioChem would suggest more ambitious fundamental research as that is the only way to develop necessary high class competencies in the country.

Summary and key factors for future

The key target for NordBioChem at the moment is to find an investor, which would be willing to establish an industrial production facility based on NordBioChem's technology. This would require a relatively huge investment and it is highly unlikely that Estonian companies or investors would be interested in such a project. Therefore, the company is negotiating with various international players for the possibilities to either license or buy the technology to establish production.

As a conclusion:

- NordBioChem has developed economically very effective and very sustainable breakthrough technology for bulk-size basic chemistry allowing for the replacement of oil with renewable non-food sources.
- The Estonian based NordBioChem has done most of its technological development, including creating 10 patents, outside of Estonia
- The still in private Estonian ownership company has benefitted from Estonian public development support programs, but that wasn't sufficient for commercial implementation of these technologies

Contact and more information: Vambola Kolbakov, http://www.nordbiochem.eu

2.4.5 Construction materials

Industry overview

There is a lot of diversity in the Estonian construction materials industry. The sector consists of companies producing basic materials such as cement as well as glass and prefabricated building components. Some of the largest construction materials providers in Estonia include Krimelte (Sealants and insulating foams), Ruukki Products (steel), Henkel Makroflex (foams and sealants), ES Sadolin (paints and alkyds) and Kunda Nordic Tsement (cement). The largest areas of construction materials produced in Estonia are therefore mineral based products (cement, concrete and mortar, lime and clinker), construction chemicals (paints, alkyds, sealants and foams) and prefabricated structural components for civil engineering (e.g. windows).

In total, the sales of the member companies of the Association of Construction Material Producers of Estonia were 687 million EUR in 2007 before the economic downturn and the industry employed about 5000 people at the time. Construction materials industry is mostly rather local due to the relatively low price of raw materials and massive products that are expensive to ship to distant locations. About 27% of construction materials produced in Estonia were exported mainly to neighbouring countries such as Latvia, Lithuania, Finland and Russia. Krimelte is among the largest exporters with approximately 95% of production exported, mainly to Russia.

R&D and education: national resources and international comparison

Most of the producers use domestic raw materials and the plants are usually situated close to the natural resources, which include sand, clay, limestone and dolomite. Utilisation of oil shale fly ash and other waste is another source for construction materials studied in Tallinn University of Technology but has not resulted in high volume industrial utilisation yet. High level research and education related to civil engineering and construction materials is mostly done at Tallinn University of Technology and partly at Estonian Agricultural University. Vocational education is given at Tallinn Technical School.[38] In addition to abovementioned fields, steel is another globally important construction material but Estonia mostly lacks the basic metals production sector and therefore, constructional steelwork is not further discussed in the study.

The main advantages of the Estonian construction materials sector are the access to inexpensive natural resources locally and low production costs due to relatively low salaries. However, the companies in Estonia are quite small and have neither high ability nor drive to adopt advanced technologies.

38 http://www.investinestonia.com/en/key-sectors/construction-materials

Advanced materials, especially nanomaterials for the construction sector have been assessed in the EU FP7 ObservatoryNANO project[39,40]. From the materials technology point of view, construction materials is a very important sector as it has high importance for Europe providing infrastructure on which all sectors of the economy depend. Key drivers for adopting new technologies and new materials in the construction sector are enhancing sustainability and improving product properties e.g. in terms of service life, easier maintenance and cleaner production processes. However, the biggest barrier for adopting new technologies is their high price and also lack of large-volume availability. Today, approximately 1% of construction related products have nanotechnology enhanced features and therefore the significance of advanced materials technologies for construction is currently very low. The most relevant areas for utilising advanced materials in the construction sector include:

- Construction ceramics
  - Self-cleaning, anti-bacterial, hygienic and scratch resistant features

- Cement
  - E.g. stronger, more durable, self-healing, air purifying, fire resistant features

- Windows and glass
  - Multifunctional windows, energy saving, easy cleaning, UV controlling and photovoltaic features

- Insulation materials
  - High performance insulation

- Paint
  - Rheology, settling, surface energy, corrosion resistance and mechanical properties improvement

There is currently some production in all the above mentioned fields in Estonia but the share of advanced materials technologies is currently very low. The main player in the field of applying advanced materials for the construction sector is the Estonian Nanotechnology Competence Centre. The centre partners with companies like Andrese Klaas, Safran and Savekate for applying nanotechnology in the companies' products: windows, clay based building materials and floor constructions, respectively. Nanotechnology research applicable to construction materials is conducted at the University of Tartu, Institute of Physics in areas of sol-gel technology, nanofilms and nanomaterials. These are, however, very far away from commercialisation and high volume production.

Relevant research in the field is conducted at almost all universities in Estonia, most notably at Tallinn University of Technology in the faculties of mechanical engineering and civil engineering. One notable area is the use of composites as constructional materials. Most of the related research is, however, focused on the metals and machinery sector and applications related to construction industry have not been commercialised. Research in the area is also conducted at the Tallinn University of Applied Sciences in the fields of hardening and strengthening technologies and different kinds of coatings. Third notable area is the utilisation of oil shale waste for construction materials such as Portland cement. Estonia also has a relatively very strong chemicals industry and large university departments in chemistry, which can provide skilled workforce to companies.

Technology transfer potential

In conclusion, the following areas with potential regarding advanced materials in Estonia can be identified.

Cement and concrete

There are several large companies in Estonia producing cement and concrete. These include Kunda Nordic Tsement, Rudus, Tartu Maja Betoontooted and E-Betoonelement. Most important university research initiatives are related to the utilisation of oil shale waste as a constituent for cement production. In Europe, companies such as Italcementi, Heidelberg Cement, Lafarge, Clariant, Nanogate and BASF have already entered the market with either nanoenhanced cement or nanoadditives for cement / concrete products. Thus it is very difficult for Estonian companies to grasp a competitive advantage in the cement and concrete sector with regard to advanced materials.

39 ObservatoryNANO: Economical Assessment / Construction sector (2009)
40 ObservatoryNANO: Focus Report 2010: Adhesives and Sealants

Window and glass

There are also several large window manufacturing companies in Estonia. These include Saint-Gobain Klaas, O-I Production and Andrese Grupi. High level physics research in nanomaterials, thin films and photovoltaics is to some extent utilisable by the glass industry. However, only Andrese Grupi is established with Estonian capital and therefore other companies will be unlikely to have high interest in conducting R&D work in Estonia. Andrese Klaas, a part of Andrese Grupi is currently collaborating with the Estonian Nanotechnology Competence Centre for developing functional coatings. In Europe, Pilkington and Saint Gobain are leading producers of multifunctional advanced glass both for construction sector and for automotive industry and thus entering the market will be difficult for Estonian companies which are very little on the global scale. Largest barrier for market entry of nanoenhanced glass is the price, which is approximately 30-80% higher than the traditional glass.

Insulation materials

Large insulation materials companies located in Estonia include Krimelte and Henkel Makroflex. Especially Krimelte, which as a company running on Estonian capital is very interesting for the future. More about these companies can be found in the company case study section. Globally, companies such as BASF, Aspen Aerogels and Cabot Corporation already have nanotechnology enabled products in the market.

Paints and construction chemicals

The largest Estonian paint production company is ES Sadolin, which has received an investment from Akzo Nobel Coatings. Based on the high national importance of chemical industry and chemistry research in Estonia, there are some R&D resources that could be utilised in the paints and construction chemicals sectors. However, there are already several companies with nanoenhanced paints on the market including Akzo Nobel, Jotun, Bioni CS and Yasar Paint and Chemicals.

Summary and conclusions

- Construction materials is the most varied sector of all compared

- R&D work
  - Very dependent of the raw material and application (minerals, oil shale, textiles, wood, chemicals)
  - Dedicated research done mostly at TUT. Chemistry and physics also at TU, KBFI and ENCC.

- Construction materials is and will be an important sector for Estonia in the future

- The industry is by nature quite local
  - 27% of construction materials go to exports and mostly to neighboring countries

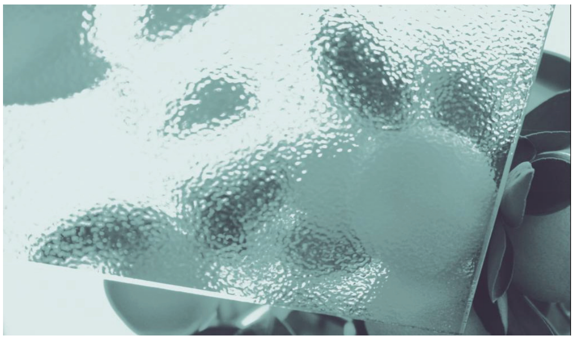
- Several large companies with very advanced products are present in the global market and it will be difficult for Estonian companies to produce advanced materials solutions that would have a significant competitive advantage. However, some niche solutions could gain even a big market share. (Ref to e.g. Silvergreen in Finland)

- There are very interesting initiatives related to advanced materials related to construction materials
  - ENCC, Andrese Klaasi, Clay Processing Services

Case: Andrese Klaas AS

Background

The company was established in 1995 and currently employs 24 people; 16 of these are in production. The main activity area is the processing of flat glass and mirror based on the needs of customers and to create added value products.



Products can be divided into three categories

- Security/Laminated glass (tempered, PVB and resin)
- Fire resistant glass
- Design matted glass + processing of glass

The main **customers** of Andrese Klaasi AS are manufacturing, building and interior design companies located in the Baltic States, Russia and Scandinavian countries. The final products include balcony glazing, sauna doors, wall mirrors, shower cabins and interior doors. **Competitors** are other glass processing companies.

Vision: To become the Baltic market leader as a manufacturer of safety and fire resistant glass.

R&D

Andrese Klaasi is a small innovative company, willing to invest return into R&D. They have a R&D focus to be able to develop with the market and offer clients something innovative every year. However, there have been fewer projects in the last couple of years due to the recension. They believe in the innovativeness of the personnel. Andrese Klaasi has also created a training system for its employees, where once a year the development of the employees is evaluated.

Andrese Klaasi has had several R&D projects.They have e.g. developed chemically-edged glass, which can be used instead of sand glass in e.g. design glass walls. Chemically edged glass is of better quality than sand glass, which gets dirty over time and cannot be washed.

University-Company collaboration

Andrese Klaasi is a partner at the Estonian Nanotechnology Competence Centre, were they are working together with Tartu University on functional coatings for glass surface (e.g. for actively shaded windows). Andrese plans to further develop the LCD-screen into window size. There has been international interest for the product. Current LCD shaded windows are too expensive.

Andrese has had a project with Tallinn University of Technolgy on measuring the pressure in tensic glass. Previously this has been possible only by breaking the glass. Unfortunately, the project was ended due to lack of funding. Information on the newest technologies mainly comes from customer needs and long relationship with partnering companies.

Andrese would be ready to hire more university students. However, currently the salary expenses are too high. Andrese Klaasi is planning to make its own fire resistant glass, at that moment they have the first Sampole ready and they are co-operating with a big chemistry company from Germany whois also interested to proceed with this project. Secondly, Andrese Klaasi is searching for new possibilities for designing the glass (beside the chemically edged): printed or painted or some other possibilities that could offer the market something new.

Lessons learned/key success factors from the interview

- The company would like employees with a mix of theoretical knowledge obtained at university and practical skills that could be developed from work experience at firms.
- Unfortunately there are too many new materials technology solutions information available, technology scouting takes time.

Contact and more information:
Gerd Veelma, CEO, **gerd.veelma@andres.ee**, http://www.andresklaas.ee/eng/

2.4.6 Textiles industry

Industry background

Textiles industry has traditionally been very strong in Estonia and it still employs approximately 14 000 people (~13% of the total industrial workforce) and generates 7% of the whole industrial production. The industry accounted for 5% of all Estonian exports in 2007.

Main product groups of the Estonian textile industry are clothing, home textiles and technical textiles. Main export articles are clothes, home textiles and knitted garments. The Estonian Clothing and Textile Association (ECTA) divides the sector into clothing and textiles subsectors in its statistics. By this division, clothing corresponds to approximately 38% of total industry production whereas the share of textiles production is 62%. The majority of people in textiles industry are, however, employed by clothing companies that employ almost 10000 people compared to other textiles production that employs close to 6000 people (2008 figures). The number of employees has dramatically decreased during the last years as the employee count has declined almost 50% from the peak years in 2001-2003 when almost 25000 people were employed by the industry.

The breakdown between the subsectors is somewhat different than the situation in the EU, where clothing accounts for 41% of total textiles industry production. The clothing industry in Europe is in difficult position due to the price pressure coming from low cost countries, especially in Asia. Thus it is generally acknowledged that the industry needs to clearly focus in high added value products in the future, where different technical textiles and products integrated with other materials groups play a key role. In Estonia, a very large share of non-clothing producing companies is producing home and interior textiles and there is very little production of industrial or technical textiles. In the interviews of key Estonian stakeholders, Ilves Ekstra and Toom Tekstiili were mentioned among companies more oriented to higher value added technical textiles.

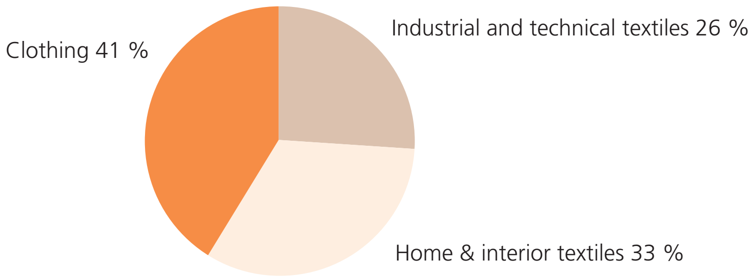


***Figure 9. Breakdown of textile industry sectors by fiber usage in Europe*[41]**

Among the 500 largest companies in Estonia, there are four textiles industry companies. The largest companies by far in the industry are Silvano Fashion group producing lingerie and Wendre that produces various home textiles. Other two textiles producers among the largest companies are Toom Tekstiili that produces home textiles and non-woven textiles for different purposes such as industrial and technical use. The fourth largest company, Mivar, is also producing home textiles.

Textile industry trends

The key trend in textile industry, especially for Europe, is the focus on adding more value to textile products and focusing the industry more on technical textiles. The strategic research agenda of the European Technology Platform for the Future of Textiles and Clothing outlined three major development trends:

- From commodities towards specialities (along the entire value chain)
- New textile applications (for different industrial sectors and application fields)
- Towards customisation (rather than mass manufacturing)

The textile industry and value chains are very complex as can be seen in Figure 10, which represents the textile industry value chain from fibre production to recycling of the final product. The raw materials of the industry are natural fibres but also man-made fibres of e.g. polymers. The intermediate products – thread, fabric and garment – are used by three notable subsectors including clothing, home textiles and various industrial applications.

41 http://www.euratex.eu/system/files/attached-files/broch-sra-def.pdf

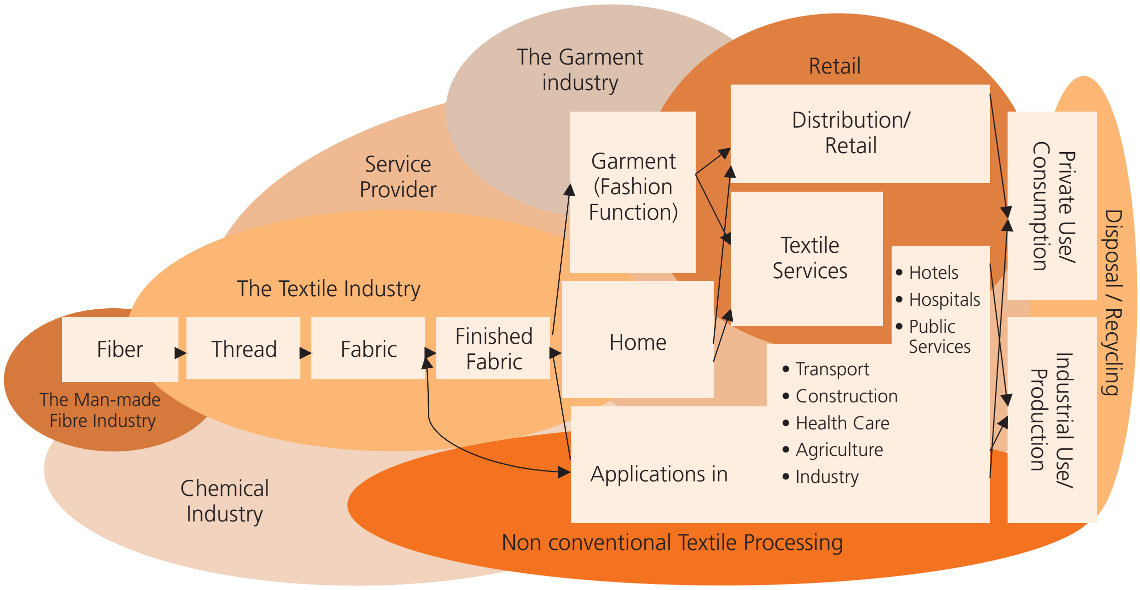


Figure 10. The world of textiles and garments

Adapted from the Strategic Research Agenda of the European Technology Platform for the future of textiles and clothing.

