Production and trade in KETs-based products:
The EU position in global value chains and specialization patterns within the EU

Final report

Authors: Els Van de Velde, Pieterjan Debergh, Arnold Verbeek

***Idea Consult**, Brussels, Belgium*

Christian Rammer, Katrin Cremers, Paula Schliessler

***Centre for European Economic Research (ZEW)**, Mannheim, Germany*

Birgit Gehrke

***Lower Saxony Institute of Economic Research (NIW),** Hannover, Germany*

Date: June 17, 2013

Zentrum für Europäische Wirtschaftsforschung GmbH
Centre for European Economic Research

This report is the background study to the European Competitiveness Report 2013. The study was commissioned by the European Commission, DG Enterprise within a Framework Contract ENTR/2009/033 coordinated by the Austrian Institute for Economic Research (Wifo) (coordinator: Michael Peneder).

The opinions expressed in the report are those of the institutions that produced this report and do not represent the European Commission's official position.

Contact

Arnold Verbeek
Competitiveness & Innovation
IDEA Consult
Kunstlaan 1-2 bus 16
B-1210 Brussel
Belgium
Phone: +32 2 282 17 19
E-Mail: arnold.verbeek@ideaconsult.be

CONTENTS

List of figures

List of tables

List of country acronyms

BE	Belgium
CA	Canada
CH	Switzerland
CN	China
CZ	Czech Republic
DE	Germany
ES	Spain
FI	Finland
FR	France
IE	Ireland
IL	Israel
IN	India
IT	Italy
JP	Japan
MA	Malaysia
NL	Netherlands
SE	Sweden
SG	Singapore
TW	Taiwan
UK	United Kingdom
US	United States

CHAPTER 1. INTRODUCTION

The European Commission has launched a study on the production and trade in KETs-based products. This report is the final background report that constitutes the basis for the chapter on Key Enabling Technologies of the upcoming, 2013 European Competitiveness Report by the European Commission.

1.1. BACKGROUND OF THE STUDY

In the Communication, "A European strategy for Key Enabling Technologies - A bridge to growth and jobs", the European Commission mentions its strategy to boost the industrial production of KETs-based products in order to allow a maximum exploitation of the EU's potential in competitive markets (EC, 2012a). Key Enabling Technologies (KETs) are defined as knowledge intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly skilled employment. They are multidisciplinary, cutting across many technology areas with a trend towards convergence and integration. The following technologies are identified as KETs: micro- and nanoelectronics, nanotechnology, photonics, advanced materials, industrial biotechnology and advanced manufacturing technologies.

In addition, in its Communication "A stronger European Industry for Growth and Economic Recovery", the Commission has identified six priority action lines (EC, 2012b). One of the priority action lines is markets for key enabling technologies in which the Commission expresses its intention to implement the European Strategy for KETs ensuring better co-ordination of EU and Member State technology policies, the funding of essential demonstration and pilot lines and cross-cutting KET projects, and the timely development of the Internal Market for KET-based products. Moreover, the industrial deployment of KETs will become a key component of relevant European Innovation Partnerships.

1.2. OBJECTIVES OF THE STUDY

The objective of the study is to analyze the current position of the EU in the global production of KETs-based products in order to assess upcoming challenges for the EU's competitiveness. The project aims at:

- providing a narrative overview of most recent technological and industry developments in each KET since 2009;
- updating estimations on future market potentials in each KET, building upon the analyses of recent trends in "market shares" in the production of KET-related technologies based on patent application data and update corresponding analyses presented in the CR 2010;
- analyzing the EU position in the value chain decomposition of two KETs-based products;
- analyzing the EU position in international trade for certain subfields of KETs-based products including changes in the EU's competitiveness over time using indicators such as market share, comparative advantage and trade surplus;
- analyzing the EU position in value chains (in terms of 'technology content') within certain subfields of KETs-based products based on unit value analysis of exports and imports:
- analyzing the specialization of a selection of EU Member States in production and trade of KETs-based products by combining production and trade statistics."

This study will use the definition of KETs-based products as defined in the Communication "A European strategy for Key Enabling Technologies – A bridge to growth and jobs" of June 2012 by the European Commission, hence a KETs-based product is: (a) an enabling product for the development of goods and services enhancing their overall commercial and social value; (b) induced by constituent parts that are based on nanotechnology, micro-/nanoelectronics, industrial biotechnology, advanced materials and/or photonics; and, but not limited to (c) produced by advanced manufacturing technologies.

This study is structured as follows: Chapter 2 provides an overview of several technological and industry developments in KETs. Chapter 3 presents an update of the market share calculations and market potential estimates of the background study for the 2010 European Competitiveness Report. In chapter 4, the value chain of two KETs-based products is analyzed namely the value chain of lipase enzymes and the accelerometer. Chapter 5 analyses the position of the EU in international trade in KETs-based products while chapter 6 summarizes the main insights obtained in this study.

CHAPTER 2. OVERVIEW OF TECHNOLOGICAL AND INDUSTRY DEVELOPMENTS IN KETS

2.1. INTRODUCTION

This chapter provides an overview of the recent technological developments in the six KETs together with examples of the development of KETs-based products. For each KET, a general introduction is provided followed by a discussion of the recent technological developments and associated KET-applications. When appropriate, general remarks on the technological developments within KETs are provided before the actual discussion of the specific applications field.

KETs generally have a wide application range as there are enabling technologies by definition. Therefore some choices have been made with regard to the technological development in KETs-based applications that will be discussed in the following sections. Applications are selected on the basis of economic relevance (both at present and future potential) and social relevance (again both at present and in the future). The applications discussed in this chapter are used to select KETs-based products for the value chain analysis (see section 4.2).

2.2. INDUSTRIAL BIOTECHNOLOGY

2.2.1. Introduction

Industrial biotechnology (IB) or 'white' biotechnology has been identified as one of the six 'Key Enabling Technologies' (KETs). The High Level Group (HLG) has defined industrial biotechnology as "*the application of biotechnology for the industrial processing and production of chemicals, materials and fuels. It includes the practice of using micro-organisms or components of micro-organisms like enzymes to generate industrially useful products, substances and chemical building blocks with specific capabilities that conventional petrochemical processes cannot provide*" (HLG IB, 2011). In other words, industrial biotechnology companies use life science techniques to find and improve nature's enzymes or develop diverse microbial systems – from bacteria, yeasts, and fungi to marine diatoms and protozoa – for use in industrial applications.

Biotechnology as a whole is defined by the OECD as "the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD, 2005). In other words, biotechnology is derived from biological knowledge and finally is associated to the evolution of biological science. The main techniques used in biotechnology, and hence also in industrial biotechnology, can be summarized as follows (HLG IB, 2011):

- **DNA/RNA:** Genomics, pharmacogenomics, gene probes, genetic engineering, DNA/RNA sequencing/synthesis/amplification, gene expression profiling, and use of antisense technology.
- **Proteins and other molecules:** Sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signaling, identification of cell receptors.
- **Cell and tissue culture and engineering:** Cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cellular fusion, vaccine/immune stimulants, embryo manipulation.
- **Process biotechnology techniques:** Fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation.
- **Gene and RNA vectors:** Gene therapy, viral vectors.
- **Bioinformatics:** Construction of databases on genomes, protein sequences; modeling complex biological processes, including systems biology.

The techniques listed above constitute the 'toolbox' of the scientist. They are the tools at hand to modify and/or use micro-organisms to achieve a certain goal (e.g. the production of a vitamin). It is clear that any advancement in the techniques themselves (which is more fundamental research) will lead to more possibilities in applied research, which in turn can lead to applications society is interested in. The spectacular advancements made in these biotechnology techniques over the past decades have enabled many interesting applications in industrial, as well as medical and agricultural biotechnology.

2.2.2. Technological developments and applications

Industrial Biotechnology entails biochemicals, biofuels and biomaterials; and is well established in the production of biochemicals for the pharmaceutical market, food & feed, fine chemicals, detergents and hygienic products. Table 2.1 provides some examples of biochemicals that are well established in the industry.

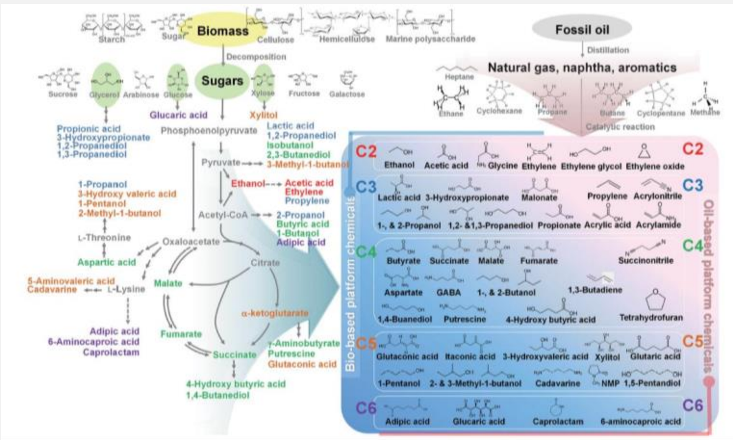
Table 2.1 - Examples of established products

Amino acids	Lipids	Organic acids	Alcohols	Vitamins	Proteins
L-glutamic acid L-lysine L-threonine	Phytosphingosin	Citric acid Lactic acid Itaconic acid	Ethanol	Riboflavin Cyanocobalamin	Amylase Phytase Antibodies

Source: OECD (2010)

Most of these established products are only available through biotechnological processes because chemical synthesis offers no alternative. For example, for proteins like enzymes or monoclonal antibodies as well as enantiomerically pure substances like L-amino acids, biotechnological processes are the only choice. In general, biotechnology tends to focus on products which are either i) not available through petrochemical synthesis or ii) available by cost-effective processes (*e.g.* citric acid, gluconic acid) or iii) earn a relatively high market price.