According to the SRA, there is some growth potential identified in clothing and home textiles but the highest growth in the future will be seen in technical textiles. Advancements in textile technology mean that textiles or textile-based composites may replace many of today's metallic and plastic materials used in various industries such as transportation, construction, machinery, electronics and medical. Total consumption of technical textiles in Western Europe was estimated to be 35,6 billion Euros in 2004, divided among the following application areas:

- Transportation 21,2%
- Protective textiles 20,2%
- Construction 15,3%
- Wooden furniture 9,0%
- Medical, pharma and health 8,1%
- Other 26,2%

The SRA defines several examples of future high value added textiles products. These include light-weight textile roofing, textile-reinforced concrete, erosion and landslide protection systems and also various multifunctional textile materials such as flame retardant materials, odour absorbing textiles, anti-bacterial textiles and stain or water repellent textiles. One other important area in the future is smart or intelligent clothing, which includes the use of multifunctional materials but also integration of various other technologies in textiles products including sensors, actuators and electricity harvesting and storage.

The key messages defined by the SRA very much apply to Estonia as well:

- Substitution of textiles by other materials is not expected and the industry will grow in the future due to new applications
- Importance of research and innovation for industry competitiveness will increase
- More networking and technology transfer is required in the European textiles industry

Summary and conclusions

- In summary, the textiles industry is still very important to the Estonian economy. The largest drawback, however, is that the industry's focus is almost solely on clothing and home textiles, which are rather stagnant areas in terms of industry growth.
  - Textiles industry needs to start looking for higher value added products
  - There is currently very little technology transfer potential seen.

- However, some interesting spearheads can be found in the industry including the collaboration between the Estonian Nanotechnology Competence Centre and Haine Paelavabrik as well as Toom Tekstiil and Esfil Tehno producing non-woven textiles. There is also potential support available from the researchers of fundamental physics and chemistry in the country.

- Implications for the industry for materials technology adaptation and development:
  - The industry is currently very much focused on clothing and home textiles, which are sectors with little growth in the future
  - The size of Estonian textiles industry means that there would be potential in adopting more value added technologies
  - There is currently little research and development work done at universities but especially companies
  - Collaboration between companies and universities should be heavily increased to transfer advanced technologies and educated workforce to the industry
  - Future development of the national industry should start with key stakeholders in the area
  - TUT (Textile technology), TKTK (textile technology), ENCC, Esfil Tehno, Toom Tekstiil, other large textiles companies

Case: Esfil Techno

ESFIL TEHNO

Background

ESFIL TEHNO AS is a manufacturing company established in 1964 in Sillamäe, the northeastern part of Estonia. The company employs currently approxiametely 80 employees, of which 10 are in head office and the rest work production. The company has 10 production lines which each require 8 people working in 3 shifts, and were already in use during the Soviet times. Exceptional in Estonia, the company has put up a production plant based on the technology it has developed itself.

Esfil Techno develops and produces by electrospinning highly efficient non-woven polymer filtering materials made of micro and nano fibres. These materials are used in their product which include

- Products-respirators
- Analytical tapes for radiation
- Water Filters and separation materials for battaries
- Air filtration

Historically, their most sold products have been respirators for nuclear power plants, as they were the main producer in the Soviet Union. Still the biggest **customers** are in Russia and former Soviet countries. Five years ago the company decided to expand to the European market. Largest **competition** includes companies like Ahlström. Current success factor relies on the technology developed in-house and the experience of mass production of ultrathin fibers. The materials and technology of the products are patented in national and European patent boards.

Technology relies on electrospinning. Electrospinning is a method for preparation of ultrathin fibers, used for e.g. textiles to produce seamless non-woven garments by integrating advanced manufacturing with fibre electrospinning. This would introduce multi-functionality including flame, chemical, environmental protection. The challenge is in difficulties of handling the barely visible fibres. Medicine is another very interesting application area including e.g. tissue engineering and drug delivery. Currently the technology has mostly only been applied on the laboratory scale.

R&D & University-Company collaboration

Esfil Techno is actively looking for new partners and ideas where to use their technology. Esfil Techno claims to have the only mass-scale production plant of electrospinning in Europe and is thus currently seen as an interesting partner for European projects. They are a partner in two researches for SMEs projects:

- New concept and technology for high energy rock fall protection fences
- Ambulatory magneto-enhancement of transdermal high yield silver therapy

The projects are funded by the commission and the research is done in, i.e. subcontracted from, a couple of universities. Esfil Techno gets the IPR. Also the European partners in the projects are seen as very important contacts. Esfil Techno has tried to collaborate with Tallinn Technical University but has not found the right partners.

Lessons learned/key success factors from the interview

- Currently the company suffers from the machinery getting old and inefficient – large investments are soon needed.
- Sales and marketing of the technology also requires more effort.
- The technology is almost too good for the current products. How to successfully find new partners and applications?

Contact and more information: Araik Karapetjan, CEO esfiltehno@esfiltehno.ee

2.5 Advanced materials technologies: Commercialisation and technology transfer

2.5.1 Overview

There are several interesting companies in Estonia developing and manufacturing high technology products based on advanced materials and a lot of relevant activities are on-going at universities that may result in new advanced materials inventions in the future with significant potential for technology transfer. In addition to research and development activities, there are already some well-established areas related to materials technologies in Estonia.

This section discusses the state of various advanced materials technologies in Estonia taking into account research and development activities performed at universities and research institutions as well as technology development done at start-up companies and more established enterprises. The section is organised according to the estimated Technology Readiness Level of the Estonian materials technologies. Technology Readiness Level is a tool for measuring technology maturity and assessing technology related risks. It is used by several international organisations such as NASA and ESA.

Technology Readiness Level scheme used for this study is based on five levels and the scheme is currently implemented by EU FP7 financed project ObservatoryNANO that uses it for assessing the readiness and impact of various nanotechnologies for the European economy. The levels in the scheme are:

- Fundamental research (TRL 1)
- Applied research (TRL 2)
- Prototype (TRL 3)
- Market entry (TRL 4)
- Mature markets (TRL 5)

Fundamental research is typically conducted at universities and research institutes and focuses on studying e.g. materials properties and characterisation. From fundamental research phase, it may typically take 5-20 years to reach the market with a new product.

Applied research is done in the interface between companies and universities. It focuses on studying and developing materials for an already identified application and the work typically results in, e.g., components or materials that solve some problem in the industry or offer a new material for an industrial application. Depending on the material and industry application, it may take 2-10 years for a technology to enter the market from applied research phase.

As the name suggests, **prototype** products mean industrially applicable products that are very close to the final solution to be sold in the market. Technology development activities focus on improving the products properties but most effort needed in the prototype phase is establishing the business and starting sales activities. When the first prototypes have been produced, it typically takes 1-3 years to start commercial production.

Market entry can be considered to happen when the company starts selling its products on a larger scale and the business is expected to be profitable. Development activities are related to the improvement of the technology. In case of a completely new technology, there are often significant differences in the products of competing companies.

In the **Mature market** phase the product has been in the market for several years and there are only small differences between competing products. Technology development activities are related to improving the existing products and creating new features or completely novel, disruptive technologies that provide a competitive advantage to the companies. Most of the investments and development are related to the improvement of production processes.

Based on the findings from the interviews of Estonian stakeholders, publication and patent study, research project database and the research group questionnaire, the status of advanced materials technologies in Estonia has been composed in Figure 11. The technologies will be discussed starting from the most mature ones and ending with fundamental research.

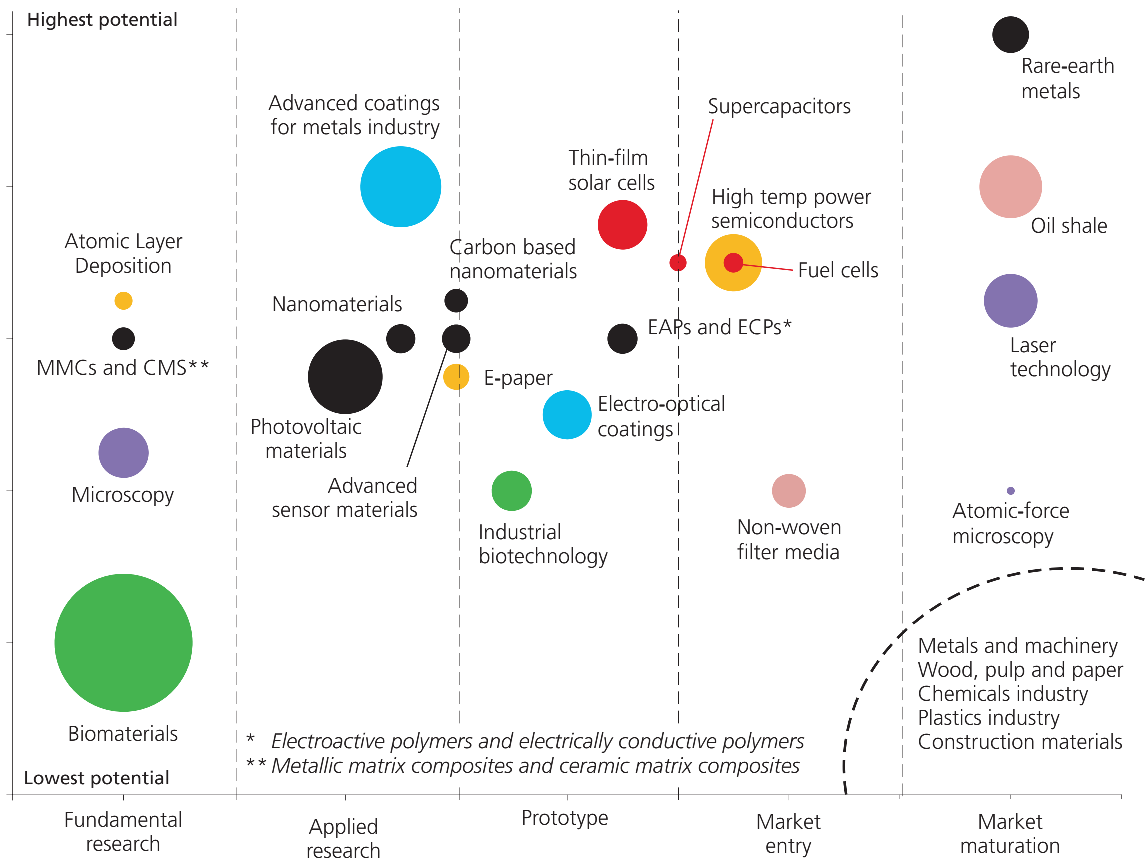


Figure 11. Characterisation of the selected industry areas in relation to materials technology

The circle size indicates the estimated global market size around 2015. The y-axis represents a relative technological and business potential of selected technologies. Technologies with highest estimated potential have both strong university and industry support (e.g. rare-earth metals and oil shale). Technologies in the middle section typically lack industry support (e.g. thin film solar cells where only one Estonian company exists). Technologies in the lower section lack Estonian wide R&D activities and typically only one party capable of developing the technology exists. Colors in the figure symbolise those areas shown in Figure 12.

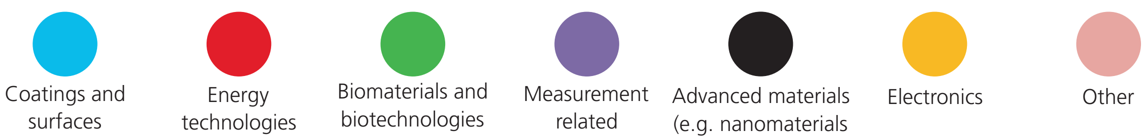


Figure 12. Colour codes of Figure 11

Almost all of the well established companies in the materials technology related industries described above are working in mature markets and have very mature technologies. Their technology potential is generally speaking very low and therefore they have been depicted in the lower right corner of Figure 11. The large majority of companies are doing subcontracting, which means that they have little technology development activities and therefore are unlikely to come up with new materials technology inventions. The key goal of technology transfer is to transfer knowledge and advanced materials technology from universities and innovative SMEs to these well established companies and as a result aim for higher added value products.

Other mature market technology areas with more technology potential include oil shale technology, rare-earth metals and oxides related technology and atomic force microscopy.

The global **oil shale** market is estimated to grow to 12 billion USD by 2015[42]. Estonia is currently the only country, which uses oil shale as the main source of energy and there is a large amount of expertise present in the country from the global viewpoint. Most of the oil shale related activities are, however, directed to the energy use but as a vast natural resource for the country, there is high potential in utilising oil shale and oil shale waste as raw material for various chemicals and polymers.

Similarly to oil shale, **rare-earth metals** are an important natural resource already being produced in Estonia by Silmet. The global market for rare earth elements is currently estimated at 1.4 billion USD and is anticipated to reach 4.1 billion USD by 2017.[43] Rare earth elements are a key ingredient in many high technologies based on advanced materials and therefore Estonia should seriously focus in exploiting this rare natural resource. Some collaborative projects have already been executed with Silmet and Estonian universities and there is a strong will nationally to put more effort in technology development.

Laser technology and Atomic Force Microscopy are the spearheads of technology commercialisation related to Estonian measurement. The laser technology research has been traditionally strong at the University of Tartu and there are companies such as Laser Diagnostic Instruments, Neweks, ESTLA and SEMENTO manufacturing and selling laser equipment. The global laser market is huge and is expected to reach 8.8 billion USD by 2014.[44] The laser market is rather mature and therefore it is difficult for Estonian companies to grow with the traditional offering. However, with the high research expertise and well established company base, the commercialisation of new laser technology in clever niche areas has clear potential for the country.

The market for Atomic Force Microscopy is currently estimated at around 100 million USD[45] and the annual market for AFM probes at 50 million USD[46]. MikroMasch has established a solid position in the probe market and is a good example of a company that succeeds in a specific very high technology niche area.

Therefore it can be concluded that with clever collaboration between Estonian universities and SMEs, the country could potentially start utilising its state-of-the-art measurement equipment better and provide considerable sales in the area as well as good foundation for other advanced materials commercialisation.

2.5.2 Technologies close to market entry

There is a considerable amount of advanced materials technologies close to market entry in Estonia. This has resulted from good inventions made at Estonian universities and start-up companies after extensive research and development with relatively low resources available. This set of companies and technologies include:

- Technologies close to market entry
  - Non-woven filter media for new applications (Esfil Tehno)
  - Fuel cells (Elcogen, collaboration with TU and KBFI)
  - High temperature power semiconductors (Clifton, TU spin-off)
  - Supercapacitors (Skeleton Technologies, similar activities in TU)

- Technologies in prototyping
  - Thin-film solar cells (Crystalsol, TUT spinoff)
  - Electroactive polymers and electrically conductive polymers (e.g. Fits.me, TU spin-off)
  - Electro-optical coatings (Andrese Klaas, collaboration with ENCC)
  - Biopolymers (NordBioChem, technology development done abroad)
  - E-paper (Visitret Displays, collaboration with TU)

42 MarketsandMarkets: Global Oil Shale Market (2011)
43 WinterGreen Research: Rare Earth Metal Market Shares, Strategies and Forecasts, Worldwide, 2011 to 2017
44 Laser 2010
45 ResearchandMarkets
46 MEMS Investor Journal

From the application side, it is notable that half of the technologies close to market entry are related to energy applications. Fuel cell technology is developed by Elcogen with university support from Tartu University (TU) and National Institute of Chemical Physics and Biophysics (KBFI). The market for fuel cells is currently estimated at 600 million USD and projected to grow up to 1.2 billion USD by 2014.[47] Skeleton Technologies aims to take their share of the 900 million USD supercapacitor market (2014)[48] in the coming years. Clifton develops high temperature power semiconductors (diodes and transistors) to the market of 6 billion USD (2010)[49], which is projected to grow up to 70% per annum. Crystalsol develops an innovative monograin thin film solar cell technology, the market of which is expected to grow up to 7.5 – 10 billion EUR by 2015.[50]

From non-energy side, Fits.me is commercialising Tartu University originated electroactive polymer technology with their robot mannequin product. On a more general level, the market for electroactive polymers and electrically conductive polymers is estimated to reach 2.78 billion USD by 2014[51] with very broad range of applications in e.g. printed electronics, OLEDs, solar cells, batteries, sensors, actuators, textiles and fabrics as well as packaging. Electroactive polymers are studied at both Tartu University and Tallinn University of Technology and they will be very important materials for electronics in the future.

Together with the Estonian Nanotechnology Competence Centre, Andrese Klaas is developing electro-optical glass coatings, which enable e.g. electrically shaded windows. The technology is at the moment in applied research and prototyping phase. Various coatings technologies for optics, electronics and metals are widely studied in Estonia and therefore there is high potential related to coatings technologies. The optical coatings market, for instance, is projected to reach 7.4 billion USD by 2012[52] with applications in flat-panel displays, cameras as well as various medical and transportation applications.

Visitret Displays is a company commercialising E-paper technology in co-operation with University of Tartu. The company has successfully closed two investment rounds during 2009-2010 and is heading its product to the quickly growing E-paper market that is projected to reach 2.1 billion USD in 2015 and up to 7 billion USD by 2020.[53]

NordBioChem and Esfil Tehno have rather different origins compared to other companies targeting for market entry in a short period. Esfil Tehno is a fiber product company with 40 years of experience in the production of non-woven polymer filtering materials. The applications range from filtering of toxic, poisonous and radioactive aerosols to the use of fiber materials for landslide prevention. The company uses Russian originated and very advanced electrospinning technology. The market for non-woven filter media will grow to 3.5 billion USD by 2015[54] and potential applications for the technology in other markets are huge, too. NordBioChem is a technology development company that coordinates technology development work for biopolymers technology, buying technology development itself from universities and research institutes around the world. The company estimates that potential market for its products is approximately 5 billion USD annually.

Advanced modelling and computation play a key role today in all advanced materials research and development as they reduce the need for practical experimentation and provide invaluable insight to the behaviour of chemical and physical reactions of materials prior to taking the results into practice. Notable computing expertise exists e.g. in computational modelling of materials conducted in the research groups of Professor Karelson at both the Tartu university and Tallinn university of Tehcnology in the field of computational chemistry. The research results are being commercialised by Molcode and Baltic Technologies that are developing technology for computational prediction of the properties of chemical compounds and materials.

Common challenge for all companies and technologies in the commercialisation phase is obtaining funding for establishing production. All the above mentioned technologies have very high potential from technological viewpoint but still require a lot of effort in transforming the potential into commercially feasible product. As can be seen in Figure 11, all of these companies are aiming at rather large markets where finding a suitable niche area is possible for a technology start-up. All of the companies have potential to start generating tens of millions of Euros revenue in 5 years of time, which would already mean a notable effect on the Estonian economy. It is, however, impossible to say, how many and which of the companies will succeed. Key issue to their success will be to find the right partners to enter the global value chains.

47 SBI Energy
48 Lux Research
49 Clifton presentation (2010)
50 Spinverse estimate based on several market research reports
51 MarketsandMarkets: Global Electroactive Polymers Market (2009-2014)
52 Global Industry Analysts
53 Displaybank
54 BCC Research

To succeed in technology commercialisation and production scale-up, companies need rather significant investments ranging roughly from 1 to 10 million EUR or even more. This can be achieved by either attracting private (foreign) investors to invest in these start-ups or more risk taking attitude from the government in funding the start-up efforts.

2.5.3 Applied research

Some of the most interesting activities in Estonia related to advanced materials technologies are currently in the applied research phase. This includes a broad range of materials that can be applied in various high technology applications. This expertise mostly builds on the fundamental research work done at the University of Tartu and Tallinn University of Technology. In brief, the status of advanced materials development in Estonia can be summarised as follows:

- Advanced materials
  - Nanomaterials (TUT, TU, ENCC)
  - Carbon based nanomaterials (TU, ENCC, Skeleton Technologies)
  - Advanced sensor materials (TUT, TU, ENCC, Skeleton Technologies, Evikon MCI)
  - Rare-earth metals and oxides (Silmet, TU, KBFI)
  - Photovoltaic materials (TUT, TU)

- Coatings
  - Coatings for metals industry (TUT, TU)
  - Coatings and thin films for electronics and sensors (TUT, TU)

The listed areas of materials are naturally somewhat overlapping but division in the abovementioned sections gives a good overall picture of the relative size of corresponding market potential.

The largest of the fields mentioned are the markets for photovoltaic materials and nanomaterials in general. A recent estimate of the photovoltaic materials market is estimated at 6.5 billion USD and expected to grow up to 17 billion USD by 2015[55]. This includes the semiconductor materials such as crystalline silicon and amorphous silicon as well as gases, chemicals, precursors and other materials needed for solar cell production. In addition to Crystalsol that is developing solar cell products, the vast research base at Tallinn University of Technology and University of Tartu means that Estonia has also broader potential for technology transfer in the area. Materials being studied include monograin photovoltaic materials, hybrid organic-inorganic materials, thin film technology for solar cells and electrically conducting polymers.

The estimates of the global nanomaterials market vary a lot but a conservative estimate from the Freedonia Group suggests that the global nanomaterial demand will be 3.6 billion USD in 2013. This includes traditional materials in nano-scale such as silica, titanium dioxide, clays, gold and silver but also more advanced nanomaterials like carbon nanotubes. The Estonian Nanotechnology Competence Centre is heavily focusing on technology transfer of nanomaterials into commercial products with its partners and results can be expected in the coming years. The subsector of carbon nanomaterials is estimated to grow up to 1.7 billion USD by 2017 according to Nanomarkets. In Estonia, University of Tartu and Skeleton Technologies are the most important players in carbon based nanomaterials research, development and production. In addition to nanomaterials, researchers in Estonia are studying e.g. micro and nanoporous carbons and micro and mesoporous complex rare-earth metal oxides. All these materials are also highly relevant to sensor technologies. The advanced sensor materials market is expected to grow up to 2.5 billion USD by 2012, which makes 25% of the whole advanced sensor market it enables (9.4 billion USD by 2012). The Estonian Nanotechnology Competence Centre has a key role in transferring the advanced materials inventions to sensor technology applications.

Another large area with very high potential for Estonian materials technology is novel and advanced metals coatings. These technologies are mainly developed at the Tallinn University of Technology and relevant activities are ongoing also at the University of Tartu (e.g. Atomic Layer Deposition) and Tallinn University of Applied Sciences. In addition to the vast research base, the large industrial base in metals and machinery (especially special tooling) and huge materials technology megatrends in tribology and wear reduction make the metal coatings one of the most potential future fields for materials technology in Estonia. The advanced coatings market for metals industry can be roughly estimated to grow up to at least 20 billion USD by 2015, consisting of somewhat overlapping subsectors including diamond-like coatings (1.7 billion)[56], nanocoatings (13 billion)[57]

55 SEMI and Linx-AEI Consulting
56 BCC Research
57 ResearchAndMarkets

and abrasion, wear and corrosion resistant nanocoatings (900 million)[58]. Also for comparison, global markets for physical vapor deposition, which is an important deposition method for advanced coatings, is estimated at 17 billion USD[59] and global automotive coatings market at 14 billion USD[60]. Due to the nationally strong industry and huge global markets with space for clever niche applications, advanced metals coatings can be considered as having the largest potential for technology transfer activities in Estonia for the following 5 years.

Table 5 shows the overall picture of what kind of research is conducted in the research groups in the Estonian Universities and to which industry sectors the researchers themselves believe they are targeting their research. Most research groups are targeting the energy sector. The research has been discussed in more detail under the industry sectors in section 2.4. The large Electronics / ICT sector consists of research groups focusing on thin films and nanoelectronics, which are mostly centred on the fundamental research side.

Table 5. Research groups working on different materials and developing technology to different industries

Data based on questionnaire sent out to research groups in fall 2010. Estimate of overall situation.

	Total	*Metals*	*Semi-conductors*	*Ceramics, concrete*	*Polymers*	*Fiber-based materials*	*Nature-based materials*	*Biocompatible materials*	*Coatings and surface treatment*	*Optical materials*	*Magnetic materials*	*Nano-materials*
Total		19	13	11	17	7	9	7	20	13	4	21
Electronics / ICT	14	7	9						9	9		9
Forest and paper	5											
Metal	8	8										
Construction	10				6							
Machinery	11	9			7							
Energy	22	8	10		6				9	6		11
Environment	15			6	6				7			9
Chemical industry	13				9				7			
Packaging industry	1											
Textiles industry	2											
Biotechnology	12											7
Food industry	5											
Healthcare / well-being	4											
Medical / pharmaceutical	10											

2.5.4 Fundamental research

The Estonian science system is very much focused in fundamental research and most of the money received by the universities relevant for materials science is used for fundamental research of physics, chemistry and biotechnology. The commercialisation of fundamental research takes typically a very long time and results can be expected in time periods of 5 to 15 years. It is very often the case that results are never commercialised. Based on the publication study earlier in this document, the fundamental research activities in Estonia can be roughly categorised in:

- Fundamental physics: Solid state and condensed matter physics (Tartu University Institute of Physics)
- Solar cells and related materials research: Tallinn University of Technology
- Electrochemistry (Tartu University Institute of Chemistry)

58 ResearchAndMarkets
59 BCC Research
60 Frost & Sullivan

There is also a significant amount of chemistry research that is not reflected in the materials technology publications.

For depicting potential application areas of various fundamental research fields, four distinct and very different applications are included in Figure 11 including:

- Atomic Layer Deposition (mostly thin films and nanoelectronics)
- Metal-Matrix composites (novel composites for metals industry)
- Microscopy and measurement
- Biomaterials

Atomic Layer Deposition is the spearhead of nanoelectronics related research in Estonia mostly performed at the University of Tartu, Institute of Physics. ALD is also extensively applied by the Estonian Nanotechnology Competence Centre. The technology has so far had a huge impact in the development of integrated circuits but the technology market is still rather small at an estimated 1 billion USD in 2014[61]. In comparison, an estimate of the global nanoelectronics market in 2015 is a stunning 409 billion USD, which is far more than all other market size estimates given for advanced materials in this section. Other important areas for nanoelectronics in the future include carbon based nanomaterials such as graphene, which is also studied at the University of Tartu. The main application areas of ALD, thin films and other fundamental condensed matter physics research are nano- and microelectronics, optics and sensorics.[62] However, it is very unlikely that Estonia would be able to establish new nanoelectronics business from scratch and more focus should be put in commercialisation of research findings.

Novel materials and composites are a field similar to novel coatings for metals industry described in the applied research section. The research is mostly conducted by the same departments as in coatings but the research is currently in a more fundamental phase. The markets for these advanced composites are still rather small (e.g. 280 million USD for Metal Matrix Composites in 2015)[63] but there is huge potential for these advanced materials when their superior properties can be applied in e.g. transportation applications with a competitive price.

The global microscopy market (estimated at 7.7 billion USD by 2015)[64] is a very quickly growing field that on a more general level describes the importance of measurement and metrology technologies for future materials technology development. With state and EU support from e.g. the structural funds, Estonian universities have invested large amounts of money into state-of-the-art measurement and microscopy equipment, which opens huge possibilities for utilising this equipment base for the development of Estonian advanced materials industry. There are already good examples (MikroMasch) of commercialisation of advanced measurement technologies and good infrastructure should definitely be utilised on a larger scale in the country.

For e.g. metals and machinery industry, non-destructive evaluation of materials and structures is growing in importance in manufacturing industries as it allows inspection of various materials without the need for breaking them down. This takes testing of structures of e.g. buildings and machinery to a new level as virtually any component can be inspected without the need for choosing specific pieces for sampling and breaking them.

In addition to the key expertise listed earlier, notable research expertise is present in Estonia in various fields of chemistry. This includes the research and synthesis of bioactive materials and new organic compounds, synthesis of stereo-isomers as well as novel super strong Lewis acids and bases. This research is mainly conducted at the University of Tartu in the Institute of Chemistry and due to the fundamental nature it is not reflect in the publication data of materials technology journals.

2.5.5 High-tech company cases

The following section includes more details of four companies mentioned in the previous section on technology transfer. In addition to these, there are several other interesting companies that could have been included. Here, we have only included cases that are based on the interviews with company representatives.

One interesting case not included is **Crystalsol** which is a university spin-off from the Tallinn University of Technology. Crystalsol has received one of the most notable venture capital investments by foreign investors in Estonia, including investors from Austria, Finland and Norway as well as significant support from the EAS.

61 Electronic.ca
62 http://www.physic.ut.ee/kile/common.html
63 Global Industry Analysts
64 Report Buyer

Crystalsol is now run by Austrian business partners and consequently was not included in the interviewed cases. Currently, Crystalsol operates at two locations. Research and development of the semiconductor powder takes place in Tallinn. Development of the device and the production process is based in Vienna, Austria. Crystalsol develops an entirely new type of flexible photovoltaic module with a significant cost and versatility advantage compared to all currently known photovoltaic technologies. The technology is based on decades of research for the Russian military and Philips semiconductor know-how from the 1960s. The core innovations are the crystalline semiconductor powder made from a patented new material and the low-cost roll-to-roll production process. Crystalsol's technology leads to cost reduction of 50-60% compared to current industry average. This means production cost below 0.3 EUR per Watt peak achievable in the medium term. At this cost level the generated electricity is cost competitive with conventional energy sources. According to Professor Mellikov at Tallinn University of Technology, who is one of the founders of the company, one of the reasons to establish the spin-off was to create a place for his PhDs to go work once they graduate.

Case: Baltic Technologies Development

Background is R&D

Baltic Technologies Development (BTD) is a biotechnology company orginally established in 1993 with the business plan to sell services from Estonia to Finland. Today the company has taken one of the R&D approaches developed in its sister company Molcode with an aim to develop novel platforms for medical drugs. BTD has lifted over 5 ME of investment money and is a limited liability company with shareholders from the US, Estonia and Finland. The company has not sold any products yet. The company employs 5 PhDs.

Technology is based on teaching computers to construct new compound properties and future products under development include:

- New generation antisense gene-silencing technology
- Novel antivirals
- Neurotrophic factor mimetics as the potential drug candites targeting
- Neurotrophic factor artemin mimetics as the potential drug candidates targeting neuropathetic pain

The **first big application** area is in neurodegerative diseases. For neurology, new componds mimicing proteins are developed to keep neurons alive. In case of neurodegenerative diseases, such as Parkinson's, the neurons die due to lack of nutrition.

Their **competive advantage** compared to other pharmaceutical companies is the new kind of platform. Traditional pharmaceutical companies slow down the progress of the disease, whereas BTD future products try to cure the cause.

Vision: To have **production started by the end of 2011.** Partnerships and confidentiality agreements have been signed with very many big pharmaceutical companies.

University-Company collaboration

Majority of the research is conducted as contract research at the universities with partial help from Estonian public funding. In addition to Tartu University and Tallinn Technical University, university partners also include Helsinki University in Finland. Research results have been published in high-class journals.

Lessons learned/key success factors from the interview

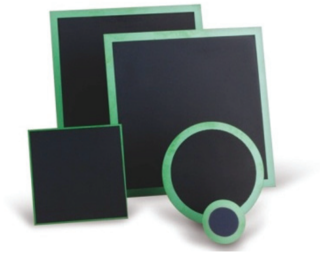
- Platform development, especially for the pharmaceutical industry, takes a long time and a lot of money.
- The company has brilliant technology with potential for a large return.
- Company was created by a professor in Estonia because he believed he had enough educated people to work at them.
- The company can be categorised both under biotechnology as well as a novel materials technology development.