Figure 2.1: Overview platform chemicals



Source: Jang et al. (2012)

Platform chemicals

One interesting application of industrial biotechnology are the so called platform chemicals, chemicals than can be used as a precursor for making a variety of chemicals and materials, including solvents, fuels, polymers, pharmaceuticals, perfumes, and food. Currently they are mostly derived from fossil resources, but increasing attention is going to the use of renewable sources instead. Once derived from these new sources, they could be further transformed into the very same broad portfolio of end-products that is produced today from fossil sources. Figure 2.1 schematizes the production of platform chemicals from both fossil and renewable sources (Jang et al, 2012).

Large research efforts are currently being made to find and modify micro-organisms in a way that platform chemicals of interest can be produced at economically interesting rates. Currently, chemicals with a broad range of carbon lengths can be produced by the sugar fermentations of microorganisms. At present, lactic acid, ethanol, and 1,3-propanediol have already been commercialized for economical bio-based production, and succinic acid, 1,4-butanediol, isobutanol, acetic acid, and isoprene are nearing large-scale commercialization as bio-based chemicals. Yet, for many other chemicals, intensive metabolic engineering is needed to enhance performance of the production of these chemicals. This includes the developments of microbial strains that have optimized pathways, can use several carbon sources, are better tolerant against the end product, use less nitrogen and ideally have metabolic pathways in order to produce platform chemicals in one step reactions (Jang et al, 2012).

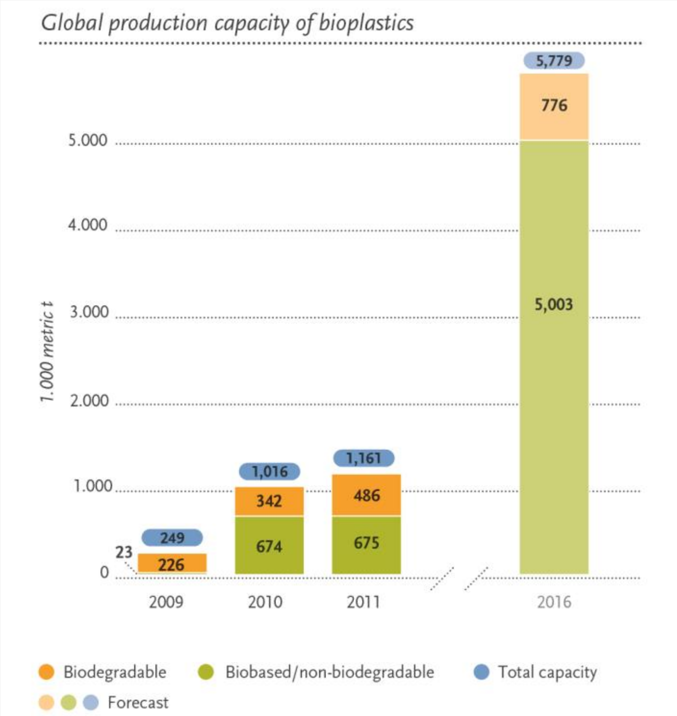
One of the economically most important chemical intermediates is succinic acid, and currently a lot of effort is dedicated to the optimization of the bio based production (OECD, 2010). In 2011 Roquette and DSM announced to invest in the production of bio succinic acid, targeting about 10 kilotons per year. According to the Chief Innovation Officer of DSM, it is possible to produce cost effectively due to the great advances that have been made over the past years. Even more, the eco-footprint of the end product is reduced at the same time, illustrating the large potential of biotechnology in this area (DSM, 2011).

Bio-based polymers

Bio-based polymers are considered to be one of the important milestones for white biotechnology (HLG IB, 2011). Polymers are long molecules composed of repeating building blocks (the monomers). In most cases biotechnology serves to deliver this building block, and conventional techniques are then used to make a chain of these building blocks. In some other cases however the micro-organisms produce directly the polymer (for example, the polysaccharides covering the cell walls of certain micro-organisms) (Sutherland, EOLSS). Over the past 20 years, the efforts have particularly concentrated on polyesters of 3-hydroxyacids (PHAs), polylactic acid (PLA) and other polymeric building blocks such as 1,3-propanediol (1,3 PDO) or polyethylene from bioethanol which are mainly naturally synthesized by a wide range of microorganisms. These compounds have properties similar to synthetic plastics and elastomers from propylene to rubber, but are completely and rapidly degraded by bacteria in soil or water. A major limitation of the commercialization of such bio-based plastics is their cost and performance in relation to petroleum-based polymers (HLG IB, 2011).

Bio-based polymers and plastics are today still in their infancy, but their production has grown at high growth rates (about 50% annually) in the past decade (HLG IB, 2011). As can be seen for bioplastics in Figure 2.2, the global production reached the point of one million tons in 2010 (after a major downturn due to the economic crisis in 2009), and the production is expected to increase dramatically by 2016 (Bioplastics Association, 2012). The market share of biobased plastics is expected to reach 10-20% in 2020, hence effectively substituting a significant part of oil-based plastics (HLG IB, 2011).

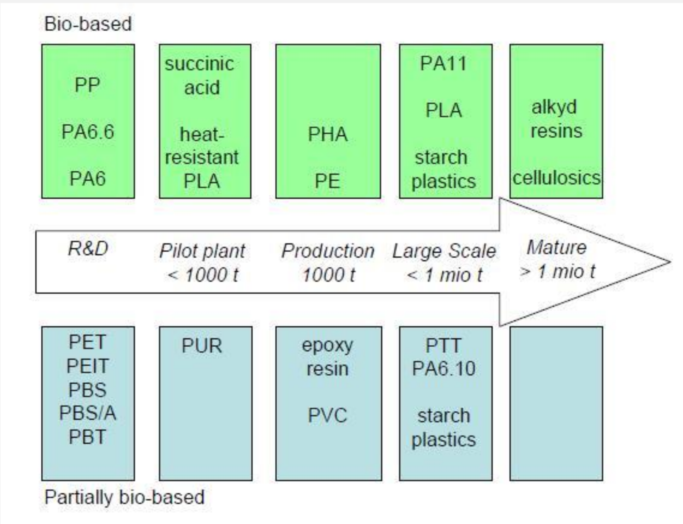
Figure 2.2: Evolution of the production of bioplastics



Source: European bioplastics association

The market potential of biobased polymers is underscored by the fact that the maximum technical substitution potential of bio-based plastics replacing petrochemical plastics is seen at 90% of polymers including fibers (OECD, 2010). For some, a substitution potential of up to 100% is seen, especially for PBT (polybutylene terephtalate), PBS (polybutylene succinate), PET and PE89. In Figure 2.3 the development stage of the diverse bio-based plastics is shown. It is clear that many applications are underway but only a few have reached large scale production.

Figure 2.3: Development stage of various bioplastics



Source: Shen et al., 2009

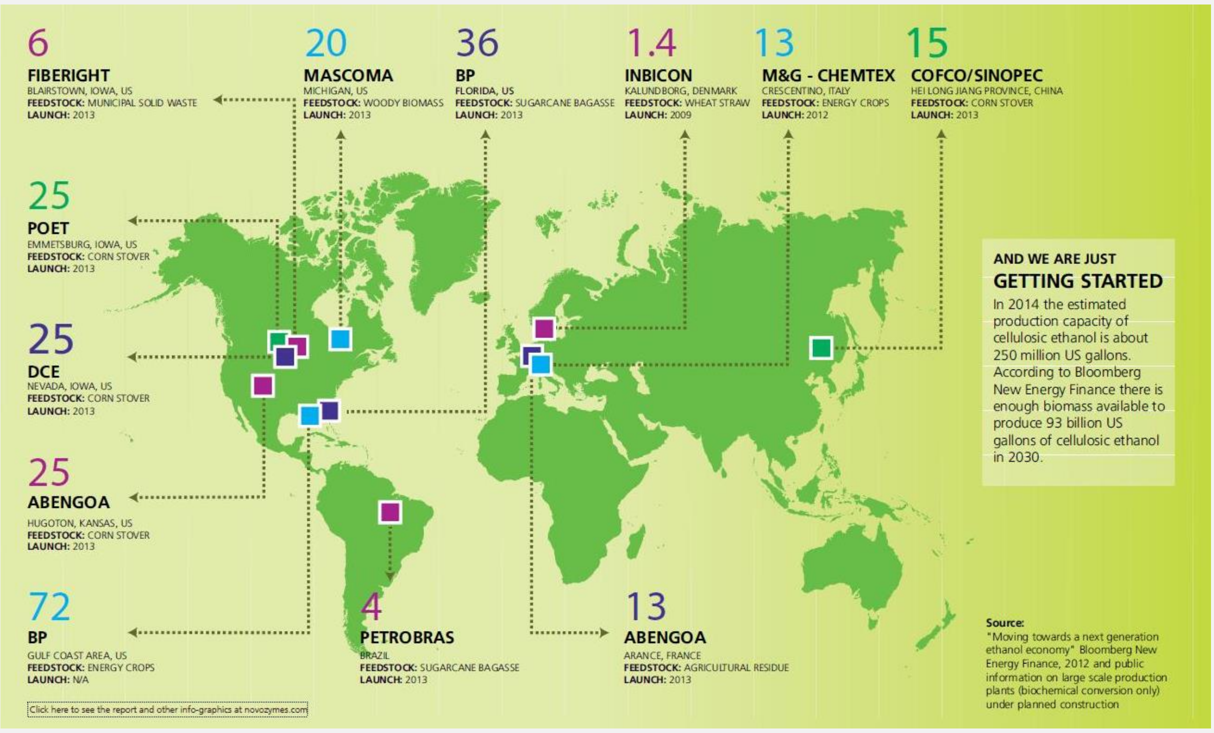
Enzymes are proteins that function as catalysts: they accelerate chemical reactions. They are the pillars in the cells of all living forms, taking care of all chemical conversions needed for the functioning of the cell. Enzymes are increasingly used to perform chemical reactions in various industries. Compared to the traditional transformation methods they can have many advantages. For example, they do not require very high temperatures and/or pressure to 'force' a chemical reaction, resulting in a significantly lower energy use, nor do they require the use of acid or alkaline agents to stimulate particular chemical reactions (they operate under 'mild' conditions). Moreover, they often deliver a very pure product yield, avoiding the difficult task of disposing by-products. The most widely used class of enzymes for industrial purposes are the hydrolases: enzymes that catalyze the cleavage of chemical binding using water as additional input. They can be subdivided in three major classes according to the substrate they cleave: carbohydrases (carbohydrates), proteases (proteins) and lipases (lipids) (Jegannathana & Nielsen, 2012).