Contact and more information: Professor Mati Karelsson, mati.karelsson@ut.ee

Case: Elcogen As

Background

Elgogen AS is an Estonian start-up company that was founded in 2001. Funding for the company has come from Estonian Business angels, Enterprise Estonia grants as well as the Finnish Power Fund II. The company's development focuses on Solid-Oxide Fuel Cells (SOFC) technology. Currently the company employs 6 people and has just moved into production phase.



Why Fuel cells? There is a market pull for the more efficient energy conversion technologies. SOFC-s are approaching pre-commercial stage in the next few years and the larger scale markets are expected to rise around 2015. **Aim is** to get production fully functional in the first quarter of 2011 and make the first zero loss year. Elcogen's **vision** is to become one of the leading SOFC core component suppliers to power system manufacturers worldwide.

One of their **challenges** is credibility. Many investors from abroad do not believe that a credible product could be developed with the small sum of only 4 Mdollars that has been invested in Elcogen so far. The small amount of investment money, on the other hand, declares a **competive advantage** as they have used much less money in development than their international competitors and therefore, they are under less pressure from investors. Another competive edge of Elcogen is the technology that is developed in-house from scratch and of course the accumulated know-how that is highly important to continue developmental work on their products. Elcogen has only three known direct **competitors** in Europe and two in the US. Competitors include Topsoe HC and HC stark. Main **customers** include companies developing or producing fuel cell systems like Wärtsilä and Ceramic Fuel Cell.

R&D & University-Company collaboration

Which industry challenge is Elcogen solving? Current SOFCs offered by different counterparties require high temperature (around 800 degC) to work efficiently, but that links directly to the increase in the price of the whole system.

Elcogen's SOFCs, on the other hand, can ensure the same efficiency but already starting from 600 degC and that gives system developers the possibility to use simpler materials and therefore, lower the price of the whole system.

In addition, Elcogen benefits from an inexpensive production process and only inexpensive and common starting materials are used while the superb effiency and durability of the SOFCs is still ensured. Therefore Elcogen is convinced that their products have a clear competitive advantage and are on their way to communicate it to other market actors.

During the past years Elcogen has invested in total more than 200 man years into R&D activities. The basic material research has been done in Estonia in collaboration with both Tartu Univerisity and Tallinn University of Technology. Unfortunately Estonian research institutes do not have notable experience in high-tech ceramics and therefore, this part of the R&D has been conducted by international research partners. To get a recognized evaluation on the developed SOFCs, Elcogen has used internationally accepted VTT research facilities in Finland.

Going international

With the exception of one or two research groups, Elcogen does not have any potential clients in the domestic market and therefore, all future production capacity will be directed into export. Main export markets are USA, Germany, Japan and other highly developed countries that have acknowleged the need for new energy conversion technologies. Nevertheless, Elcogen's activities will contribute to Estonian high-tech exports.

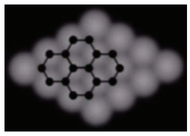
Lessons learned/key success factors from the interview

- Despite notable funding problems in 2004-2006 the company survived due to the owners' belief in the technology and the company
- Technologies of tomorrow need present enthusiasts and visioners to survive.
- For a small company in a small country it is often hard, though not impossible, to penetrate huge high-tech markets.

- Fuel cell patents are currently seen as ways to declare your effort, but actual know-how is kept as in-house secret, very much relays on business secrets that cannot be patented.
- Collaboration between universities and companies would benefit both sides. Companies contribute to commercialisation by having market expertise that universities usually lack of. Therefore having the best possible technology that no-one knows of, is clearly not enough.
- International collaboration may give better ground for success.

Contact and more information: Enn Õunpuu, CEO, enn@elcogen.com

Case: MikroMasch



Company

MikroMasch produces probes for scanning microscopes which are mainly used in research laboratories of companies and universities. The company has been operating for about 10 years (last 3 years more actively) and has established a solid position with about 15 % market share in this niche high-tech market. Although their headquarters is located in Estonia, the production takes place in Zelenograd in Russia, as no clean rooms are available in Estonia. They now have plans to start production in Finland (possibly replacing the Russian operations). For sales and marketing they have daughter companies in the USA, Japan and China (+MikroMasch Trading in Europe). Currently they have 20 employees of which 5 in Estonia, the turnover of about 1.5 MUSD (in 2006), and about 3000 customers in >200 organizations.

Products

The probe or micro needle is the most important part of a scanning microscope. A micro needle is an extremely small – its diameter is merely 0.3 micro meters – diamond shaped silicium needle that resembles a gramophone needle. In a microscope, it moves across molecules like a sensor, enabling the makeup and structure of molecules to be analyzed on a computer. MikroMasch produces a wide variety of scanning probes categorized according to their main features as regular, conducting, magnetic, high resolution, long scanning and torsional ones.

Background

The technology was discovered by the original shareholders (Pavel Kudinsky + 2 others) at Moscow Electrotechnical Institute more than 10 years ago. Their success factor: "right time, right place". The need for scanning probes was emerging, they had the skills based on microelectronics manufacturing and facility available (clean room, CVD etc.)

R&D and University-Company collaboration

MikroMasch does active R&D and uses most of its profit for this. The company has a wide network of partners and customers abroad which is the basis for the R&D co-operation: continuous feedback, ideas, needs for further development. They have an especially close co-operation with Moscow State University, Russia, Stanford University, USA and universities in Finland. In Estonia, they have worked with University of Tartu and they have been a partner at the Nanotechnology Competence Center (but sold their shares at the end of 2010). The work resulted in improvements of diamond probes and will be produced by a new daughter company in Finland. Another active collaborator has been Tallinn TU/Materials Technology Institute (esp. Mechanical Engineering/Priit Kulu). The company claims that they have provided several ideas to universities in Estonia, e.g. AFM courses, but the interest has been low (also access to microscopes in universities not easy). They have also one EuroStar project with funding via EAS. This seems very bureaucratic (they use external service provider for preparing the applications).

Lessons learned/key success factors from the interview

- Key success factor: own technology and skills, good networks
- MikroMasch has entered the market, created a good position and wants to grow. Target in 5 years: double the market share and sales, have a set of new products
- Business environment in Estonia is good (low bureacracy & clear rules regrading e.g. taxes and export), but production (no cleanrooms and skilled people available In Estonia) and customers and key R&D collaborators are abroad
- Estonian University co-operation not providing value for them at the moment

Contact and more information: Pavel Kudinsky, CEO, pavelk@mikromasch.com

Case: Skeleton Technologies

Background

Skeleton Technologies is developing and producing supercapacitors and energy storage materials. History dates back to Tartu Tehnoloogiad OÜ, founded in 1997 as a research arm, for **materials development** for carbide derived carbon and supercapacitors, of the former Skeleton Technologies Group having R&D facilities in Sweden, Switzerland, US, and Russia. During 2000-2007 the company also carried out **contract research for world´s leading companies** such as Toyota Motor Corporation, Samsung SDI, Honeywell Chemicals During that period the company generated revenue of *ca* 2 M USD and effectively returned the initial investment. Contract research started to wind down in 2005 after an intellectual property dispute with Toyota. In 2008 an attempt to commercialize the technology was made by forming Carbon Nanotech. Due to lack of vision and not understanding the market needs, Carbon Nanotech went bankrupt.

Skeleton Technologies was founded in 2009 by a new business development team led by Anti Perkson and Taavi Madiberk who bought out the assets. The goal is to commercialize the supercapacitor technology. Currently the company has successfully attracted **customer** leads including General Motors, Samsung SDI, Peugeot, and Citröen. Main **competitors** include IOXUS. Skeleton Technologies has been given the same ranking in technology and business development as IOXUS by Lux Research.

Technology and R&D

Ultracapacitors have gained ground as a solution to energy storage problems in applications where batteries and conventional electrolytic capacitors are unsuitable. Ultracapacitors offer the unique combination of high power and energy densities at very fast reaction times for short periods of time as well as store and release energy with a substantially higher efficiency rate (95%+) than batteries. **Why Ultracapacitors?** 1) The problem of fuel/energy costs is substantial in the automotive and locomotive industry. Ultracapacitors capture and release energy, which would be otherwise lost. 2) Ultracapacitors combined with batteries are used to eliminate damages from power outages accounting for up to 100 B USD in damages in the U.S. alone.

Skeleton Technologies could produce supercapacitors in similar size than its competitors, but with up to twice as high power density per volume and twice as high energy density per volume. These results have been verified by University of California. Skeleton Technologies **proposes to reduce costs for the end-users** by lowering the price of ultracapacitors by 2-4 times, which could possibly be disruptive for the entire ultracapacitors market.

Skeleton Technologies also **differentiates from competitors** by developing both the material and the supercapacitors. The latter is closest to commercialization, but wide-scale research carried out over the years has shown the carbon material's superiority in other fields as well. Examples include actuator material in robotics with University of Tartu Prof. Alvo Aabloo, an absorber material with Uppsala University, and a gas purification material with Max Planck Institute. Currently, a 1-year 200 000 EUR R&D contract is under way with European Space Agency and the company is participating in a hybrid capacitor FP7 project. Since 1997 there has also been scientific cooperation with University of Tartu.

Technology commercialisation

After the long technology development process, Skeleton Technologies' supercapacitors are now **ready for production scale-up**. The biggest challenge for scaling up the production is the lack of financing. As it is relatively difficult to find skilled workforce in Estonia for development and production of the high technology supercapacitors, Skeleton Technologies has created contacts with international experts that can be recruited after securing financing.

Skeleton Technologies is in the process of applying for a Government Grant matched with private investments to develop a cost-effective scalable production technology. Small-scale commercial manufacturing is planned to be launched in 2013 and full-scale manufacturing in 2014-2015. The State of Michigan and Columbus, Ohio in the US and some German regions have expressed interest in bringing Skeleton´s R&D and potential production to their locations.

Challenges

For a small company it is difficult to find partners and funding nationally and thus the company needs to talk with large global players. It is, however, very difficult to stay independent and at least currently the company wishes to establish production in Estonia supported with capital investment rather than licensing the technology, also seeing national funding instruments as an incentive.

Lessons learned from the interview

- Hard R&D work for more than a decade has now resulted in a product that is commercially competitive
- It has been very difficult for the company to secure funding for its operation, especially the production scale-up phase
- There is not enough skilled workforce being educated at Estonian universities – the company has educated many people themselves
- Business developers and scientist should work together to achieve goals.

More information from Taavi Madiberk, CEO, taavi.madiberk@skeletontech.com

Case: Fits.me „Virtual fitting room for online clothing retailers"

Background

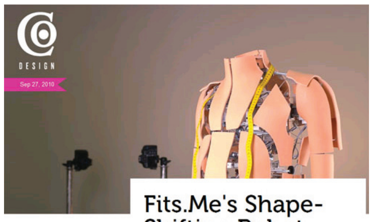
The company is a university start-up, launched in 2007. Currently the company employs 18 people but is expanding quickly. **Business idea:** Fits.me offers a new „sci-fi" solution: a robotic mannequin that takes your body measurements and mimics your shape, so that you can see exactly how clothing would fit you, online. Launched in June 2010 Fits.me has already shown promising results for clients: One German test-run showed that the robots increased sales by 300%, while reducing product returns by 28%. Customers include big retailers like Hawes&Curtis.

How does it work?

Fits.me provides a fitting room service for internet clothing retailers. The retailer realizes two main benefits:

- Returns of ill-fitting products will be reduced significantly, decreasing costs and increasing profits;
- Sales to previously insecure customers increase revenues, especially at the higher product price points.

After the customer has entered his body measurements, he can see the fit of a clothing item – just like a real-life fitting room. The robotic mannequins are used to mimic the shape and size of the customer and show the customer photos of the mannequin wearing different sizes of clothing. Fits.me can show the true fit with real-life photos of the clothing as it looks on the customers' body.



Fits.Me's Shape-Shifting Robot Lets You Try On Clothes, Online

Where is the materials technology?

Fits.me mannequin **brings together competences from diverse fields** ranging from apparel design and anthropometrics to IT, robotics and mechanics. Application of smart-skin (sensitiive to garment pressure) technology is in development phase. The base technology was largely developed by the research partners at Tartu University – Laboratory of Intelligent Materials and Systems (Estonia), Tallinn Technical University – Centre of Biorobotics (Estonia) and Human Solutions GmbH – the leading provider of anthropometrical data (Germany).

Currently, the technical development is led by Prof. **Alvo Aabloo**, heading the Intelligent Materials and Systems Laboratory of Institute of Technology at University of Tartu, and Dr. **Maarja Kruusmaa**, heading the Center of Biorobotics at Tallinn University of Technology, Estonia. Current research projects of Professor Aabloo include e.g. development of artificial muscles.

University-Company collaboration

Fits.me buys **contract research** from the universities where the technology was developed to further develop the mannequin. Product development also includes e.g creating a woman mannequin.

Lessons learned/key success factors from the interview

- It took years of fundamental research and 3,5 years of product development before the company could be launced.

Contact and more information: Alvo Aabloo, alvo.aabloo@ut.ee, http://www.fits.me, http://www.ims.ut.ee

2.6 Education and Human resources

Higher level materials science and technology education is carried out at all the universities in Estonia. More details about the universities can be found in section 2.2.1. The relevant education for each industry sector is mentioned under the industry sector reports in section 2.4. This section gives an overview of where the educated people go to work.

The amount of employees working in research and development in industry has steadily risen since 2007 despite the economic downturn. The R&D personnel count in total in Estonia between 2007 and 2009 was: 2686 (2007), 3023 (2008) and 3122 (2009). The effect of the economic downturn can be seen in manufacturing industries where the size of R&D personnel dropped from 854 in 2007 to 663 in 2009. However, during the same period the amount of R&D personnel in companies doing scientific research and development more than doubled from 304 in 2007 to 643 in 2009.

This is due to the increase of scientific research and development focused companies as the share of doctoral degrees in R&D positions is 25% in these companies (see Table 6). In the manufacturing industry, less than 5% of R&D positions are fulfilled with doctors. The figures are similar when considering people with master's degrees. 15% of R&D personnel in the manufacturing industry possess a Master's degree whereas the figure is 34% in scientific research and development.

Table 6 reveals that the current capabilities of implementing very high technology solutions in Estonian manufacturing industries are very limited due to the low number of highly educated workforce (Doctor's or Master's).

Table 6. The share and amount of highly educated workforce in different industry sectors in 2009

	Total	*Doctor's*	*Master's*	*Other*
Total	**3122**	**274**	**688**	**2160**
Manufacturing total	**663**	**32**	**101**	**530**
Food	56	0	8	48
Textiles	23	0	3	20
Forest	26	0	6	20
Chemicals	76	4	7	65
Plastics	22	0	0	22
Fabricated metal products	20	0	5	15
Electronic and electrical	244	20	45	179
Machinery and transportation equipment	95	3	12	80
Furniture	12	0	0	12
Scientific R&D	**643**	**161**	**221**	**261**

To be able to do any kind of technology transfer there has to be educated people to apply the new technology in a company. Human resources are especially a challenge in materials technology as it is very research intensive and understanding and applying it requires a basic knowledge of the technology. Only after understanding the technology can it be further developed – either alone in the company or together with the university. Unfortunately, even on European scale the number of students studying materials technology is decreasing and efforts have to be done to keep it competitive with the other more modern subjects. Universities in Estonia are also facing the problem of having too many drop-out students. The current solution to the problem is a decrease in the yearly intake of students. Another possible solution could be to make the education more relevant to current and future industry needs and increase the information exchange between universities and the industry.

In all but two of the interviewed cases most of the PhDs were employed by universities, this was especially true with the more traditional fields of materials science such as metals and machinery. To benefit the society and companies at least a small portion of PhD studies should be done in cooperation with companies or based on company needs. Interviews also suggest that it is difficult to find university students with business sense, one thing that could be added to the curricula or obtained from internships in companies.

Some small efforts are underway to tackle these problems. At Tallinn University of Technology, the Department of Materials Science has taken in two industry PhD students and the research is being done together with Crystalsol OÜ. Similarly, the Department of Materials Engineering has taken in at least one industry PhD student and the work is being done together with Norma. The government provides separate support for this. In 2010, a two year specialisation in nanotechnology under the physics Master's Programme was made available at Tartu University together with the Nanotechnology competence centre. It works in collaboration with approximately seven industry partners, all partners in the competence centre. Efforts have been put into advertising this program, however many companies beyond the partners had not heard of it yet. At this stage it is difficult to comment on the success of these programs as they are so young.