Under the class of **carbohydrases** we find well known enzymes such as amylase and cellulase. They have as substrate starch (a polymer of sugar units serving as a major reserve of carbohydrate in plants) and cellulose (a polymer of sugar units having a structural function in the plant cell wall)[1]. Both enzymes have a long tradition of use for industrial purposes. **Amylase** is used in a wide range of applications, e.g. in the brewing industry (where it is used to make the individual units better available for yeast fermentation), baking industry, paper industry and detergent industry. The recent surge in the production of bioethanol as renewable energy carrier has opened a new major market for amylase, where it is constantly developed to deliver higher ethanol yields. **Cellulase** has been commercially available for more than 30 years, and is commonly used for paper recycling, juice extraction, as detergent enzymes and animal feed additives. Fungi that cause the rotting of wood possess excellent cellulases and have been preferred over bacteria for cellulase production over the past years. Research efforts are focused on improving the performance of the enzymes and the enzyme yield through direct genetic engineering as well as on the discovery of new micro-organisms with even higher potential for cellulase production (Kuhad et al, 2011). The foremost promising application of cellulase with regard to the future lies in the production of second generation biofuels, which will be discussed in more detail below.

Cellulases are currently the third largest industrial enzyme worldwide, by monetary value, due to their numerous applications. However, cellulases may become the largest volume industrial enzyme if enough progress is made to allow cellulosic biomass to be used in other areas. This is because the use of starch as input for the fermentation of sugar to produce bioethanol clearly competes with the food industry, which raises strong ethical questions. Therefore it would be a major step forward if cellulosic material (which is not edible and abundantly available) could be used instead. The current challenge is to develop enzymes that can be produced at low cost (at high titers) and deliver a good catalytic conversion of the cellulose (Kuhad et al, 2011). Scientists have found a number of fungi (most notably the fungus *Trichoderma reesei*) that are very effective cellulase producers, and these micro-organisms have formed the basis for many enzyme engineering efforts (Chundawat et al, 2011). Significant advances have been made in this field, and a number of companies currently commercially produce these enzymes (e.g. Novozymes since 2010). However, a general problem with enzymes that also applies to cellulases, is that their stability in industrial conditions is rather low. Therefore currently enzymes are developed that perform better at industrial conditions (temperature, pH,…) (OECD, 2010). Cellulosic ethanol is currently moving from pilot stage to large scale projects. According to an overview provided by enzyme producer Novozymes (see Figure 2.4), many large scale projects are soon to be launched. Yet, this figure demonstrates at the same time the uncertainty that is still present in the next generation biofuel field, as BP very recently cancelled its investment (BP, 2012). It will become clear in the next years whether it is indeed possible to engage in large scale and commercially viable cellulosic ethanol production.

[1] Given their different functions in the plant (energy storage versus cell wall strength), starch is typically easier to break down into its composing sugar units than cellulose (which for example cannot be digested by humans unlike starch).

Figure 2.4: Overview of recent large scale cellulosic ethanol plant investments



Source: Novozymes

Note: The number above each plant refers to the production volume (expressed in million gallons per year). The company behind the investment is indicated underneath in bold.

Lipases differ greatly as regards both their origins (which can be bacterial, fungal, mammalian, etc.) and their properties, and they can catalyze the hydrolysis, or synthesis, of a wide range of different carboxylic esters and liberate organic acids and glycerol. Traditionally they have been used in the paper and detergent industry, exploiting their capability to cleave lipids. However, as it was discovered that lipases are powerful tools for catalyzing not only hydrolysis, but also various reverse reactions, such as esterification, transesterification, and aminolysis in organic solvents, they have been used for synthesizing molecules (biocatalysis) as well as cleaving them. This property has made them the most important group of biocatalysts for biotechnological applications. Their biocatalytic power has allowed them to penetrate new markets like the oleochemical and pharmaceutical industry (Schörken & Kempers, 2009; Sangeetha et al., 2011). They are also explored for their potential in biodiesel production (Tan et al, 2012). Current research is focusing on the reduction of the enzyme's production cost (which remains today too high for a broad penetration of the market) as well as improvement of the stability of the enzyme during chemical conversions (Sangeetha et al, 2011).

Biorefineries

A biorefinery uses biomass as input and processes it into many different products in the same way a petroleum refinery uses petroleum. It is anticipated that many bio-sourced products will be produced from biorefineries fed with biomass. The concept biorefinery refers to a combination of integrated plants addressing i) processing and fractionation of renewable raw materials; ii) transforming feedstock to various products from food, feed, fibers, bulk and fine chemicals up to biofuel; and iii) recycling the products after use where possible (FitzPatrick et al, 2010). In a biorefinery, all of the above described individual applications can be produced. The idea behind a biorefinery is to combine several of these individual processes to improve their economy (OECD 2010).

Biorefineries are not likely to be fully demonstrated before 2015 (Foresight, 2010). The problems are (among others) the rather early development stage of the core technologies and the lack of returns to scale compared to petroleum refineries. Given this and the complementarity between biotech and traditional chemistry, a promising strategy is to integrate a biorefinery into an existing chemical production (OECD 2010). In this regard, the Commission expressed its aim to promote the setting up of networks with the required logistics for integrated and diversified biorefineries, demonstration and pilot plants across Europe as industrial biotechnology is only one range of different existing process technologies that can be used in an integrated manner handling diversified feedstocks in such a biorefinery, leading to a variety of diversified outputs[2]. To illustrate the different processes that may be combined in a biorefinery, Table 2.2 lists examples of biorefinery projects currently taking place in the US.

Table 2.2 - List of biorefinery projects in the US

Project name	Lead Partner/ Project Period	Project cost	Project Description and Status
Integrated Biorefinery for Conversion of Biomass to Ethanol, Power and Heat	Abengoa Bioenergy	N/A	Construction of a 1,200 tons per day commercial biorefinery producing cellulosic ethanol and also power and heat to operate the facility. Agricultural residues would be converted via enzymatic hydrolysis to sugars and fermented into cellulosic ethanol. Agricultural residues along with ethanol plant residual solids and waste water treatment biogas, will be used to generate the necessary heat and power to make the facility energy self-sufficient. Current Status: Award Date: September 2007. Record of Decision was issued January 2011 and supplementary analysis issued July 2011.
Design, construct, build and operate a commercial processing plant as part of an integrated biorefinery to produce lignocellulosic ethanol primarily from corn cobs.	POET Project Liberty	N/A	Demonstration of the benefits of integrating an innovative lignocellulose-to-ethanol biochemical process into an existing dry-grind corn processing infrastructure on a commercial scale. 700 dry metric tonnes per day of lignocellulose, primarily from corn cobs, will be processed to produce 25 million gallons of lignocellulosic ethanol per year. Up to 80% of the corn dry mill's existing natural gas use will be displaced through renewable, alternative energy. Current Status: Award Date: September 2008.
A commercial-scale biorefinery converting biomass into biofuels and power.	Range Fuels	N/A	Plant uses a thermo-chemical process to combine pressure, heat, steam and biomass to produce synthesis gas, or syngas, a mixture ofhydrogen and oxygen that can be converted to a wide range of products. Current Status: Award Date: November 2007.
Demonstration Plant - Biomass to Fischer-Tropsch Green Diesel	Flambeau River Biofuels	N/A	Construction and operation of a thermal gasification and gas-to-liquids plant ingegrated into the Park Falls Mill to produce green diesel for transportation fuel, waxes, and heat and power that replaces natural gas. The plant will produce 1,190 barrels per day of clean, zero sulfur renewable biofuels, waxes, and heat and power that replaces existing natural gas use from forest biomass. Current Status: Award Date: September 2008
Integrated Biorefinery Demonstration Plant producing Cellulosic Ethanol and Biochemicals from woody biomass.	Lignol Innovations, Inc	N/A	Plant for the continuous production of cellulosic ethanol, high purity lignin and furfural from hardwoods. Plant will process 100 tpd of woody biomass, initially local hardwood which is plentiful, and in future test campaigns, softwood and agricultural residues. Current Status: Award Date: TBD
Mascoma Frontier Biorefinery Project	Mascoma Corp.	N/A	Project would initially produce up to 40 million gallons per year of denatured enthanol from approximately 1,300 dry metric tonnes per day of cellulosic materials consisting primarily of wood wastes. Current Status: Award Date: February 2009
NewPage: Project Independence	NewPage Corp.	N/A	Construct & operate a thermal gasification and gas-to-liquids plant integrated into Wisconsic Rapids Mills to replace natural gas use and produce liquid biofuels that will be converted into renewable diesel. Current Status: Award 1 Sept. 2008; Award 2 TBD.
Pacific Ethanol	Pacific Ethanol Inc.	N/A	Design, construct and operate a feedstock flexible demonstration facility producing cellulosic ethanol. Capacity of 2.7 mill gallons of ethanol per year. Current Status: Operational 2009
Red Shield Acquisition	Red Shield Acquisition	N/A	Construct integrated biorefinery that will extract hemicelluloses from wood chips to make biofuel and other specialty chemicals at existing pulp mill. Cellulose & lignin will be maintained in the pulp manufacturing process. Facility will produce 1.5 million gallons per year of Current Status: Award Date: January 2010
Verenium: Jennings 1.4 MGY Demonstration Plant	Verenium Corp.	N/A	Project is operating the demonstration facility to validate findings from the pilot plant operation in the production of cellulosic ethanol from purpose-grown energy crops and agricultural residuals. This demonstration facility is fully integrated from feedstock pretreatment to recovery and distillation of the biofuel product. Current Status: Award Date: September 2008

Source: US department of Energy

[2] EC Communication on Innovating for Sustainable Growth: A bioeconomy for Europe, 2012

2.3. PHOTONICS

2.3.1. Introduction

The European Commission has identified photonics as one of the Key Enabling Technologies. According to Pierre Aigrain, "Photonics is the science of harnessing light. Photonics encompasses the generation of light, detection of light, management of light, through guidance, manipulation, and amplification, and most importantly, its utilization for the benefit of mankind". An appealing comparison is that photonics bears the same relationship to light and photons, as electronics do to electricity and electrons (Photonics 21, 2012). Photonics covers the whole spectrum of visible and invisible light, including microwaves and X-rays. The unique properties of light allow the development of applications that would not be possible otherwise. By using light (photons are energy-rich light packages) as information carrier and as energy carrier, photonics adopts more and more tasks that previously were done by means of electrical and electronic processes. For example, the large majority of telecommunication happens today over optic fibers (HLG Photonics, 2011), that provided ground for the success of the World Wide Web. Photonics is increasingly present in our everyday life. As Table 2.3 illustrates, the number of applications is very diverse. They can be found in fields as varying as energy, manufacturing, communication, medics and defense.