University of Tartu and Tallinn University of Technology also have a joint Graduate School of Materials Technology.

International graduates were thought as another problem. Compared to Western Europe salaries in Estonia are rather low and it is difficult to attract foreign students and researchers. Currently, most of the Master's teaching is also conducted in Estonian. Nonetheless, the Department of Materials Science at the Tallinn University of Technology, together with the Tartu University has opened a new international Master curricula in "Processes and materials for sustainable energetics". The education by the curricula is focused on the science and technology of different energy materials. At the moment students from 11 countries are taking courses from the curricula. Related to materials technology, the Institute of Chemistry at Tallinn University of Technology has also started the first international study program on combining chemistry and biology. Currently this is the only program in Europe teaching the subject. Other western competitors can be found in U.S.

On European scale, an analysis of specialisation for high-growth disciplines indicates that chemistry, physics and most branches of engineering have shown a relative decline in researchers specialising in keys areas directly impacting nano- and materials technology and processing technologies ability to deliver new products, processes and manufacturing jobs[65]. It seems that despite the efforts of the EU to seek to increase its investment in cooperative translational research in manufacturing, there appears to be insufficient support to Europe's higher education sector to train young researchers in the key technical disciplines to deliver the results. The report believes that new measures are needed within the European NMP framework programme to increase the gene pool of early stage researches engaged in translational cooperative research with industrial researchers.

To bridge the gap between education and especially the traditional industry co-operation is extremely important. Most of the industrial interviews conducted suggested that the education and thus graduate students at universities do not fit their needs. Theoretical knowledge of students is good but they lacked the skills and experience to work in the industry. In general it is not wise for any university to provide students for the need of just one company. However, a joint effort in e.g. practical works and thesis works would benefit both. Companies should either give ideas to practical works or hire students for the duration of the work. The government could support this kind of activity more actively.

There is at least one Technology platform in Estonia trying to bridge the gap: the manufuture Estonian Platform. The initiative is coordinated by Mechatronics Association in partnership with Tallinn University of Technology, Innovative Manufacturing Engineering Systems Competence Centre (IMECC), and Federation of Estonian Engineering Industry. The **mission** of the Manufuture Estonia platform (being in line with the European Manufuture Platform) is to propose a strategy for the industry, based on research and innovation, for:

- speeding up the rate of industrial transformation;
- securing high added value employment;
- winning a major share of world manufacturing output in the future knowledge driven economy.

65 NMP EXPERT ADVISORY GROUP (EAG), POSITION PAPER ON FUTURE RTD ACTIVITIES OF NMP FOR THE PERIOD 2010 – 2015

3 Materials technology abroad: co-operation and competition

3.1 International collaboration

3.1.1 Research collaboration

Collaboration with international organisations is essential for the success of a small country like Estonia. Collaboration with international players seems quite common for university research groups as the large majority of research group leaders that responded to the questionnaire reported having collaboration with international partners. From the total of 52 research groups, more than 70% reported international partners and the total number of international partners was 90. Countries with most partners include Finland (18), Sweden (10), Germany (9), USA (6), Switzerland (5), France (4), UK (4) and Poland (4), which makes 2/3 of all partnerships reported. Aalto University (9), Helsinki University (4), Uppsala University (3) and Lund University (3) were the most reported collaboration partners.

Estonia is also doing well in the level of international collaboration in materials science publications. According to SCImago Journal rankings, 53% of materials science publications from Estonia have international partners. This number is comparable to Denmark (56%), Sweden (54%) and Norway (52%) and exceeds e.g. Latvia (50%), Finland (47%) and Lithuania (30%).[66] The share of international collaboration in materials science slightly exceeds the average international collaboration in Estonia (49%).

3.1.2 Industrial collaboration

Very many of the bigger companies in Estonia are foreign owned and international collaboration comes explicitly from this ownership. The bigger foreign owned companies, especially in the forest industry but also others, bring the newest technology expertise to Estonia through their local production plants.

Some of the smaller companies, being sub-contractors, used their international customer network to gain insight into ongoing trends and technology needs. Many of them have long term trusted relationships with one or two big international customers who provide them with specifications of the final product needed and the production in Estonia works out a way to obtain these specifications. This kind of customer-driven technology/production development benefits the Estonian manufacturing industry very much. The small companies should use it even more.

Many of the high-tech industry interviewees told that they were involved in some EU-projects: most of them being research for SMEs. In these projects SMEs can use EU money to buy research from a research provider such as a university. The project always has to have at least three industrial partners and two research partners. At the end of the project the company partners own the IPR of the results obtained. These projects are a very good way to gain new contacts in Europe and also probably get some new results for development. Unfortunately, so far, none of the companies have utilised any of the results they have got. The research provider was also in all interviewed cases a foreign partner. Currently it seems that in addition to these projects, Estonian (high-tech) companies should more actively look for real partners for real EU-projects where they can do part of the development also in-house.

3.2 Materials technology research and development internationally

3.2.1 Latvia

Latvia has taken a similar approach to Estonia in 2001 with defining a “knowledge-based model” and establishing a set of National Research Programmes.[67] This includes the definition of priority scientific areas that include the following for the period from 2010 to 2013 (along with more detailed definitions of areas related to materials technologies):

66 www.scimagojr.com
67 Science in Latvia – National Research Programmes (http://izm.izm.gov.lv/upload_file/Zinatne/vpp/Zinatne_Latvija_EN.pdf)

- Energy and environment (technologies of renewable energy resource extraction and utilisation, technologies diminishing climate change, and biological diversity)
- Innovative materials and technologies (computer science, information and signal processing technologies, nanostructured multifunctional materials and nanotechnologies)
- National identity
- Public health
- Sustainable use of local resources (mineral deposits, forest, food and transport) – new products and technologies

To support materials sciences and other related fields, Latvia is planning to establish National Research Centres for areas including "Technologies of Acquisition and Sustainable Use of Energy and Environmental Resources", "Information, Communication and Signal Processing Technologies", "Forest and Water Resources" and most notably "Nanostructured and Multifunctional Materials, Structures and Technologies".

The Latvian research system is divided in two types of scientific support programmes: 1) fundamental and applied research and 2) market-oriented research. The fundamental and applied programme supported in total 166 projects in 2010 and the market-oriented programme had 15 ongoing projects in 2010, of which 4 continue also in 2011.

In addition to the above mentioned programmes and areas, Latvia implemented several National Research Programmes within the period from 2005 to 2009. The materials technology programme included the following focus projects:

- Inorganic materials for photonics and energetic
- Inorganic materials for optoelectronics and microelectronics and advanced methods in structure research
- Materials for photonics and nanoelectronics based on new functional low-molecular and high-molecular organic compounds
- Biomaterials and medical technologies
- Development of nanoparticles, nanostructural materials and thin-film technologies for creation of functional materials and composites
- Design of functional materials/nanocomposites, development of technologies and properties thereof
- Participation in ERA-Net programme MATERA in EU FP6
- Functional materials for resistive switching memory
- Modelling dynamics of adaptive multifunctional materials and structures.

The application areas include thin films for optoelectronic and microelectronic devices, li-ion batteries, fuel cells, ceramic membranes for energetics, solar cells, sensor technologies, medical diagnostics and nanocomposites. The programme received in total 5,4€ funding for the period from 2005 to 2009.

The continuation for materials technology programme for the period from 2010 to 2013 is called "Development of Innovative Multifunctional Materials, Signal Processing and Information Technologies for Competitive Science Intensive Products"[68] and includes the following objectives:

- Generation of multifunctional materials and their nano-order multilayer coatings and application thereof in energy converter devices
- Signal registration and processing technologies (including sensor technologies and materials)
- Self-reinforced multifunctional polymer composites with innovative nanostructured modifiers
- Innovative solid tissue replacement material
- Development of an original system meta-modelling method

Another programme focus on the "Sustainable Use of Local Resources" includes e.g. utilisation of Latvia clay for development of new products. In conclusion, materials technology focus areas defined by Latvia are very similar to the strong areas of Estonian materials technology. Focus areas such as 1) materials for energy, 2) sensor technology and sensor materials, 3) nanomaterials (especially for electronics), 4) multifunctional polymer composites and 5) biomaterials can be identified. So far, Latvia seems to lag behind Estonia in terms of R&D expenditure (% of GDP), human resources in science and technology, patent applications and doctoral students.

68 http://www.cfi.lu.lv/eng/projects/national-research-programs/national-research-program-of-latvia-in-materialsciences/

3.2.2 Lithuania

The Lithuanian status in materials sciences is very similar to other Baltic countries. Advanced materials research and technology development has been very recently studied by Valiulis and Škamat (2010)[69]. The Lithuanian public R&D system consists of 21 universities, 9000 teaching staff and 2800 PhD students. The strongest areas in research are biotechnology, biochemistry, chemistry, mathematics, physics (especially laser physics), ICT, electronics and power-engineering.

The following institutions and universities and their research areas have been identified in the study of Valiulis and Škamat:

- Lithuanian Energy Institute
  - Production of thermo insulating fiber
  - Synthesis of new catalytic coatings with active elements of metal oxides
  - Plasma nitriding of austenitic stainless steels and alloys
  - Modification of materials surface layer by deposition of a – C:H films
  - Deposition of hydrocarbons containing coatings and yttrium stabilised zirconium coatings (especially for fuel cells)

- Semiconductor Physics Institute (SPI)
  - Materials science and nanotechnology
  - Ultrafast processes in semiconductors and superconductors
  - Terahertz technology
  - Metrology and the development of National Standards

- Institute of Physical Electronics, Kaunas University of Technology
  - Thin films and surface engineering
  - Application of ion and plasma methods for nanostructures and nanomaterials
  - Development of new materials and structures
  - Potential application areas: coatings for sensors and MEMS devices, passive layers in microelectronics, wear and chemical resistant protective coatings for industry and biomedical applications

- Vilnius Gediminas Technical University
  - Nanotechnologies in refractory materials (Institute of Thermal Insulation)
  - Composite aircraft structures (Antanas Gustaitis Aviation Institute)
  - Heat treatment of alloy steel welded joints arc spray, coating technology (Department of Materials Science and Welding)

The research institutions in Lithuania mostly focus on fundamental research and the largest reason for lacking R&D effectiveness is said to be the absence of critical mass to support R&D activities. Improvement of the situation would require larger research institutions as well as better support from the business sector.

Also similarly to other Baltic countries, Lithuania has prepared its own knowledge based economy study in 2004.[70] The study highlights three high technology sectors with high potential for Lithuania including:

- Biotechnology sector
- Laser technology sector
- Information technology and telecommunications sector

The country has since established a number of National Technology Platforms, which are associations of enterprises, research institutions and financial groups operating in a specific sector of the Lithuanian economy on the basis of a joint activity agreement. Technology platforms relevant to materials technology include[71][72]:

- Future manufacturing (36 members)
- Apparel and textile industry (10 members)
- Biotechnology (29 members)
- Photoelectricity (10 members)

69 Advanced Materials Research and Technologies Development: Lithuanian Experience (2010)
70 The Knowledge Economy in Lithuania – A study of The Industry's Prospects (http://www.innovation.lv/ino2/publications/knowledgeeconomy.pdf)
71 http://www.tpa.lt/ENG/FP7/files/NTP_platforms.pdf
72 http://www.ntplatformos.lt

- Laser and light technology (8 members)
- Forestry sector (14 members)
- Nanoelectronics and electronics (17 members)
- New materials technology (9 members)
- Construction technology (15 members)
- Hydrogen and fuel cells (12 members)

The National Technology Platforms are well documented and their feasibility studies, strategic research agendas and vision work can be found in the Technology platform website[73] in both Lithuanian and English.

In summary, Lithuania seems to have taken a very collaborative approach in the development of advanced materials technologies but there are no real indications of results yet available. The study of advanced materials research gives a somewhat negative view on the R&D capabilities of the country but the National Technology Programmes seem to have generated a lot of interest among Lithuanian enterprises, universities and research institutes.

3.2.3 Finland

High quality materials research is a key competence area in Finland which is expected to renew the Finnish industry. Application driven materials R&D is conducted to create new solutions for selected application areas from both existing industry needs as well as to create new industry areas.

To exploit the capability of over 4000 researchers in 250 groups and drive the research towards selected future applications Tekes, the main public funding organisation, set up the Functional Materials Programme in 2007. The total volume of the seven year Programme is 205€, of which Tekes accounts for 84€; currently it consists of 43 university driven research and 29 industry projects (31 ended), with over 100 industrial companies involved. The high involvement of industry partners is due to the use of consortium research projects, where public research organizations and companies join forces effectively.

The project portfolio covers several research areas including understanding materials properties, control and tailoring of materials and functionalities, processing aspects, and new materials based applications. The Programme puts special emphasis on environmental aspects and life cycle management by funding this research as well as raising awareness. The Programme focuses on four thematic areas:

- Biomaterials for medical use,
- Material and processing solutions leading to cost-effective mass-manufacturable intelligent structures,
- Responsive materials, and
- Novel materials for energy technologies.

When building new projects, the end-user needs are taken into account and product value chains recognized to find the most critical research areas and opportunities. International cooperation is elementary for each project to form world-class research consortia capable of transferring the results later towards real applications. The programme has an active multi-disciplinary network from different fields in academia and industry working closely together. Foreign partners are invited to join the projects – and to utilize and expand the core network.

Part of the industry driven research and cross-disciplinary collaboration is enabled within the newly established **Strategic research centres of excellence for science, technology and innovation** (SHOKs). For example the Fimecc (Finnish Metals and Engineering Cluster), SHOK has several Programmes conducting materials research jointly with the industry for the needs of new demanding and light applications.

In addition to the SHOKs and Tekes the Academy of Finland is starting a Programmable Materials Research Programme in 2011 which aims to fund more fundamental research.

In addition to dedicated effort on materials technology development, Finland has also directly funded nanotechnology research since 2004 with several governmental programmes. Today over 200 Finnish companies are actively developing and utilizing nanotechnology in their everyday business, and revenue is expected to grow to 1.2 billion Euros by 2013. As an indication of what might be coming, six out of 11 of the top most innovative Finnish companies to watch in 2010, as listed by the cleantech guru Shawn Lesser, are developing applications based on nanotechnology: Beneq, Canatu, Picodeon, Braggone, Enfucell, and Liqum.

73 http://www.ntplatformos.lt

3.2.4 Sweden

The Swedish research council believes that materials technology has an important interdisciplinary role[74] when answering world-wide challenges in areas such as energy technology, climate change and environment. The "European Strategy Forum on Research Infrastructure" (ESFRI) is mentioned as an important guide for more joint European infrastructure projects in technology areas that could be released in a few years. The council aims to put more funding efforts into areas mentioned in the strategy including e.g. materials science.

VINNOVA, the Swedish Governmental Agency for Innovation Systems, has four governmental programs around materials technology:

- Designed Materials (2006-2009)
  - including e.g. Designed Materials – Capability Testing and Concept Verification and Designed Materials – Industrialisation
- Green Materials from Renewable resources (2003-2007)
- Light Materials and Lightweight design
- Sectoral R&D Programme for Forest-based Industry (2006-2012)
  - The programme focuses on sections of the National Research Agenda, primarily those relating to wood and wood processing and pulp-paper.

According to the Swedish national strategy for nanotechnology written in 2010[75], nanotechnology (including advanced materials technology) is a potential growth area for Swedish industry. Also from an international perspective, Swedish nanotechnology occupies a strong scientific position. Monitoring the opportunities as well as risks related to the development and use of this technology are needed in the future to safeguard the potential of the area. In general in Sweden, as in the rest of Europe, the area has developed organically and is starting to become so wide-ranging that the knowledge from different research authorities and interest groups needs to be coordinated. Overall the strategy believes that nanotechnology affects so many areas and that it is not desirable to coordinate all aspects under a single "nano policy". However, the current fragmented situation is a problem and thus two main proposals for actions are proposed:

1) **A delegation for better oversight** to official bodies and have broad oversight of the development and use of nanotechnology
2) **Support for coordinated international work** with an aim to increase national consensus regarding the direction in which Sweden wishes to influence the development.

In addition to these, the government hopes to identify areas for thematic efforts in order to increase the utilization of nanotechnology and work actively to link nanotechnology to broad public goals, such as environment, energy and health goals. Different actors from universities, the public sector and industry should collaborate to target efforts on dealing with these challenges. Growth will be created by **linking nanotechnology to existing efforts as well as generating production related knowledge** of the technology's opportunities that would be broadly distributed to companies.

3.2.5 Norway

Norway activated a national research strategy work in 2001 and in the period of 2003 to 2005 the country executed foresight studies in selected key areas including advanced materials, biotechnology, energy, ICT and fish farming. The Advanced Materials Norway 2020 sets several goals for the country's materials technologies by 2020.

- Materials and manufacturing
  - Norway is a major supplier of aluminium, silicon, plastics and ferroalloys
  - Success is based on customized and specialty products knowledge through the entire value chain
  - Advanced materials and nanotechnology is the key to future success
- Transportation
  - Strong niche areas in e.g. light structures, multimaterial solutions, sensors, fuel cells and hydrogen technology

74 http://www.vr.se/download/18.76ac7139118ccc2078b80004579/Forskningsstrategi_20092012_VR.pdf
75 Nationell Strategi för nanoteknik €Ökad innovationskraft för hållbar samhällsnytta. Borälv et al. 2010. Vinnova Policy. ISSN: 1651-3568.

- Energy
  - Knowledge and ability to adopt functional materials and nanotechnology enable success in various energy technologies such as solar, wind, hydrogen technology, batteries, fuel cells and environmentally friendly gas technology
- Building and construction
  - Main value added is based on utilisation of locally available raw materials
- Oil and gas
  - The country has a very strong position in offshore engineering and other related technologies
- ICT
  - Success based on knowledge in specific niche areas: integration of advanced functional materials and silicon nanotechnology

Based on the strategy studies, Norway established a NANOMAT programme for nanotechnology and new materials, nanoscience and integration. For the period of 2007-2016, the programme focuses in four thematic areas in the following priority order: **1) energy and environment, 2) ICT including microsystems, 3) health and biotechnology, 4) ocean and food.** By 2016, the annual budget of the NANOMAT programme is expected to reach approximately 30 million EUR. The sub areas under the selected priority areas are strikingly similar to Estonian competences:

- Energy and environment
  - Gas conversion, CO2 capture, petroleum production, solar panels, hydrogen technology, batteries and energy harvesters, energy efficiency, biofuels
- ICT inclusive microsystems:
  - Nanomaterials and nanocomponents for electronics, data storage, optics, sensors, actuators and RF components, integration of nanomaterials into sensors and actuators, nanostructuring, nanofluidics
- Health and biotechnology
  - Biocompatible materials, sensors and diagnostics, medication
- Ocean and food
  - Tracing of food, smart packaging, food monitoring, surface treatment to prevent algal and bacterial growth

It is clearly identified that future success in advanced materials requires high degree of interdisciplinary collaboration and convergence in various disciplines including: physics, materials science and technology, chemistry and biochemistry, molecular and cellular technology, optics, surface science, microelectronics and scientific instrumentation. Thus, in addition to the selected thematic areas, success in materials technology needs strong support from fundamental sciences as well as expertise in modern tools including synthesis, manipulation and fabrication, characterisation and modelling.

3.2.6 Denmark

Denmark became more active in materials research long time ago when the government decided to establish National Research Strategies in selected key areas important for the Danish society and economy. The country had Materials Technology Programmes ongoing from 1988 to 1997 and in 1999 The Danish National Strategy for Materials Research was created. The country spent 300 million DKK (40 MEUR) and 500 person years in materials research and development already in 1995 and by 1997 the amount of funding had almost doubled to 900 million DKK. The reason for selecting materials technology as a strategic area was that materials affect the development within all other technological or scientific areas.

The goals for the National Research Strategy in materials defined in 1999 were:

- Technological innovation and increased employment
  - Materials research is often a prerequisite for progress in other technological areas
- Improvements in the quality of life, the environment and health
  - Materials strongly contribute to improving the quality of life
- Higher quality of education, and accelerated production and dissemination of knowledge
  - To maintain the high quality of Danish materials research

Based on a study called "Materials Research – a Proposal for a National Strategy" Denmark defined four high priority areas for future materials technology development:

- Nanotechnology and functional nanostructures
- Microsystems
- Biocompatible materials
- Functional polymer materials

Currently the country is focusing more on thematic areas in its strategic prioritisation. The thematic areas including materials technology are called "**Energy, climate and environment**" as well as "**Production and technology**". They can be considered as an evolved version of the materials technology programme as they focus more on finding solutions to society challenges at large rather than focusing on tight areas of technology[76]. On the other hand, Denmark has accepted the fact that a small country cannot nor should be a world leader in all strategic growth technologies and a significant amount of co-operation with leading international partners is needed. Moreover, the research should be conducted in a way that Danish companies can adopt them in their products and production processes.

Concrete examples of the thematic areas of Danish research are the focused efforts in energy technology funding. In 2010, more than 100 million Euros were invested in energy technology research. The effort can already be seen in the EU FP7-Energy and Intelligent Energy statistics where the Danish share has exceeded 8% while the country contributes less than 2% in the EU budget.[77]

3.2.7 Europe in general

The FP7 NMP framework programme is one of the biggest RTD program in Europe funding the field of nanomaterials and new production technologies with over 400 million Euros annually for the years 2007-2013. The amount is expected to grow, going from 380 million in 2007 to 620 million in 2013. "NMP aims to support Europe's drive to be the world-leading innovator and supplier of advanced materials adding high value and a competitive advantage to industrial products in key sectors. The present programme is designed to tackle the multiple challenges currently facing European industry, with accelerated demand for higher quality and higher added-value products, rapidly increasing competitiveness from Asia and elsewhere and the need for restructuring, particularly of the energy and transport sectors brought on by the recent financial crisis. New and advanced materials play a central role in supporting many of the priority areas in FP7, particularly health, ICT, transport and energy."[79]

In November 2009, the NMP Expert group of 25 experts published a position paper on the future of RTD of NMP for the period of 2010-2015.[79] In addition to making future recommendations for the program the paper also presents the present state-of-art in respective NMP fields. The paper emphasises the importance of "cross-cutting and enabling technologies, including the development of new characterisation and instrumentation methods, modelling and understanding of complexity, nonlinearity and functionality both by design and through bottom-up approaches". The paper believes that technology push and industry pull both need equal consideration. Whilst stimulating the creativity of Europe's research scientists at the fundamental level, clear aims regarding industrial application should also be defined. To ensure rapid and effective technology transfer to industry, particular attention should be paid to start-ups and SMEs, especially their patenting issues. Also the process of turning research results into products needs acceleration through different support mechanisms. The paper also lists several research priority areas under the following themes

- Life Sciences and Health Care
- Energy: Conversion, Storage and Efficient Use
- Environment (Air, Water and Soil)
- Chemicals, Consumer and Household Goods
- Construction and Housing
- Food & Agro-Biotechnology
- Fibers, Fabrics and Textiles
- Transport: Aircraft and Automotives
- Civil Security

76 RESEARCH2015 – A BASIS FOR PRIORITISATION OF STRATEGIC RESEARCH
77 Annual report on Danish energy research programmes

According to the state-of-art review of the paper, there are a number of indicators that materials research will become a battle ground for delivering the benefits of industrial technologies:

- The EU is world-leading in advanced materials sales (~80% >US and Japan)
- Strategic investment by the US, Japan and China in materials research programmes are on a competitive level
- Strategic investment in large facilities by the US, EU, Japan and China to support materials research programmes
- Bibliometric studies of nanotechnology scientific publications
- Principle locus on industrial nanotechnology R&D investment
- Largest number of submissions to NMP calls per year in FP7

In 2008, EU research spending on nanotechnology from all **public sources** was $2.6 billion (approx 30% of the world total). [78] The strongest nanotech public sector funding programmes are in Germany, France and the UK with Germany being the biggest with approximately 400 million Euros annually (ref2). **Private R&D investment** amounts to only $1.7 billion in Europe compared to $2.7 in the US and $2.8 billion in Asia. [79]

In Europe there is currently one Era-Net in materials technology working under the NMP-programme. Altogether 13 countries or regions are participating in this MATERA Era-net including Finland, Belgium, Spain, Poland, Israel, and Latvia. MATERA offers participants 1) a simplified way to initiate and participate in R&D projects at the European level 2) an opportunity to easily access international know-how 3) an opportunity to integrate into international value chains. Matera funds joint research projects of partners in the countries. Funding comes from the local governments, EU-funds the joint activities of the network. Altogether the Matera ERA-Net has launched six calls during its existence. The final call was in early 2011 with the goal to:

- launch transnational, interdisciplinary, innovative, R&D projects related to materials science and engineering
- narrow the gap between basic materials research and applied problems
- shorten the time-to-market of scientific outcomes

3.2.8 Russia

During the last 5-10 years, Russia has become significantly more active in the area of nano and advanced materials technologies. There is a huge research base available in the country and the state is currently driving technology transfer activities through organisations such as RUSNANO. Russia has recently established several programmes for regulating the science and technology development, two of which are most relevant for materials sciences:

- National Technological Base (2007-2011)
- Development of Nanoindustry Infrastructure in the Russian Federation (2008-2010)

These programmes together correspond to approximately 1.5 billion EUR of funding[79] and in addition, RUSNANO is investing close to 1 billion EUR annual in nanotechnology industry development in Russia.
Nanotechnology has been identified as a key future technology in Russia and it is in close relationship with materials technologies in e.g. RUSNANO projects. The projects financed by RUSNANO are divided into 6 clusters with example projects similar to Estonian competences:

- Solar energy and energy efficiency
  - Thin film solar panels
  - Lithium-ion batteries
- Nanostructured materials
  - Novel light composite materials
  - Flexible polymer packaging materials
- Medicine and biotechnology
- Engineering and metalworking
  - Metal-cutting tools with nanostructured coatings
  - Wear-resistant products made of nanostructured ceramics and metal
  - Nanostructured non-metallic coatings

78 NMP EXPERT ADVISORY GROUP (EAG) POSITION PAPER ON FUTURE RTD ACTIVITIES OF NMP FOR THE PERIOD 2010 – 2015
79 Dmitry Filatov OECD presentation

- Optoelectronics and nanoelectronics
  - RFID tags and metallic packaging materials
- Infrastructure projects

Based on the findings in interviews and desk research, a large amount of Russia related expertise still exists at Estonian universities and companies. Moreover, many successful inventions that recently have or are currently being commercialised are of Russian or Soviet origin. This means that as Russia is currently significantly increasing its investments in the application of new materials technologies there is clear potential for two way knowledge and technology transfer between Estonia and Russia.

Firstly, there is a huge research base related to materials technologies available in the Russia, which can be easier utilised with Estonian expertise and knowledge of the language. This technology expertise in terms of intellectual property rights (IPR) and technology development capabilities is cheaper than similar expertise in western countries. It is also feasible for Estonian universities and companies to hire skilled students and workforce from Russia and other Eastern European countries whereas hiring workforce from western countries is unfortunately very expensive. RUSNANO's large investments in establishing high technology manufacturing in Russia mean that there are clear possibilities for Estonian high technology companies to apply for funding for establishing their future manufacturing in Russia (a requirement of RUSNANO investments).

In summary, large amounts of money are currently being invested in materials technology development and establishing new manufacturing capabilities in Russia which undoubtedly means possibilities for Estonia, too. On one hand, Russia has good fundamental knowledge in several fields of science and technology and there is clear potential for Estonia for transferring this knowledge into the country. On the other hand, investments from RUSNANO mean one feasible funding instrument for establishing high technology (nanotech) manufacturing if the company is willing to establish the production plant in Russia.

3.2.9 Rest of the world

Globally leading countries and materials technology leaders by technology status and investments include USA, Japan, China and Germany. These countries, as well as other major economies of the future like South Korea, India, Brazil, Russia and South Africa have been typically selected as key partners for national materials technology programmes in other Nordic countries.

Estonian universities and companies are already somewhat linked with European countries, especially the Nordic countries (including the Baltics), Germany and occasionally with more remote partners especially in the U.S. The emerging economies like China, India, Brazil and Russia play undoubtedly a huge role in the future demand for materials technology demand due to their fast economic growth. On the other hand, Asia is and will be the key player, especially in electronics and ICT sector with technology leaders in Japan and South Korea as well as huge amounts of semiconductor manufacturing capacity in e.g. Taiwan.

Due to the fact that most of the neighbouring countries of Estonia are focusing their materials technology efforts on similar technology areas as Estonia, there is no real need or resource for Estonian universities and companies to start searching for collaboration and technology transfer partners outside its neighbouring countries or Europe. Large investments and technology development efforts in materials technology are already done in the Nordic countries, the Baltics, in Germany and the rest of Europe. Moreover, the proximity of Russia means a huge potential for technology and knowledge transfer both from and to Estonia with Estonians having a natural advantage compared to other countries by their good knowledge of Russian.

3.3 Summary

- Universities in Estonia are very well connected internationally.
- Many companies have international connections through their clients or owners.
- Companies are less connected to international research institutes or other companies doing R&D.
- Most of the neighbouring countries of Estonia are focusing their materials technology efforts on similar technology areas as Estonia.

- All neighboring countries have established Materials Technology R&D Programmes during the last ten years. In addition to these several Nanotechnology Programmes have been established. The outcomes and results of these programs are still somewhat unclear, mostly because they are so difficult to measure.
  - Most benefits have been seen in increased cooperation between academia and industry
  - Another benefit is increased international cooperation: but cooperation has mostly been facilitated beyond the boards of Europe.
  - In R&D programmes it is notable that the Nordic countries and the Baltics are not collaborating with each other.
  - Despite the current programmes, the trend is to focus more on finding solutions to society challenges or user/application driven research in general rather than focusing on tight areas of technology
  - The benefit of a technology program is the possibility to find new solutions to new business areas through multidisciplinary efforts.

- In nanotechnology the Nordic countries have all taken different approaches
  - Norway aims to become a leader in some niche area while at the same time they want to maintain the research infrastructure to be able to adapt quickly to new trends. They aim to build "big projects" that address fundamental research, development, innovation, and academia-industry collaboration in certain defined areas.
  - Denmark aims to become the world leader by 2020 in applying nanotechnology in industry, generating growth and meeting the societal needs.
  - Finland aims to encourage the industry to utilize nanotechnology more efficiently and also build a new company base on nanotechnology.
  - Sweden, the only one that currently does not have a nanotechnology program, aims for achieving better oversight of nanotechnology development and use in the country and activate support for international activities. The challenge is to get different actors from universities, the public sector and industry to collaborate to target efforts.

- The European Commission through its NMP program is tackling somewhat the same problems as Estonia but on a larger scale:
  - There are multiple challenges currently facing European industry, with accelerated demands for higher quality and higher added-value products, rapidly increasing competitiveness from Asia and elsewhere and the need for restructuring, particularly of the energy and transport sectors brought on by the recent financial crisis.
  - NMP in general aims to support Europe's drive to be the world-leading innovator and supplier of advanced materials adding high value and a competitive advantage to industrial products in key sectors.
  - NMP has also selected several key thematic areas it supports more, some of which correspond to the key areas in Estonia.

- Russia has a very strong base in fundamental research, which could be exploited in Estonia.

4 Conclusions and recommendations

4.1 Recommendations for materials technology stakeholders

4.1.1 Business potential and technology transfer in materials technology

Based on Figure 13, there is a large number of potential materials technologies in Estonia with various levels of technological maturity. This also means that there cannot be a single approach that would best support the whole field of materials technology but each maturity level needs its own set of means and tools that support commercialisation of the technology or technology transfer. The findings and recommendations for taking full advantage of business potential and improving technology transfer in materials technology are therefore discussed separately for each technology readiness level.