Table 2.3 - Division of photonics by subfields along with examples of applications

Field of Technology	*Applications Examples*
Production Technology	Laser Materials Processing Systems Lithography Systems (IC, FPD, Mask) Lasers for Production Technology Objective Lenses for Wafer Steppers
Optical Measurement and Machine Vision	Machine Vision Systems and components Spectrometers and Spectrometer Modules Binary Sensors Meas. Systems for Semiconductor Industry Meas. Systems for Optical Communications Meas. Systems for Other Applications
Medical Technology and Life Science	Lenses for Eyeglasses and Contact Lenses Laser Systems for Medical Therapy and Cosmetics Endoscope Systems Microscopes and Surgical Microscopes Medical Imaging Systems (only Photonics-Based Systems) Ophthalmic and Other in Vivo-Diagnostic Systems Systems for In-Vitro-Diagnostics, Pharmac. & Biotech R&D
Optical Communications	Optical Networking Systems Components for Optical Networking Systems
IT: Consumer Electronics, Office Automation, Printing	Optical Disk Drives Laser Printers and Copiers, PODs, Fax and MFPs Digital Cameras and Camcorders, Scanners Barcode Scanners Systems for Commercial Printing Lasers for IT Sensors (CCD, CMOS) Optical Computing Terahertz Systems in Photonics

Lighting	Lamps LEDs OLEDs
Flat Panel Displays	LCD Displays Plasma Displays OLEDs and Other Displays Display Glass and Liquid Crystals
Solar Energy	Solar Cells Solar Modules
Defense Photonics	Vision and Imaging Systems, Including Periscopic Sights Infrared and Night Vision Systems Ranging Systems Munition / Missile Guiding Systems Military Space Surveillance Systems Avionics Displays Image Sensors Lasers
Optical Systems and Components	Optical Components and Optical Glass Optical Systems ("Classical" Optical Systems) Optical & OE Systems & Components Not Elsewhere Classified

Source: Optech (2007) and Aschhoff et al. (2010)

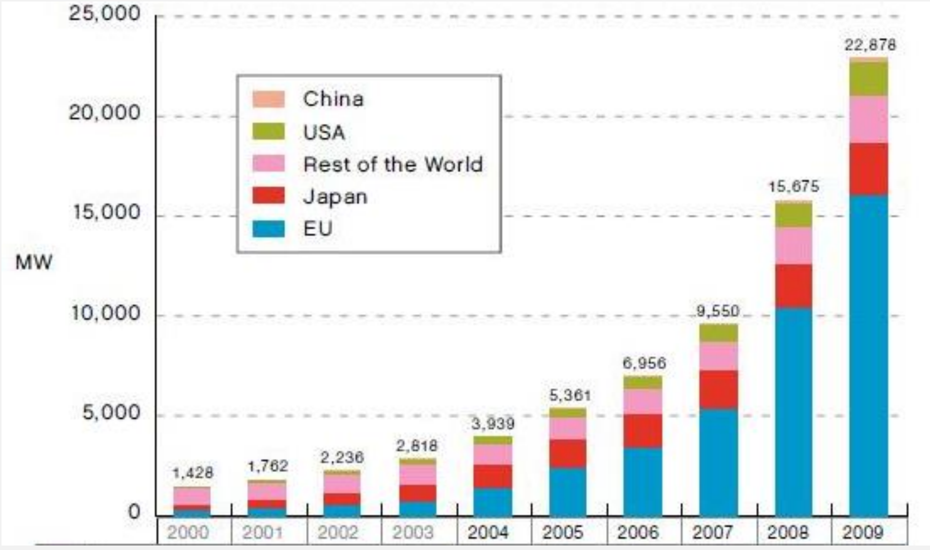
As there are numerous applications of photonics, we will focus on the developments in the field of solar energy, optical communication, lighting, and displays in the next sections.

2.3.2. Technological developments and applications

Solar energy

One of the best known applications of photonics is the capturing of solar light for energy purposes. The advantage of the use of solar energy is obvious as this source is abundantly available on earth (though with strong regional differences). The search for renewable energy sources has led to a strong increase in the use of solar energy worldwide in recent years. As can be seen in Figure 2.5, the installed photovoltaic capacity amounted to about 23000 MW in 2009, with Europe having the lion's share. Yet, this represents only a tiny fraction of total electricity generation (less than 1 percent). Even if the installed capacity is expected to grow with an annual rate of about 25% on average worldwide between 2010 and 2017, it will become at best a modest source of energy supply in the short term. The main challenge for solar energy is to reach cost parity with other energy sources for electricity generation during peak demand times, as it is currently rather dependent on government support (NRC, 2012).

Figure 2.5: Evolution of installed photovoltaic energy capacity over the period 2000-2009



Source: European photovoltaics industry association

The best known method to capture sunlight and generate electricity is **photovoltaics** (PV). This method uses semiconductor material having photovoltaic properties, that is, materials wherein an electric current is generated upon exposure of light. This implies that photovoltaics generate an electrical current directly in the process of capturing light (while other systems use intermediate carriers of energy).

The **first generation** photovoltaic solar panels are made of a crystalline structure which uses silicon (Si) to produce the solar cells that are combined to make PV modules. This includes mono-crystalline, poly-crystalline, and silicon ribbon technologies (Chaar et al, 2011). In 2010, over 75 percent of the capacity of PV systems installed was first-generation solar cells. Silicon photovoltaics are the most mature and widely accepted form of PV, and they still exhibit some of the highest conversion efficiencies of available technologies. PVs are expected to continue to dominate the market till 2017, although they are expected to lose market share to emerging technologies (NRC, 2012).

Second generation photovoltaics uses the so-called thin film technology. The advantage of this technology lies in the fact that the thickness of the deposited layers is barely a few microns thick (smaller than 10 µm) compared to crystalline wafers (more than 100 µm), in addition to the possible creation of flexible PV modules. The resulting advantage is a decrease in manufacturing cost due to the high throughput deposition process as well as a lower cost of materials. Yet, this technology has the disadvantage that the thin layers absorb less incoming solar radiation, and hence the resulting efficiency is lower (Chaar et al., 2011). However, the reduced costs more than offset the lower efficiency, making this technology economically viable. Second-generation photovoltaics accounted for approximately 21 percent of the global installed capacity in 2010 and are projected to gain market share over the next years, reaching 38 percent of installed capacity in 2017 (NRC, 2012).

While the second generation emphasis lies on the reduction of material cost, the **third generation** approach is to target both lower costs and higher efficiency. Third generation is among others concerned with the development of multiple junction technology and the introduction of nanocomponents in the PV cells. Multiple junction technology (or tandem technology) refers to the attempt to create a PV cell that absorbs a wide range of wavelengths, reducing one of the largest inherent sources of losses of traditional PV cells. The introduction of nanoscale components is done as they sometimes can reduce the limitations seen in other PV technologies. In fact, one of the most promising applications of nanotechnology lies in the area of solar energy (NanoRoadSME, 2006). The use of carbon nanotubes and quantum dots for solar energy purposes will be discussed in more detail under the KET nanotechnology (section 2.6.2), where the concepts of carbon nanotubes and quantum dots will be introduced.

The concept of **concentrated solar power (CSP) systems** differs from photovoltaics in the fact that an intermediate carrier of energy is used. Indeed, one of the disadvantages of photovoltaics is the weak potential for energy storage as batteries or other means of electrical storage must be employed to store the power generated when the sun is out (NRC, 2012). The idea of CSP systems is to use relatively simple optical reflectors to direct the light towards a liquid, which will then be heated. The resulting steam can then be used to generate electricity. At the same time, the energy from the sun can be stored as heat in the liquid for quite some time, which is the major benefit of concentrated solar power systems over photovoltaics (ESMAP, 2011).

The most common available form of CSP is the parabolic trough concentrator (PTC) (see Figure 2.6). These systems are usually set up on one-axis tracking systems, which track the sun during the day. This type of plant consists of a parabolic mirror focusing sunlight on a tube of heat-transfer medium, usually oil, which is then heated and used to create steam to drive an electric generator. The parabolic-shaped and facetted mirrors concentrate the sunlight on the receiver tube. There are several innovations in parabolic trough collector (PTC) technology under development or in prototype status. Current R&D focuses on cost reductions in the assembly and production process, lighter collector structures, new materials for collector structures (such as aluminum), and new heat-transfer fluids (e.g. molten salt and direct steam) (ESMAP, 2011).

Figure 2.6: Parabolic trough concentrator

Source: Acciona Solar Power

Beyond the most commercial trough technology, which represents 94 percent of the installed CSP plant capacity today (Irena, 2012), other technologies are becoming more commercial and are likely to increase their market shares in the near future. One example is the Solar Tower Plant, also called Power Tower (see Figure 2.7), a system commercially operated in Spain by Abengoa). This system concentrates the incoming direct solar irradiation onto a tower-mounted receiver where the heat is captured, typically generating high temperatures. The generated heat then drives a thermo-dynamic cycle, in most cases a water-steam cycle, to generate electric power (ESMAP, 2011). Power tower systems offer a more efficient alternative to parabolic troughs that are currently dominant in the CSP market. They deliver better conversion efficiency, make more efficient use of land, and the mirrors needed are less expensive to manufacture and maintain than the parabolic mirrors used in trough systems. An important drawback of tower technology is that it requires a large investment, implying that only large scale plants can be economically viable (NRC, 2012).

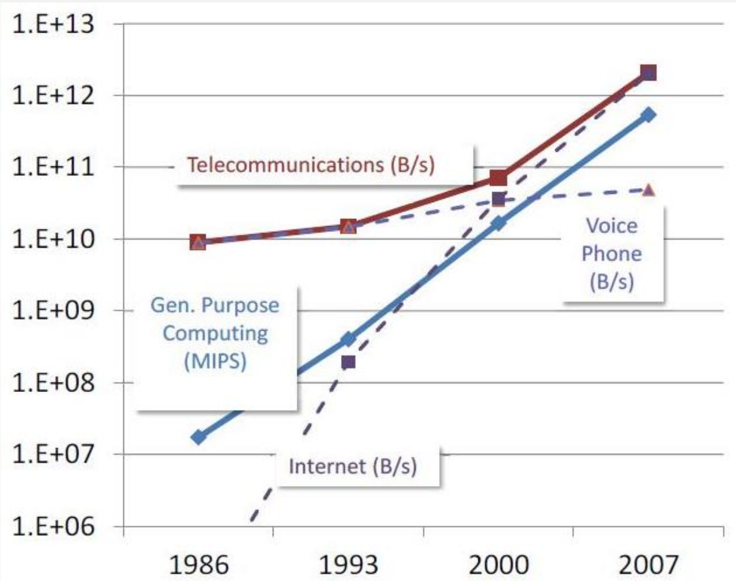
Figure 2.7: Solar Tower of Abengoa near Seville

Source: Abengoa

Optical communication

Today, optics serves as the most important mode of transportation of information. The exchange of information is based on the generation of light impulses and the transmission of these impulses over optical fibers. Optics has become the major way of communication thanks to its potential to transport very large amounts of information (NRC, 2012). One famous example is the World Wide Web, which has been able to connect remote places by using optical fibers for long distance communication. As can be seen in Figure 2.8, the internet took over the voice telephone as the largest mode of information exchange, resulting in a hundred fold increase in network bandwidth over the past decade.

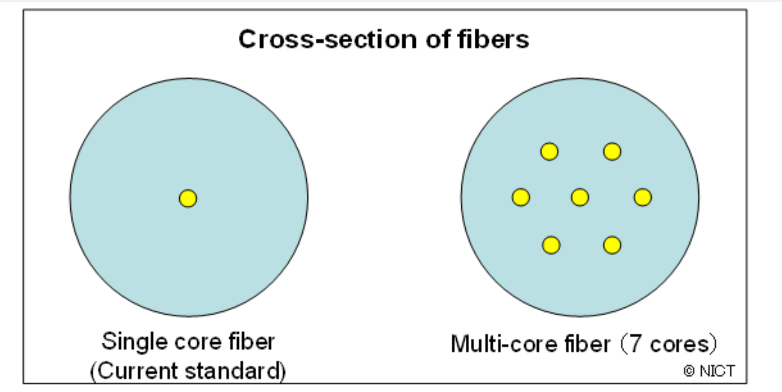
Figure 2.8: Information traffic (expressed in bytes per second) for voice telephone, the internet and overall communication for the period 1986-2007



Source: NRC, 2012

While in 1988 an undersea optical cable could transport about 280 Mb/s, today systems that can carry 5 Tb/s are available, and in terrestrial systems up to 10 Tb/s has been realized (transoceanic systems tend to have somewhat lower capacity due to a number of technical reasons involving very large distance transportation) (NRC, 2012). At the heart of this tremendous increase in information transportation capacity lie a number of technical advancements. One of most important ones is the development of 'wavelength division multiplexing' (WDM), which was first used more than 10 years ago and allows to transmit diverse channels of different wavelengths, hence effectively increasing the amount of information transported per fiber. This has resulted in fibers carrying up to 100 different wavelengths at one time. Apart from WDM, other improvements have been made as well. Even though the advancements in terms of capacity have been tremendous, it is far from certain that it will be able to follow the future demand. So far, optical communication is based on the use of single core, single mode fibers, but a study of the theoretical limitations of this type of fibers illustrates that they may not be sufficient to serve future demand, which is estimated to increase about hundredfold (Essiambre, 2009; Winzer, 2010). Therefore, current technology will need to be extended to multiple mode/ multiple core fibers. The core of the fiber refers to the physical room in the fiber where the actual transmitting of light waves occurs. Hence a multi core fiber contains several independent data streams (see Figure 2.9 for an example with seven cores which is currently one of the most investigated types). A multiple mode fiber is a fiber with a larger than usual core, which allows independent data channels on each of the orthogonal spatial modes. Both technologies are currently actively investigated. One of the major challenges today is to overcome the crosstalk between different data sources that can arise in these settings (Sillard, 2011; NRC, 2012).

Figure 2.9: Single core optical fiber versus multiple core fiber



Source: National Institute of Information and Communications Technology (NICT, Japan)

With the spectacular growth of data communication in mind, saving on energy consumption is becoming a key issue. This is particularly relevant since there are no returns to scale associated with increased data traffic for optical communication. Therefore techniques are being developed to model (and eventually reduce) the energy consumption of optical fiber networks (NRC, 2012).

Displays

Display technology forms an essential part of the information age. The cathode-ray tube (CRT) display technology has long been the standard, however despite important advancements they have remained rather bulky and heavy, and they have been gradually replaced by other technologies since early 2000. One of these technologies is plasma display technology, based on the deployment of electrically charged ionized gases, which allows for flat displays with good picture quality (e.g. high refresh rates). This plasma display technology is well suited for large screen applications but production of smaller (computer) screens is not economically viable. Liquid display technology, on the other hand, has grown from the smaller computer segments to larger screens, where they have overtaken plasma screens. This display technology allows for light structures that use less energy than plasma screens and also provide good picture quality. The lower energy use has enabled many mobile (= battery driven) applications. As such LCDs have become the dominant type of display over the past decade. During this period, LCD technology improved significantly in several aspects like resolution, quality, reliability, size, cost, and capability. LCD technology is omnipresent in our life, as it is used for cell phones, desktops, TV's, and they are thought to dominate the display market for the next decade (NRC, 2012).

In recent years, a new technology using organic light emitting diodes (OLEDs) has emerged that could have a potentially large impact on the display market. OLEDs make light by exploiting the electroluminescence (the generation of light upon the imposition of an electric current) of the organic semiconductor materials they are made of. As such, an array of OLEDs can directly generate the displayed image rather than light a modulator to create the displayed image (as is the case for LCD). Because the image is directly generated, light is not wasted in intermediate steps, and the displays can be thinner as generating the image is a single-step process. OLED-based displays can therefore be brighter than LCDs and consume less power. Other key advantages of these OLEDs are the fact that displays are light in weight, emissive fast, operate at a very low voltage and offer the prospect of simple fabrication. Moreover, the use of organic molecules is more durable and offers potential for flexible displays (Kalyania & Dhobleb, 2012). Currently the first prototypes of such flexible display mobile phones are appearing (TechRadar, 2013).

Today, OLEDs are used in many applications like cell phones, digital cameras and MP3, where their superior energy use and display quality is of great advantage. In 2012 the global OLED market amounted up to 5 billion dollar, and is expected to grow to 26 billion dollar by 2018, a 31.7% compound average growth rate. Mobile phones are the largest end use applications and account for 71% of the total OLED displays market (Transparency Market Research, 2013). However, the OLED technology experiences difficulties to break through in larger display markets, like the television market. It is expected that important progress in manufacturing technology will be needed to obtain more cost competitive products in this area (Semenza, 2010; NRC, 2012). Several large players in the television market already offer OLED televisions, but due to technology constraints, producers struggle to mass produce larger models (The Wall Street Journal, 2013). It is expected that technological advancements in this area will allow the share of OLED television displays to surpass the share of mobile phones in the second half of the decennium (Transparency Market Research, 2013).

Lighting

While OLEDs are used mostly in display applications, the conventional LEDs (that use inorganic semiconductor material instead of organic) are rather used in the area of lighting[3]. A light bulb emits light after heating up to a certain temperature, which is a rather inefficient process. Replacing the traditional forms of lighting, it has the potential to save significantly on energy consumption. According to the US Department of Energy (DOE), the LED technology as a whole has the potential to reduce the American lighting energy usage by almost half (DOE, 2012). This is underscored by a study of McKinsey (2009) of abatement costs of pollution that showed that lighting offers the second largest potential for cost savings, after insulation. Examples of the use of LED technology are traffic lights, street lamps, regular lamps, and car lights (Ahn, 2013). The LED technology is likely to benefit from the trend of governments to impose restriction on energy use, especially in the area of lighting. The LED technology also suffers from some disadvantages as LED technology based products are rather expensive and sensitive to high temperature, leading to difficulties in a number of applications. Despite these current limitations, LED technology is thought to become increasingly important for society (NRC, 2012).

[3] LEDs are however also used in TV applications, but only for the purpose of backlighting (the illumination of the screen), while the screen itself is still of the LCD type. Hence the often used term LED TV is somewhat misleading, as they are essentially LCD TVs with LED backlights (CNET, 2011).