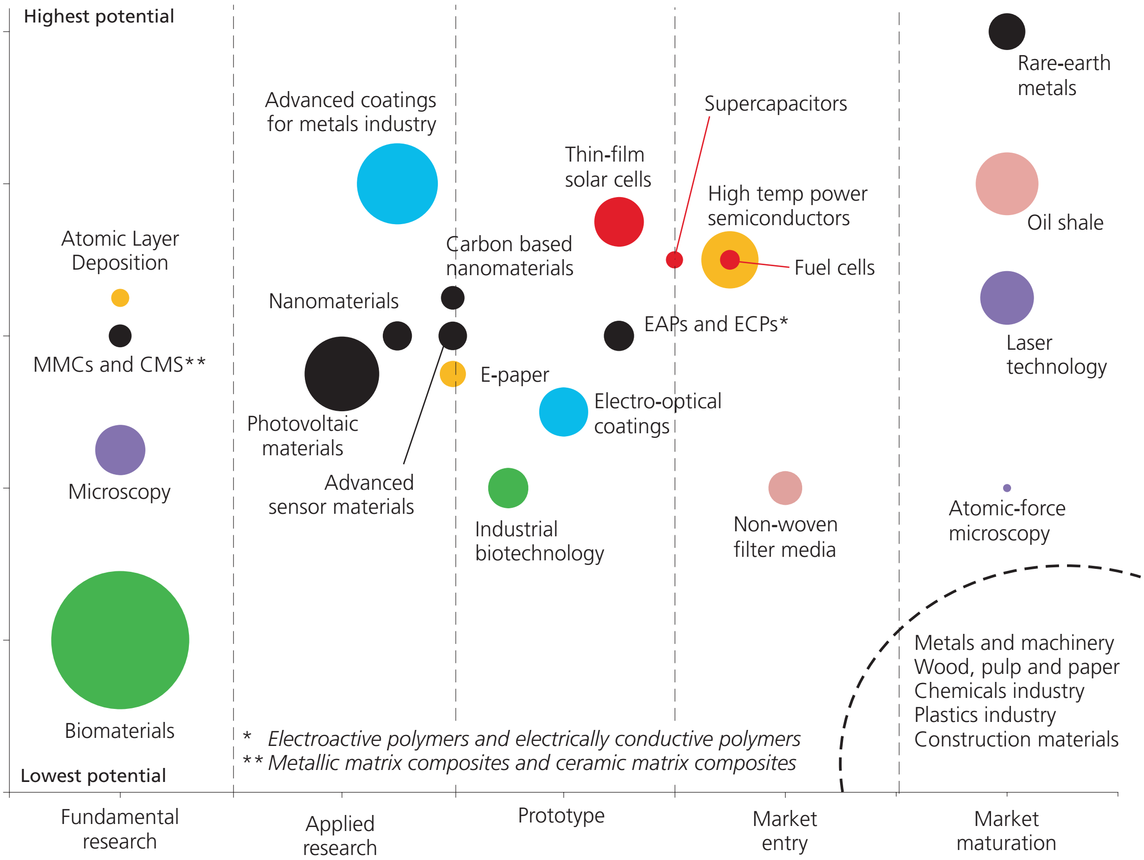


Figure 13. Characterisation of the selected industry areas in relation to materials technology

The circle size indicates the estimated global market size around 2015. The y-axis represents a relative technological and business potential of selected technologies. Technologies with highest estimated potential have both strong university and industry support (e.g. rare-earth metals and oil shale). Technologies in the middle section typically lack industry support (e.g. thin film solar cells where only one Estonian company exists). Technologies in the lower section lack Estonian wide R&D activities and typically only one party capable of developing the technology exists. Colors in the figure symbolize those areas shown in Figure 12.

4.1.2 Conclusions and Recommendations based on technology readiness level

Mature technologies and well established companies

- This is by far the largest part of materials technology done in Estonia. Potential companies benefitting from this are well established companies in various industries:Metals and machinery
  - Wood
  - Chemicals
  - Plastics
  - Construction materials

- The activity with the largest economic potential and lowest risk for Estonia is to motivate these companies to create and produce higher value added products. To achieve this:
  - More educated workforce is needed in companies in these "traditional industries"
    - Tune teaching programmes more for company needs, including more joint projects together with the industry.
      - Presentations could be made that emphasise the benefit for the company to hire a person with knowledge of e.g. material science.
      - Industry needs could also be mapped better.
    - Students should be provided with better chances to work for industry during studies
    - Students need more practical experience from working for the industry
    - More joint projects already during the studies would make it easier for the industry to hire the students once they graduate.
      - More knowledge of advanced materials and materials technology in general is needed in companies ("applying materials knowledge is key to success in all areas")
    - Universities need to better communicate their expertise to the industry
    - Industry needs to better communicate their needs to the universities
    - It will start with small steps. Once some companies start upgrading with success, others will follow. Success stories have to be emphasised
    - More educated workforce is needed in companies for them to be able to implement advanced materials

  - Interest in high technology and materials technologies need to be awaken in companies
    - More discussion and collaboration projects are needed between companies and universities
    - Before this will happen on a larger scale, the government needs to provide incentives for companies to collaborate
    - Currently there is little culture for doing R&D in "traditional industry" companies

  - Not everything needs to be invented in Estonia
    - Clever technology scouting can provide possibilities for Estonian companies to take advantage and commercialise technology from abroad. **"Estonian universities could be important partners also to interpret and transmit the most relevant information on new technologies to companies"**
    - There is no need to invest in inventing the wheel again. For example the ENCC could sometimes do a bit of technology scouting also from abroad.
    - More active partnering with foreign companies needed (target: change from sub-contracting to co-development; often requires a rise in own competence, however)

- In addition to manufacturing industry mentioned above, a few core technology areas exist in Estonia based on local natural resources and long traditions
  - Rare-earth metals and oxides production
  - Oil shale technology
  - Laser technology

- These technologies and companies developing them are important for continuous development of advanced materials in Estonia

Technologies close to market entry

- Technologies and companies close to market entry are very important for the success of Estonian materials technology in the short term
- The companies, however, are not that interesting from technology transfer point of view as they are focusing all their efforts on trying to commercialise their main product.

- Companies with technologies in this group typically need the following:
  - Investments in final phases of product development (public/private)
  - Investments in establishing production (private)
  - Highly skilled team in technology and business
  - Business knowledge of technology commercialisation and good international contacts (especially in the case of materials technologies)
  - Dedicated experts needed, because this knowledge seldom exists solely in the technology or business developers

- With good support from private investors, public sector, highly determined and skilled team there is a potential to grow new success stories from companies close to market entry in 3-5 years
  - These may very well become comparable to e.g. Skype

- On the other hand they may turn out to be worthless
- The first phase to get technologies to market is make prototypes. This is a necessary development phase very often forgotten by public funders. Dedicated funding for prototyping is needed.
  - Prototyping is the next step after an R&D project has successfully ended. Without a prototype you cannot sell your idea further to investors. Prototype funding should especially be directed to newly started high-tech companies who need evidence of the performance of the product. In materials technology development projects in particular prototypes can be expensive to make.
  - Universities could also be encouraged to make "less real" prototypes to check if their ideas work in reality.

- The size of investment needed for a materials technology innovation to enter the market is usually very much higher than for an ICT innovation, the initial investment being in the order of 1-2Me. A small country cannot afford many of these and international money has to be attracted too. When calculating the benefit of the investment the potential amount of working places it produces should be very high on the scale of criteria.

Applied research

- Technologies in the applied research phase typically have the highest potential for technology transfer
  - Carbon based nanomaterials
  - Advanced materials for e.g. sensors use
  - Nanomaterials in general
  - Photovoltaic materials
  - Advanced coatings for metals industry

- There is currently a clear mismatch between materials technology inventions in Estonia and requirements and capabilities of the industry
  - Very many advanced materials inventions do not arise interest among industrial companies, which is very typical internationally too.
    - One path for utilising these technologies is to establish spin-off companies, this has already happened with many close to market entry technologies but requires highly determined people with business knowledge, and is more of an anomaly than a practice
    - Another path is technology transfer to international organisations, which does not currently exist on a broader level in Estonia
    - To speed up the adaptation, the technologies should be developed together with industry partners.

  - Highest potential for technology transfer exist in the metals industry coatings segment
    - Large company base and university research base mean that there is both supply and potential demand for the technology
    - Huge global market means there is a lot of room for advanced coatings (e.g. nanocoatings) in the market in various niche areas that can the existing industrybut especially new spin-off companies

  - There are also other interesting initiatives for technology transfer in Estonia
    - Both Tallinn University of Technology and University of Tartu have hired/are hiring technology transfer experts
    - Estonian Nanotechnology Competence Centre is an important initiative for transferring nanotechnology results to companies, the results remain to be seen
      - In this case typically the companies expect result transfer in 2-3years time.

  - Universities are currently key players in applied research, their role needs to be clarified in order to get companies more interested in collaboration
    - A single patent is almost never enough for successful technology transfer, larger patent families around a specific technology are needed (University of Tartu, Institute of Technology is following this kind of model!)
    - There are very few good examples of successful technology transfer in the world, why would Estonia make a difference?
    - Moreover, technology transfer is seldom possible without incentives from the public sector
    - **Universities should be more attractive partners to private companies, there is much more value to the economy with a technology being commercialised by an Estonian company than with a single patent sold abroad**

- Funding for research needs to be reorganised / reconsidered
  - Fundamental research funding is easier to get than funding for applied research
    - EAS funding should be made less bureaucratic
  - Universities are measured by number of publications, which is a bad measure for true applied research
    - Funding instruments should force universities to involve companies in projects
  - Applied research can also be done in companies.
    - High-tech companies that have entered markets should be encouraged to continue research
    - During the last 2 years, there have been too many grants to companies
      - According to the director of the Enterprise Capability Division at EAS, companies have applied and received the grants but could not use all the money

- Equipment
  - In certain areas the university laboratories have state-of-the-art equipment that could be used by the industry as well.
  - More personnel to operate this equipment are needed.
  - Universities should offer the use of equipment time more frequently to companies.

Fundamental research

- Fundamental research is the basis for all advanced materials technologies and very important for all future development
- There are internationally strong areas of research in Estonia in some areas of fundamental physics, chemistry and materials

- The huge number of different areas of research means that it is very difficult to create world class technology in several areas
  - A small country should carefully think of focus areas where it is putting its efforts in order to provide industrially applicable findings, either for local industry or for international technology transfer
    - The country should define a national strategy and roadmap for future focus areas in materials technology based on strong areas of research and potential synergies in the university research (coatings technology is a good example)
    - **Moreover, universities and even research groups should have a concrete strategy on where to develop their expertise**
      - Currently the problem of changing their research themes according to open calls and programmes.
    - This needs to be done in close collaboration with the industry to make the gap between technology development and market needs narrower

- In addition to coordinated actions, universities and research groups need to put effort in communications
  - Concrete example: it is very difficult for a foreigner to find out what is being studied in Estonia in materials technologies and how to collaborate with Estonian research groups
  - Even local industry or universities do not know what is being studied and developed in Estonia
  - Raising awareness and communicating better nationally and internationally is the cheapest way for getting more out of research results!

- Very few people in Estonia seem to know what is happening around them regarding science and technology
  - Universities need to listen to companies more
  - Companies need to listen universities more
  - Government needs to listen universities and companies more

4.1.3 In conclusion: Main recommendations to certain key players

- Many areas in the technology transfer chain currently need governmental or industrial support
  - There is a big risk that the funding given will be too scattered

- Research groups should create a strategy and a roadmap for their research.
- Funding agencies should rethink instruments for applied research (where patents and publications alone are bad measures of excellence)

- Industry-university collaboration:
  - Researchers: Raising awareness of current research
  - Both: Enhancing technology transfer through joint projects

- Technology transfer experts: You are needed. But you have to have business knowledge.
  - Always a gap between research and business.
  - It is never enough to have superior technology
  - In general this has been a gap in the ecosystem that needs governmental support.

- Manufacturing Industry needs an upgrade. Materials technology can help.
  - Large companies: Hire more educated people.
  - Small companies (as there are so many), play an important role: Seek more actively for R&D collaboration. Solutions:
    - Own effort such as case example PEG
    - Competence centers, that handle the bureaucracy for you
    - Industry associations are putting in an effort and can help you along the path.
    - Contact technology transfer experts at universities.
  - Special for Estonia: Better use of rare earth metals by increasing extent of value added.

- High-tech companies: The road is long. Don't give up.
  - Many believe you are the future of Estonia.
  - Once you make it, pay back and continue to develop your technologies in Estonia.

- Competence centers: you are making a good effort
  - When the time is right you should broaden your scope a bit and include new university faculties and companies.
  - Also remember to do some international technology scouting. Not all technology needs to be developed in Estonia.

- Teachers and those responsible for education
  - Many of the professors in materials technology will retire within the next five years. Education of PhDs and post doctorates are also needed to replace them. This is also an opportunity.
  - Very weak connection with industry: more industry projects needed?

4.2 Mind-game: Extreme Future scenarios for materials technology in Estonia

The following scenarios are a mind-game about what could happen if one of the following extremes happened. The scenarios only take into account the fact that national governmental funding can be changed and makes assumptions of how the university and the industry would react to these policy changes. It also assumes that the overall amount of governmental funding remains the same during the following 5-10 years. All the assumptions are predictions based on the data gathered so far and especially the point of the funding staying the same for 5-10 years depends very much on external funding sources such as the European Commission, the economy of the country and the general science and technology policy of the Estonia. The scenario that **only** fundamental research would be funded is not discussed as the benefits would take longer than 10 years to realise.

4.2.1 Extreme Scenario 1: National Governmental Funding given only to applied research that benefits the existing manufacturing industry

- Funding is mostly given to joint projects between companies and universities
- Some focus on which industries/themes should be selected to ensure real impact in the selected themes

- In 5-10 years
  - The industry will have more educated people => more in-house R&D
  - There are joint projects between universities and industry
  - Some companies are moving up in the value chain
  - All research is done based on company needs
  - Companies are ready to invest more in R&D
  - Companies are starting to do joint R&D projects with foreign partners.
  - Despite some companies moving up the value chain, most likely many companies have left the country or gone bankrupt due to higher personnel costs.

- Trade-off and risks:
  - Focus is on traditional business areas.
  - No new business areas are likely to emerge.
  - Unsure if this effort ensures global competiveness in 2020, especially if there are too many focus areas.

- Condition: Companies are actively involved in R&D, ready to learn and recruit people.

4.2.2 Scenario 2: National Governmental Funding given only to applied research that benefits creation of new high-technology companies

- To have an impact, this approach needs more public funding than the previous scheme. The support is also needed for a longer period of time.
- There is more risk, but also much more opportunities to create new businesses and renew and modernize the industry.

- In 5-10 years
  - Potentially a set of new companies established in new business areas.
  - Industry structure slowly renewing.
  - New technologies will be developed in companies.
  - Impact on economy most likely still small
  - High-tech companies start to turn education in a new direction as more competent people are needed in these areas
  - Materials technology companies tend to grow additional business around them as they are at the beginning of the value-chain => new clusters will emerge.

- Trade-off and risks:
  - As the existing manufacturing industry should develop by itself with their own money there is a risk they won't.
  - The high-tech companies don't make it or they are bought out too early.
  - A big risk is that venture capital is not found early enough.
  - Fundamental research on a broad scale is not funded => too focused technology development?

- Is there enough governmental money to succeed? How to choose the best as only a few investments can be made.
- Is there enough experienced support in Estonia to coach start-up companies and make them succeed in global business?
  - Note! These companies need both money and other type of support/coaching (business planning, partner search/evaluation, legal support, facilities, etc.).

4.2.3 Scenario 3: All National Public Funding of materials technology development is stopped

- Extreme scenario where all governmental funding to materials technology development and the money is given to other technologies or developments.

- In 5-10 years
  - Very little materials technology research left (mostly EU-funded).
  - Most skilled people have retired or moved abroad. => Estonia loses the ability to understand how to apply new/right materials in new products.
  - Some efforts have been put into technology scouting from abroad but due to lack of educated people and technology know-how not a lot of new technologies are applied.
  - Only big foreign owned companies apply newest knowledge: Estonia is in the subcontracting role.
  - The manufacturing industry will be in the same state as in 2011, but has lost market share and competiveness as the world has moved on.

- The unlikely opportunities
  - To survive, the manufacturing companies start investing more in R&D.
  - University personnel are employed by companies => R&D done there.

- As materials technology is a key enabler in many areas (such as biotechnology, energy technology etc.) it is unlikely that its funding will be stopped completely as it is a part of the development chain.

- In this scenario, the renewal of the manufacturing industry suffers most.

4.3 Estonian materials technology programme

4.3.1 Assessment of necessity

- There are very many public initiatives to increase collaboration: competence centres, technology programmes and cluster development programmes. In addition, many other funding instruments for starting a company already exist or are being planned (innovation voucher, education, SPINNO) etc.
  - Many programmes are working in highly overlapping areas and thus it is very difficult to identify the relevant ones for industrial companies
  - Most of the innovation development is highly dependent on EU structural funds and therefore the impact of decreasing funding at some point may create a shock adversely affecting innovation activities.