2.4. MICRO- AND NANOELECTRONICS

2.4.1. Introduction

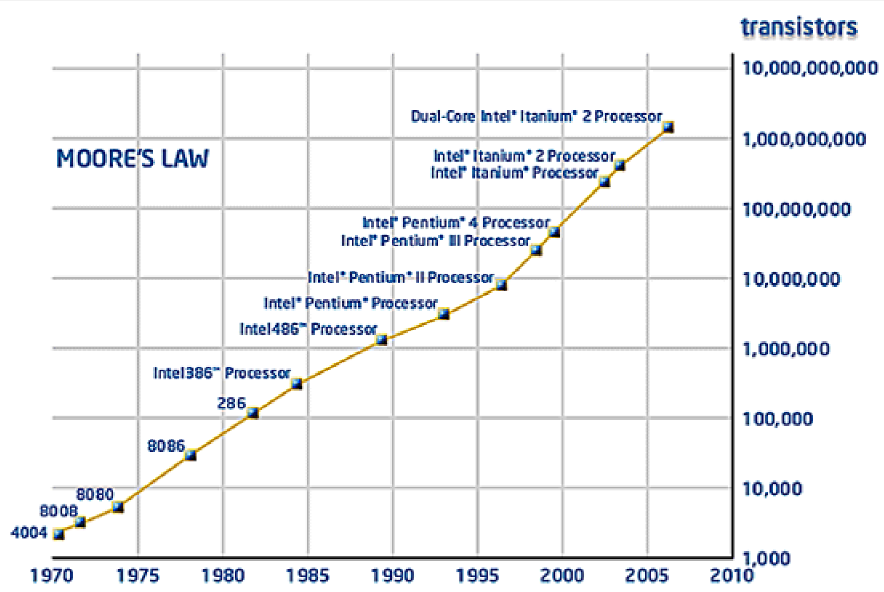
The KET micro- and nanoelectronics (MNE) bears close relationship to the development of the information age. Several decades of innovation have pushed the boundaries of what computer power can achieve at an ever decreasing cost. Today, MNE-based components are integrated into virtually all domestic devices, such as cars, home appliances, smart-phones, computers, televisions, cameras. They have transformed virtually every sector of industry, be it automotive, ICT, medical or banking sectors (HLGMNE, 2011). MNE has three basic elements, namely components that function as part of the computer memory, components that play a role in information processing, and system architecture that brings these functions together in a functional chip. Apart from this, there are also sensors and actuators, linking the electronics to the outside environment. Before turning to a discussion of the recent technological developments for specific applications, we will provide an overview of the general trends that are taking place within micro- and nanoelectronics.

2.4.2. Technological developments and applications

General trends: More Moore (MM) and More than Moore (MtM)

In 1965 Gordon Moore, co-founder of Intel, noted a pattern in the evolution of the number of transistors on integrated circuits (ICs), as they seemed to double approximately every two years. The doubling of the number of transistors enabled a corresponding increase in the performance of the ICs. This observation is nowadays referred to as Moore's law. This law, which implies an exponential growth over time, continued to be remarkably accurate over the next decades (see Figure 2.10). The semiconductor industry has taken this law seriously and has used it to set R&D targets and long term planning.

Figure 2.10: An illustration of Moore's law



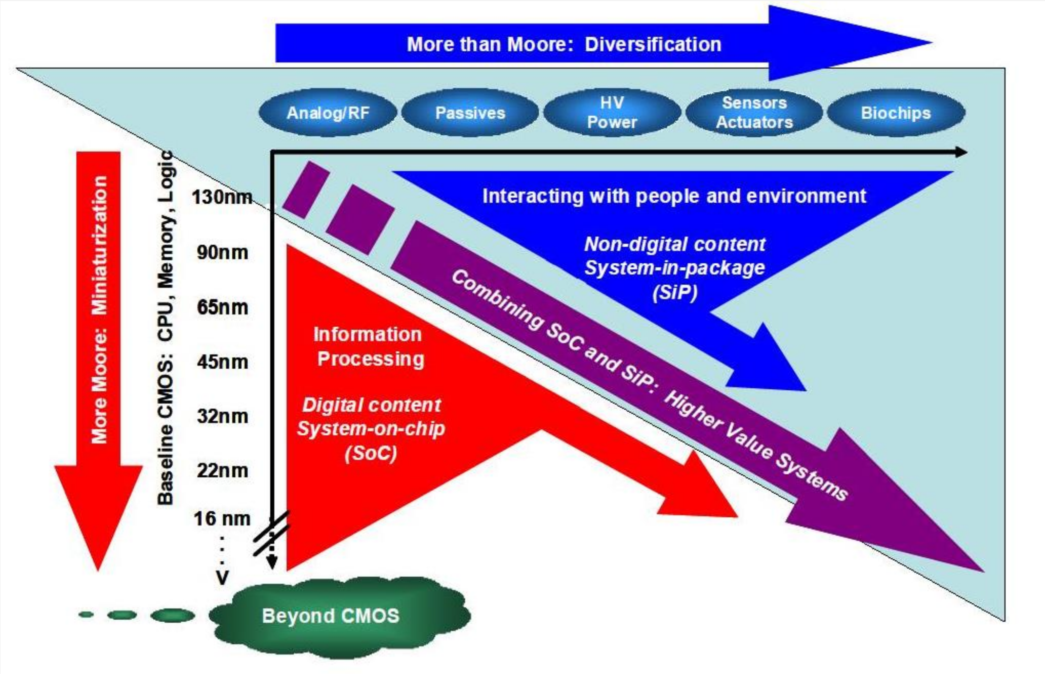
Source: NJTech Reviews

There has been a trend of shrinking the physical sizes of electronic features, in order to obtain higher density (which results in lower cost per function) and better performance (speed and power use). All efforts that focus on continued miniaturization is referred to with the term **More Moore**, as it uses the 'traditional' recipe to obtain better integrated circuits. The spectacular advancements made through constant miniaturization have allowed a virtuous circle of functional profitability and investment in better products which in turn has led to an exponential growth of the semiconductor industry and impact on everyday life (ITRS, 2010).

The spectacular advancements in terms of miniaturization would not have been possible without associated progress in manufacturing techniques. This is a very good example of how manufacturing technologies are enabling technologies: a solid and effective manufacturing basis underlies the widespread success of a given product. Two techniques that have greatly impacted the production of ICs will therefore be discussed under the KET advanced manufacturing techniques (section 2.7.2).

More recently a second trend emerged in electronics, i.e. the integration of more and more non-digital functionalities. This migration of non-digital components occurs in the package containing the integrated circuit (system in package), or even into the chip itself (system on a chip) (ITRS, 2010). These extra non-digital functionalities do not necessarily scale according to Moore's law, but they can provide extra value in different ways (HLG MNE, 2011). Therefore this is referred to as '**More than Moore**'. Both trends are presented in Figure 2.11.

Figure 2.11: Schematic overview of the More Moore and More than Moore principles



Source: IRTS (2010)

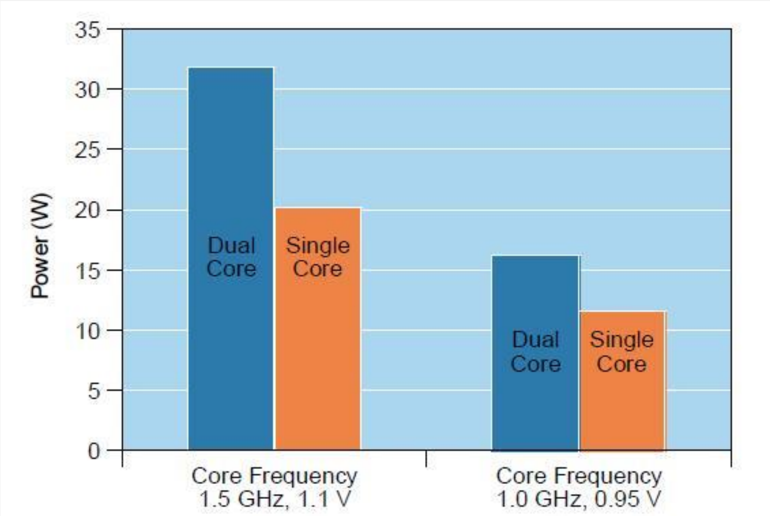
The added non-digital functions may imply analog and mixed signal processing, the incorporation of passive components, high-voltage components, micro-mechanical devices, sensors and actuators, and micro-fluidic devices enabling biological functionalities. More than Moore technologies should not be regarded as an alternative or competitor for More Moore. In contrast, the heterogeneous integration of digital and non-digital functionalities into compact systems will be a key driver for a wide variety of application fields, such as communication, automotive, environmental control, healthcare, security and entertainment. Whereas "More Moore" may be viewed as the brain of an intelligent compact system, "More-than-Moore" refers to its capabilities to interact with the outside world and the user (ITRS, 2010).

The next section will discuss the evolutions of some specific applications. First, the fundamental functions of microelectronics, namely information processing and memory, will be discussed. These functions are typically comprised under the More Moore term. Next, Micro Electro Mechanical Systems (MEMS) will be discussed. MEMS are systems that include a digital function and a mechanical function, which allows interaction with the outside world. MEMS are examples of the integration of heterogeneous functions (More than Moore trend).

Microprocessor

One of the major events in the area of microprocessors over the past years is the large scale introduction of **multicore processors**. A multicore processor is a processor that contains multiple central processing units in one integrated structure (chip). Before the advent of multicore technology, improving the performance of a processor was usually done by speeding up the processor's frequency. However, this typically comes at a price, as this is associated with strong increases in power consumption (a rule of thumb is that doubling the frequency causes a fourfold increase in power consumption). An alternative is then to use multiple processing units that can work in parallel, hence splitting up the work to be done, which can give the same results of using a single core with a higher frequency. As can be seen in Figure 2.12 an increase of the frequency of a single core processor from 1 GHz to 1.5 GHz almost doubles power consumption while going from the single core 1 GHz to a double core 1 GHz demand much less extra power.

Figure 2.12: Example of power consumption of single and dual core processors



Source: Freescale (2009)

Following the same reasoning, one could opt for multiple processors on different chips (so-called multiprocessors). For most applications (like regular PCs and laptops) the multicore technology is used, while for others (such as servers) multiprocessors are used. The advantage of multicore processors is that the communication latency is typically lower than that of a multiprocessor. Bandwidth between cores of a multicore processor is also typically higher than a multiprocessor. This is due to the proximity of the processor cores (Domeika et al., 2008).

The current trend is to create homogeneous multicore devices, that is, devices containing identical cores. In the future heterogeneous multicore devices may become more important, as using specialized cores can serve to offload the main cores which can lead to a performance advantage and lower power use. Given a diverse workload, a heterogeneous multicore system with fast (high frequency) and slow (low frequency) processors, the heterogeneous processors can be assigned specific tasks with a more efficient overall result (Saez et al, 2011). There is also a trend towards the integration of more cores. Currently PCs with six and even eight cores already exist. A further increase is not expected in the near future as the use of multicore processors is rather demanding on the software side (it has to be adapted to parallel processor work), which currently limits the progress of multicore technology. Writing applications that execute in parallel is not straightforward and sometimes even impossible. Moreover, while in a dual core system the distribution of tasks is still rather straightforward, in a many core system applications must be redesigned to take optimal advantage of the processing power available. Hence a correct handling of the software issues and avoidance of inefficient cores will be crucial for the further development of multicore technology. Despite this, there is little doubt that the trend of increases in the number of cores per devices will continue over the next years (Freescale, 2009).

Computer memory

It is common to make a distinction between computer memory that is volatile or non-volatile in nature, that is, memory that retains information when electricity is powered off or not. Volatile memory serves as temporal storage of information while non-volatile memory (such as hard disks or Flash memory) can be used for long term storage. Typically volatile memory is very fast, while non-volatile memory has a substantially lower cost (Deng & Zou, 2011). The **dynamic random access memory (DRAM) technology** is nowadays become the main type of volatile memory. The name stems from the fact that (i) the access to stored data does not depend on the location of storage (hence the random access) and (ii) information is stored through a charge in an electronic circuit, which can leak away and therefore needs to be refreshed from time to time (hence dynamic).

There are multiple developments going on in the field of DRAM. For many decades this memory technology has been successfully scaled down to achieve higher speed and increased density of memory chips at lower bit cost, following Moore's law. However, its functioning through a charge containing capacitor is starting to limit its potential for further downscaling. An upcoming technology that might replace DRAM over the next years is called ZRAM[4]. It derives its name from the fact that it does not require a capacitor and can function with a transistor alone. This allows it to scale down further and reach higher densities. Moreover, this technology does not require major modifications in terms of material or production process (Makarov et al, 2012). Some leading semiconductor companies have already shown interest in this technology (EETimes, 2006; CNET, 2007), but so far not used it commercially.

In the field of non-volatile memory, the **Flash technology** has gradually taken over the role of more traditional long term storage like magnetic disks. This technology allows to erase and write whole blocks of memory at once (hence the name Flash). Its major advantages are the small physical size, the absence of mechanical components (which makes it robust to rough handling), low power consumption, and high performance. They are increasingly replacing conventional storage applications, particularly in mobile and embedded applications, where either size and power or performance is important. The cost of Flash memory has dropped in terms of Moore's law over the past years. Even though there remain some concerns on the potential of Flash memory for large scale data storage, many companies are currently facilitating the use of Flash in their storage systems (Deng & Zhou, 2011). For example, Google has announced to use Flash based drives in its servers, as an effort to reduce the energy consumption (InformationWeek, 2008).

Flash technology is a charge based storage technology, like DRAM, and therefore facing limits of scalability. In the longer term scientists see an evolution towards a universal, non-volatile type of memory, as the advantages of non-volatility are obvious. A range of new memory technologies that are both non-charge based and non-volatile have been proposed in recent years. Two of the most promising technologies for a future universal memory (that can be used in all applications) are **Resistive RAM (RRAM)** and **Spin Torque Ram (STRAM).** The RRAM uses a metal-insulator-metal structure, and the properties of the insulator can be set at different levels by applying an electrical field. The STRAM uses magnetic layers, which can have its magnetization direction changed between two states, hence storing information (Kawahara et al, 2012). However, although very promising, both technologies are currently only in the prototype stage (Makarov et al, 2012).

MEMS

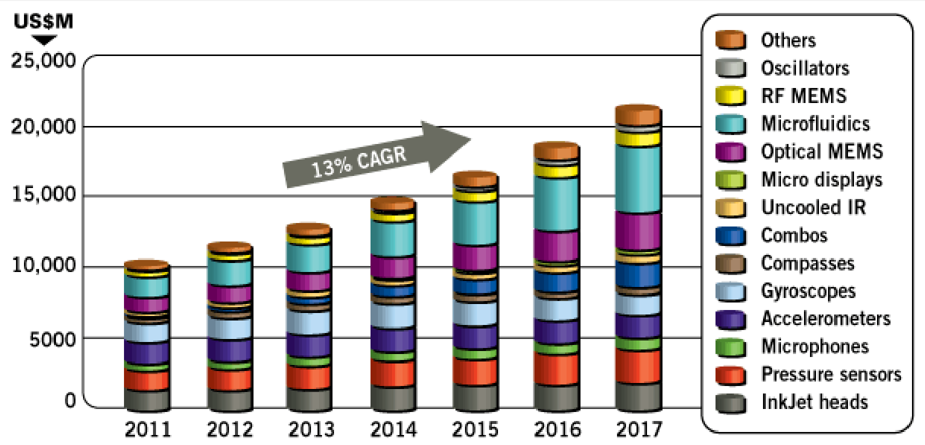
Micro-Electro-Mechanical Systems (MEMS) are miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using microfabrication techniques. Their defining characteristics are small

[4] As is true for many upcoming technologies, ZRAM is sometimes often named differently, namely as 1T RAM, stemming from the fact that there is still one transistor (1T) but no capacitator.

size (from several millimeters down to less than one micron) and the combination of several mechanical and electrical functions. The types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. MEMS have the capability to interact with the environment through sensors and actuators and to process signals through their microelectronic circuit (Ryhänen, 2010).

MEMS encompass a broad class of systems. Examples include radio frequency MEMS, that allow communication with the outside world through the use of radio waves, accelerometers measuring the acceleration of a given object and microfluidics MEMS. In Figure 2.13, the composition of the current market by subfield as well as the projections for future market developments are given. The figure shows that the MEMS market is expected to grow strongly in the next years. Traditionally MEMS have been used extensively in automotive applications, but there is on-going trend towards the use in (mobile) consumer electronic devices, making these devices more intelligent and aware of the environment (Ryhänen, 2010).

Figure 2.13: MEMS forecast through 2017



Source: Yole Développement (2012a)

Over the past years, MEMS have experienced a strong trend towards the integration of sensor and actuators, along with integrated circuits, onto a common silicon substrate. This integration of digital and non-digital functions is in line with the More than Moore trend. From a manufacturing point of view, this integration can be achieved by combining the standard IC process sequences (such as CMOS[5]) with compatible micromachining and thin film deposition steps. The additional fabrication steps can precede (pre-CMOS) or follow (post-CMOS) the regular CMOS process, or can be performed in between the regular CMOS steps (intermediate-CMOS) (Ghosh & Bayoumi, 2005). The physical integration of several functions has the advantage of lower cost (less material needs to be used), better signal transmission between the different functions (less noise) and less power use (Yurish, 2007). Moreover, as most use the standard IC processes and materials, these MEMS can be produced on a large scale and brought to the market at low cost. The continued integration of functionalities will therefore be one of the main drivers of the further expansion of MEMS (Ryhänen, 2010).

[5] CMOS (Compatible Metal Oxide Semiconductor) is a widespread technology for constructing integrated circuits.

2.5. ADVANCED MATERIALS

2.5.1. Introduction

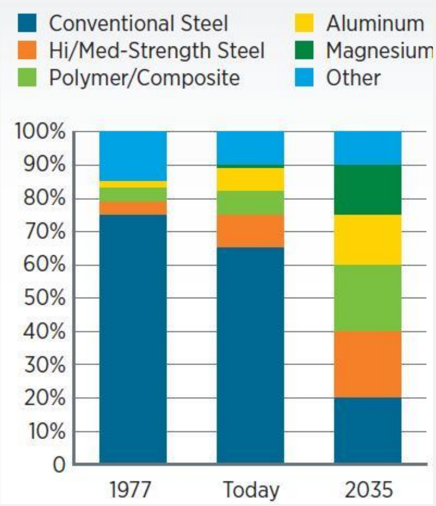
Advanced materials are the building blocks of every physical product and hence are omnipresent in our everyday life. Materials technology is a complex and multi-disciplinary science that deals with every stage from development to manufacturing in the search for improved or new functions. In recent years, much attention has gone to “smart” or “active” materials. In advanced materials, researchers aim to understand the relationship between material microstructure/composition and its technical properties, how microstructure influences behavior in different applications and how it is achieved and can be modified and controlled by manufacturing technology (EuMAT, 2006). It is clear that advanced materials act as a strong enabling technology as for new products to be developed it is often essential to have materials with desired properties and/or functions. An internal supply of advanced materials is therefore considered crucial for Europe, as having this only outside Europe makes the whole economy vulnerable (HLG MAT, 2010). Typical examples of advanced materials include lightweight materials, materials that can function in extreme conditions, materials that can serve as protective coating (against various external factors), or materials that have some sort of ‘smart’ functionality. In the next sections, we will discuss lightweight materials and materials resistant to extreme environments.

2.5.2. Technological developments and applications

Lightweight materials

Lightweight materials have been of interest for quite some time, for example in the automotive industry. Replacing parts with lightweight counterparts allows cars to carry advanced emissions-control equipment, safety devices, and integrated electronic systems without an associated weight penalty. Using lighter materials also reduces a vehicle’s fuel consumption, because it takes less energy to accelerate a lighter object. For example, a 10% reduction in vehicle weight can result in a 6%–8% fuel-economy improvement. In this respect, lightweight materials will be particularly useful as they offset the weight of power systems such as batteries and electric motors (DOE, 2010). In the automotive industry, there has a trend towards the integration of other materials, next to steel (see Figure 2.14). A well-known example is aluminum, which offers good strength and low density compared to steel. In the short term, aluminum in combination with high strength steel and composites is expected to substitute conventional steel, which can lead to environmental benefits (Palencia et al., 2012). In the longer term, 50% to 75% in weight reduction for some components will be possible through the use of advanced materials such as magnesium and carbon-fiber-reinforced composites. Figure 2.14 shows that these new materials are expected to contribute significantly by 2035, bringing down the share of conventional steel in cars from 60% to 20%.