- It may be very difficult to position materials technology programme among other public support and funding instruments as many of the leading innovating companies already belong to multiple clusters and thus a new programme is likely to increase the amount of bureaucracy.

- A small country (as a small company) has to be very flexible and change quickly according to emerging trends and societal needs.
  - It is cheaper to find the best technology abroad.
  - It is very expensive to develop in house.
  - However, with the development knowledge (as well as with knowledge of basic sciences) it is easier to apply new knowledge quicker.

- However, in Estonia materials technology research plays a fundamental role in developing knowledge and skills for the future.

4.3.2 Approach and focus

According to the conclusions of this study the efforts on materials technology in Estonia could be targeted as follows. Number 1-4 are examples of existing efforts, discussing benefits, challenges, and disadvantages of each. Number 5 is the one we primarily recommend. In this option we have gathered the benefits of each of the previous options.

1. Industry driven small R&D programme on materials technology with 5-10 key players.

- Very similar to the competence centers (ENCC, IMECC). However,
  - Should be even more focused on companies' needs
  - Should require more commitment and own efforts from companies gradually
- There is room for more for small R&D programs in areas including
  - New energy technology materials (High-tech companies: Elcogen, SkeletonC, Crystalsol and universities they are working with)
  - Rare earth metals and materials technology (Silmet…)
  - Recycling issue and materials technology (with Weerec AS, AS Balteco, OÜ Aquator, OÜ Wellspa Sumar AS)
  - Metals coatings and surfaces (Many toolmaking companies, Norma, BLRT…)
- Nanotechnology Competence center should broaden scope and include also other research faculties.
- In five years: Cross-disciplinary activity between existing clusters?
- **Summary**
  - **Benefit:** More focused on solving certain specific problems, industry-based approach. With true company involvement better chance for successful technology transfer. Biggest potential in getting more R&D in companies.
  - **Challenge:** Industry might not be ready to even wait for 3-5 years for new solutions. Industry should also put in own man-power in the projects to really be involved. The program should also do technology scouting beyond Estonian boarders. It is often cheaper to buy a new technology than develop it oneself.
  - **Disadvantage:** Facilitation/Management of Program is a rather big expense compared to programme size. University research will be very much "ordered work". Not all are ready to do this.
  - **To succeed:** Needs true involvement of companies and a good manager to enhance the collaboration. Companies should also have to know what they need.

2. Applied research Materials Technology programme (where each project has to have industrial partners)

- Programme to distribute part of the governmental funding with a focus on applied research.
- Clear focus on match-making companies with universities.
  - Program management supports and facilitates this
- Funding for 3-4 emerging needs/application areas.
  - Defined together with the companies
- Programme committee should include companies from different industry sectors to get the cross industry-benefit of materials technology
  - Companies could include e.g. Norma, Krimelte, BLRT, Estonian Cell, Estiko Plastar, ES Sadolin AS, Esfil Tehno, Toom Tekstiil, Viru Keemia Grupp, Silmet, Raitwood, Kunda Nordic Tsement
- Facilitating activities are supported by funding to increase the effects of facilitating.
- There is a decreasing trend for technology push programmes, and thus the involvement of companies is important.
  - The biggest challenge is convincing the companies to join such a programme.
  - One benefit to companies could be the distribution of knowledge from academia to the industry. This would also include knowledge accumulated in research groups abroad.
- Important to have collaboration with the existing programmes
- Part of materials technology funding for fundamental research is still distributed as before directly from the funding institutions.
- **Summary**
  - **Benefit:** Strong emphasis on funding joint industry-university projects. With large potential to increase collaboration. Would give materials technology research a more application/user oriented approach.
  - **Challenge:** How to choose the areas to fund? How many of the areas should come from industry needs and how many from emerging needs? How to get companies involved, if needs are not their own.

- **Why is a program needed – why not fund only separate projects?** The program would create a better consensus of what areas are funded. Program management could e.g. focus on international activities and market the entity abroad. Possibility to collaborate with other national programmes. Facilitation could also enhance building new projects.
- **Disadvantage:** More man-years needed to decide which areas need support. Risk of getting too broad. The **areas have to be focused. Risk of being on-top of existing programmes.**
- To succeed: In the beginning it might be wise to start with smaller one-to-one projects and in three years increase the number of industry partners in the projects. Needs true involvement of companies and a good facilitator to enhance the collaboration.

3. Programme to distribute all funding given to fundamental research and applied research funding in materials technology development

- Would be similar to the current Energy Technology program
- **Benefit:** determines how the funding in Estonia is allocated.
  - The disadvantage is the high-level of bureaucracy involved, including many man-hours of work to find a consensus.
- Would require strong involvement of the industry to focus the program
  - Problem: does the industry understand what it needs in long-term?
- Similar benefits as choice 2.
  - With the trade-off that the entity is huge.
- The other question is who evaluates the excellence of fundamental research.
- There is a need to do more applied research. Programme could make funding for applied research more attractive and easier to apply.
- **Summary**
  - **Benefit:** There will be an entity that knows what kind of materials research is funded in Estonia. Programme could create better balance between fundamental and applied research.
    - **The true benefit** of a materials technology program would be to create cross-disciplinary areas that result in new business areas where Estonia could have a competitive advantage. However, currently research and development is facing the bigger problem of too little university-industry collaboration and this should be solved first.
  - **Challenge:** Huge entity. How to define the focus of the programme. How to define what kind of fundamental research should be funded. How does the program relate to the existing ones? How to make sure that the companies are involved?
  - **Disadvantage:** Huge entity. Money distribution will be made very bureaucratic
  - **To succeed:** The program has to have a focus. Otherwise no programme is needed.

4. Supporting actions but no Program to distribute funding

- Research funding could be directed as is today, through ministries, Archimedes foundation, EAS etc.
  - We highly recommend bigger but less projects with higher risk in addition to smaller applied research projects done in collaboration with companies.
- Supporting actions could include
  - Dissemination of research results to (manufacturing) industry (one-to-one discussions)
  - Technology scouting for industry
  - Workshops on specific topics mostly based on industry needs and university results marketing.
  - Business coaching to high-tech start-ups
  - Facilitator could also give funding and education guidelines to policy makers based on knowledge gathered from players.
  - Facilitator should bring together different players and activities, including different programs, industry associations, institutes etc.
  - Facilitator could also make a detailed roadmap for certain areas of development together with the players to influence funding decisions.
  - Reorganizing education and getting more industry projects during education is of great importance as well.
  - In a couple of years, an important part of facilitation should be put on international activities and partnering.
- **Benefit:** Less bureaucracy when distributing funding. Facilitator could concentrate on the supporting actions for which there is a huge need (e.g. enhancing university-industry collaboration).
- **Disadvantage:** Less connection to industrial needs in funding decisions and less knowledge of the overall funding picture. If no funding is related to facilitation actions will they lose their effect?
- **Challenge and Big Risk:** Will less funding be given to materials technology if there is no programme?

- **To succeed:** The facilitator has to know the materials technology development field in Estonia, understand industry needs and be up-to-date with world-wide developments and trends.

5. Programme with strong support actions to prepare for future funding "Materials R&D to business"

- Programme has two phases.

- First phase lasts 2-3 years where there is a strong emphasis on programme support actions
  - Facilitation concentrates on
    - Dissemination of current materials technology research to traditional industry
    - Enhancement of industry-university cooperation.
    - Help in applying for funding of joint applied research projects (both national and international funds)
    - Activation of industry to do R&D
    - Activating materials technology industry-education projects
  - In dedicated areas (as chosen in this report), together with industry associations, technology-industry roadmaps should be done and value-chains could be explored
  - An important part of facilitation should focus on international activities
- After the first phase there will be a midterm evaluation to assess the continuation of the program.
- In the second phase, the programme could include own funding focused on getting materials technology to business.
  - However, the distribution of this funding should be made as simple as possible.
- For best results, the programme should be started soon after this feasibility study has ended.
- The key success factor is related to the programme coordinator/facilitator. This person has to
  - understand the technology
  - understand technology transfer
  - understand industry needs
  - Know the situation in Estonia
  - Be up-to-date with world-wide developments and trends
  - Work in cooperation with other iniatives (industry associations, clusters, other programs, international programs etc.)

4.3.3 Key success factors and challenges

- Estonia materials technology field needs more concrete collaboration between universities and industries and this should be facilitated in all possible ways starting from joint education efforts to joint R&D projects.
- The materials technology society of Estonia needs to be brought together.
- Many of the professors today will be retire in five years. A challenge is to make sure there knowledge and skills is passed on to their peers and to companies.
- It should be understood that companies based on materials technology take a long time to develop. However, they are more likely to build on existing knowledge, industry and build a value-chain around them.
- Facilitation is needed. But the role of the facilitator is very important. This makes it challenging.
- Funding needs to support more applied research and university cooperation. There is a big risk that the funding schemes will turn out to be too complicated and scattered.
- The different programmes in Estonia should not compete against each other. Many players are involved in several.
- The biggest challenge is getting the traditional industry involved. All those we interviewed were interested but hoped for more support and activity from the university side.

Appendix A: Scientific publications

Table 7. Estonian materials technology publications in different journals with high impact factors

Journal name	*Count*	*Description*	*Impact factor*
Physica Status Solidi B-Basic Research	158	Condensed matter	1.150
Thin Solid Films	88	Thin films	1.727
Journal of Physics: Condensed Matter	49	Condensed matter	1.964
Applied Surface Science	44	Surfaces	1.616
Solid State Communications	44	Condensed matter	1.837
Journal of the Electrochemical Society	42	Electrochemistry	2.240
Physica B: Condensed Matter	33	Condensed matter	1.056
Wear	33	Wear, surfaces	1.771
Synthetic Metals	31	Polymers, superconductors, novel carbon etc	1.901
Journal of Alloys and Compounds	27	Alloys and compounds	2.135
Ferroelectrics	25	Ferroelectrics	0.447
Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms	23	Measurement	1.156
Optical Materials	20	Optical materials	1.728
Solar Energy Materials and Solar Cells	20	Solar energy	3.858
Journal of Solid State Electrochemistry	18	Electrochemistry	1.821
European Physical Journal B	17	Condensed matter	1.466
Journal of Materials Chemistry	16	Materials chemistry	4.795
Chemistry of Materials	15	Materials chemistry	5.368
Chemical Vapor Deposition	14	Chemical Vapor Deposition and related technologies	1.829
Journal of Optoelectronics and Advanced Materials	14	Optoelectronics	
Journal of Organometallic Chemistry	13	Organometallic chemistry	2.347
Journal of Physics and Chemistry of Solids	13	Condensed matter	1.189
Journal of Non-Crystalline Solids	12	Amorphous and glassy materials	1.252
Materials Science Forum	12	Materials science, solid state physics and solid state chemistry	0.399
Surface Review and Letters	12	Properties and processes at the boundaries of materials	
Physica Status Solidi B-Basic Solid State Physics	11	Solid state and materials physics	1.150
Carbon	10	Carbonaceous solids	4.504
International Journal of Solids and Structures	8	Mechanics of solids and structures	1.809
Experimental Mechanics	7	Mechanics, characterization and testing	1.542
Materials Science and Engineering B-Solid State Materials for Advanced Technology	7	Solid state materials	1.756
Physica Status Solidi A - Applications and Materials Science	7	Solid state and materials physics	1.228

Table 8. Authors with most publications relevant to materials technology

Only publication in high impact journals have been taken into account

Name	*Count*	*Institution*	*Area*
Brik, M.G.	72	TU IP	Solid state physics
Kukli, K.	71	TU IP	Thin films, Atomic Layer Deposition
Zazubovich, S.	62	TU IP	Solid state physics
Aarik, J.	51	TU IP	Thin films, Atomic Layer Deposition
Meissner, D.	43	TUT	Photovoltaic materials
Kirm, M.	42	TU IP	Novel functional materials
Kristoffel, N.	41	TU IP	Superconductivity
Konsin, P.	39	TU IP	Ferroelectricity and superconductivity
Mellikov, E.	37	TUT	Photovoltaic materials
Nagirnyi, V.	34	TU IP	Wide-gap inorganic materials
Hizhnyakov, V.	32	TU IP	Solid state physics, superconductivity
Öpik, A.	31	TUT	Photovoltaic materials, electrically conductive polymers
Krunks, M.	29	TUT	Photovoltaic materials, thin films
Aidla, A.	28	TU IP	Nanoelectronics and thin films
Lust, E.	28	TU IC	Electrochemistry, fuel cells, supercapacitors
Sherman, A.	28	TU IP	Superconductivity, crystal optics, laser physics
Sildos, I.	28	TU IP	Laser spectroscopy
Mikli, V.	27	TUT	Thin films, coatings
Lushchik, A.	25	TU IP	Solid state physics
Sammelselg, V.	25	TU IP/IC	Surface science, solid state physics and chemistry
Volobujeva, O.	25	TUT	Microscopic studies of materials, solar cells
Uustare, T.	24	TU IP	Solid state physics, nanostructures and coatings
Krustok, J.	23	TUT	Solar cells
Bereznev, S.	20	TUT	Solar cells
Raudoja, J.	19	TUT	Solar cells and solar cell materials

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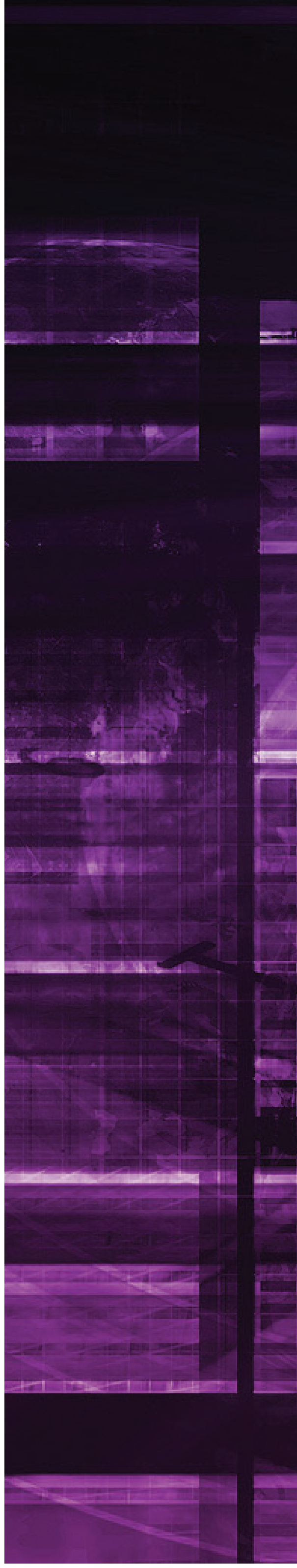

Previously published in "Innovation Studies":

1/2002 Competence Centre Programme Estonia. Feasibility Study
Available in English

2/2002 Innovation in Estonian Enterprises 1998–2000
Available in English and

3/2003 Business Incubation: Review of Current Situation and Guidelines for Government Intervention in Estonia
Available in English

4/2003 Optimising the Design and Delivery of Innovation Policy in Estonia: an Evaluation of Policy Instruments for Intensifying Business Innovation
Available in English

5/2004 Access of Enterprises to Venture Financing in Estonia: Feasibility Study of Government Support Scheme
Available in English

6/2006 Evaluation of the Design and Implementation of Estonian RTDI Policy: Implications for Policy Planning
Available in English

7/2007 Innovation in Estonian Enterprises 2002–2004
Available in English

8/2007 Impact Evaluation of Spinno Programme in 2001–2006
Available in English

9/2007 Innovation Staff Recruitment Programme Feasibility Study
Available in English

10/2007 Evaluation of Estonian RTDI Policy Mix
Available in English

11/2008 Ettevõtete tehnoloogiainvesteeringu teostatavuse analüüsi lõppraport
Available in Estonian

12/2008 Mid-Term Evaluation of the Competence Centre Programme
Available in English

13/2010 Estonian Biotechnology Programme Feasibility study for an Estonian biotechnology programme
Available in English

14/2010 Eesti ettevõtete uued võimalused – ärimudelid, ava tud innovatsioon ja riigi valikud
Available in Estonian

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