Figure 2.14: Typical composition of cars, past and in the future



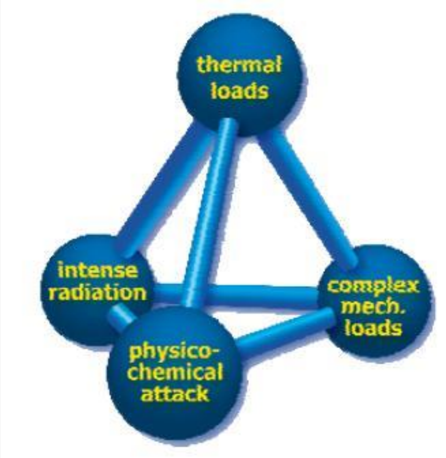
Source: DOE (2010)

The interest in magnesium is derived from the fact that it is the lightest engineering metal available at earth: it has about 2/3 of the density of aluminum and 1/4 of that of iron. Besides low density, magnesium based materials exhibit good specific mechanical properties, machinability, castability, weldability and thermal stability. However, as magnesium has low ductility, modulus of elasticity and limited strength and creep resistance at elevated temperature, it is rarely used in its pure form. Instead, it is usually alloyed with other elements like aluminum, zinc, silver and zirconium to improve its properties, although this potential can be further optimized (Alam et al., 2011).

Materials resistant to harsh conditions

Materials can be subject to harsh environmental conditions during usage. These environmental factors can be of thermal, mechanical, radiated or physico-chemical nature (see Figure 2.15). While any of these forces separately already poses challenges for material design, they often occur together leading to extreme and complex loading conditions of materials (Extremat, 2010). High temperature, for example, not only weakens chemical bonds, it also speeds up the chemical reactions of corrosion (DOE, 2008). The capability of materials to resist harsh environmental factors often imposes limits on production processes. For example, the operating temperature of several processes has to be limited to what materials can handle while higher process efficiencies could be obtained at higher temperatures (EuMAT, 2006). As a consequence the economic as well as environmental gains possible from advanced extreme environment resistant materials are considerable and the subject of intensive research.

Figure 2.15: Types of external factors resulting in extreme conditions for material use



Source: Extremat (2010)

In this area intermetallics constitute a new important class of engineering materials. Intermetallics are compounds created by the binding between different metals (like aluminum, iron, and titanium) and have crystal structures that are different from those of the constituent metals. They possess crystal structures with an ordered atom distribution, and due to their properties they occupy the intermediate position between metals (who are for example very sensitive to corrosion) and ceramics (who are known to be very temperature and corrosion resistant) (EuMAT, 2006). They have relatively low densities, high melting points, good thermal conductivities, and excellent high temperature strengths. Many intermetallics also show a yield strength anomaly, this is, their strength increases rather than decreases with temperature. As a result, these intermetallics are particularly investigated for structural applications at elevated temperatures, for example for use in aircraft engines where some intermetallics are already used today (Cinca & Guilemany, 2012). There is strong interest from the aerospace, automotive and turbine power generation markets to use intermetallics-based structures. It is expected that advanced materials based on intermetallics will allow higher engine efficiencies which will lead to significant reductions in fuel consumption and a considerable decrease in exhaust gas emissions (Frommeyer & Rablbauer, 2008).

Apart from their use as structural components, intermetallics can also be used as coating against environmental influence. Intermetallics based on aluminum are particularly useful since they are able to form protective alumina scales under hostile conditions. This alumina (formed by the reaction of aluminum with oxygen from the surrounding environment) is one of the best protective surface oxides and therefore a very effective protector against corrosion at high temperatures. Currently intermetallics are already used for surface coatings while many more applications are underway. Research efforts are devoted towards finding the optimal metal composition and coating technology in function of the respective applications.

2.6. NANOTECHNOLOGY

2.6.1. Introduction

An atom, the basic building block of every form of inert and living matter, is so small that it is beyond human's perception. However, at the end of the 20th century, with the breakthrough of nanotechnologies, it was realized that the nanometric size, close to that of atoms, is no longer beyond perception or range of action. Nanotechnology has now become a part of our everyday life (Pautrat, 2011). Nanotechnology is a very diverse, naturally multidisciplinary cross-cutting concept that covers a wide range of developments from novel approaches for the development of new materials to structures with tailor-made unique properties. The emergence of nanotechnology has potential implications for the creation or refinement of a wide range of materials and devices with applications across society from medicine and electronics to materials and energy related topics like storage, efficiency and transportation (HLG Nano, 2010).

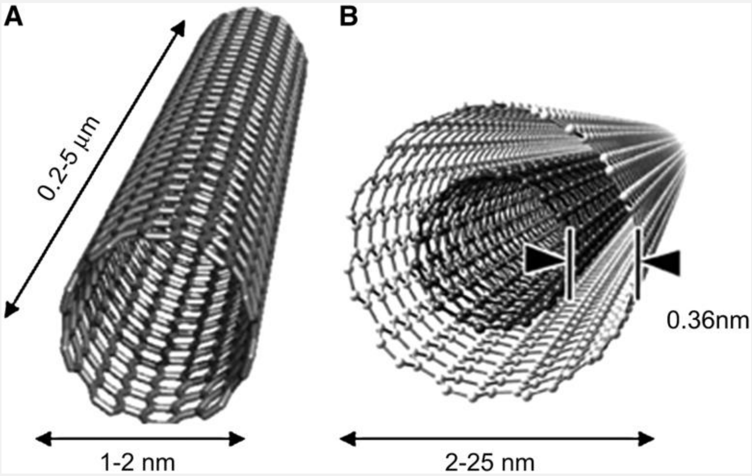
The defining characteristic of nanotechnology is the involvement of materials with extremely small dimensions, but obtaining a precise definition of the scope of nanotechnology is not straightforward. It is commonly described as "the study of the controlling of matter on the nano scale. Generally nanotechnology deals with structures sized between approximately 1 and 100 nanometre (10-9 metres) in at least one dimension, and involves developing materials, structures or devices within that size" (HLG Nano, 2010). In the next sections, the developments of several promising applications of nanotechnology are discussed namely carbon nanotubes, graphene and quantum dots.

2.6.2. Technological developments and applications

Carbon nanotubes

Carbon nanotubes (CNTs) are tubes based on rolled graphene sheet. Graphene is a layer of atomic thickness made of pure carbon. A carbon nanotube has the periodic structure of a crystal. The diameter of a CNT is a few nanometers while its length can reach hundreds or thousands of nanometers. There are two main types of nanotubes available today. Single walled nanotubes consist of a single sheet of graphene rolled seamlessly to form a cylinder while multi-walled nanotubes consist of an array of such cylinders formed concentrically and separated by about 0.36 nm (see Figure 2.16).

Figure 2.16: A single and double walled carbon nanotube



Source: Reilly (2007)

Over the last two decades, CNTs have formed part of extensive and multidisciplinary research due to their superior properties over other materials and wide range of applications. In fact, they have been designated in several occasions as the most researched materials of the 21st century (Ying et al., 2011). CNTs display a combination of highly interesting properties like a high tensile strength (which can be more than 100 times that of stainless steel, while at the same time being lighter material), thermal conductivity (comparable to diamond), stability and resilience, as well as different electrical properties (they can be excellent conductors – comparable to copper – or semiconductors depending on the arrangement of the graphene sheet) and their ability to establish different types of interactions with a variety of (in)organic chemicals (Herrera-Herrera, 2012). Many applications arise from the surprising and desirable properties they exhibit, some of which are already being used in new and improved products (ION, 2012). Below we will provide some examples[6].

As mentioned in the section on photonics, an important application field of carbon nanotubes is solar energy. The need to decrease the cost of solar electricity in order to become more competitive with other energy sources has driven research in unconventional photovoltaic (PV) device fabrication methodologies using materials that are abundantly available on earth. One of the technologies that have emerged from these efforts is organic photovoltaics (OPV). In recent years, a remarkable increase of the power conversion efficiency (PCE) of laboratory-scale, solution-processed OPV devices has been realized, from the range of 2% to current efficiencies in excess of 10%, a value that is widely considered as a benchmark for commercialization. The incorporation of CNTs in the active layer of photovoltaic cells is promising as they possess excellent electrical conductivity needed for the generation of the electrical current and offer the ability for widely tunable absorbance throughout the visible and near-infrared (NIR), which could increase the percentage of absorbed photons in OPV devices. However, a number of issues still have to be resolved before the full potential of CNTs can be exploited (Ferguson et al., 2013; Tenent et al., 2009).

The possibility to use CNTs for water purification purposes has been extensively investigated in recent years. CNTs have particularly received growing attention due to their capability to display superior durability and separation characteristics. The introduction of CNTs constitutes a significant potential breakthrough for the desalination (the removal of salt from saline water) technology. Several studies on the transport properties of CNTs have found that the extremely smooth hollowed structure of nanotubes could facilitate rapid transport of liquid and gas molecules in channels and hence offer high flux membrane separation performance. Notably, the small and precise diameter size of CNTs is also proved to reject most ions (such as salts), hence only water molecules are allowed to permit through the nanotube hollows (Goh et al., 2013). In this context another advantage of CNTs is that the surface modification of CNTs with materials such as polymers, metal nanoparticles, biomolecules, and metal oxides allows them to form nanocomposites (NCs) that do not allow biofilm formation. Biofilms are layers of bacteria that can grow on various substrates, such as water purification membranes, causing great efficiency losses and eventual breakdown of the membrane (Upadhyayula & Gadhamshetty, 2010). Yet, a number of difficulties remain, such as the synthesizing of CNTs of controlled diameter and length, which turns out to be problematic so far. The commercialization of CNT-incorporated desalination technology is still at its premature stage, more scientific and technical inputs will be needed to exploit the full potential of CNTs in this field (Goh et al, 2013).

While the previous examples discuss emerging applications, CNTs are already introduced in a number of commercial products. For example, exploiting their excellent mechanical properties, CNTs are used today as reinforcing material for tennis rackets and bicycle components, products that typically need light but strong materials (ION, 2012). CNTs have proved to be excellent in absorbing the impact of incoming projectiles (Kostopoulos, 2010), and recently a bullet vest based on CNT technology has been commercialized (Amendment2, 2012). They are also used in resins to render material conducting, and in applications involving high efficiency gas absorption (Pautrat, 2011).

Apart from the limitations mentioned above, CNTs face some other general shortcomings. The process of making CNTs is difficult and expensive. It involves vaporizing graphite at high temperature and having it reform on metal as tiny tubes. Currently, CNTs cost a few hundred dollars per gram which is a lot but nevertheless a major

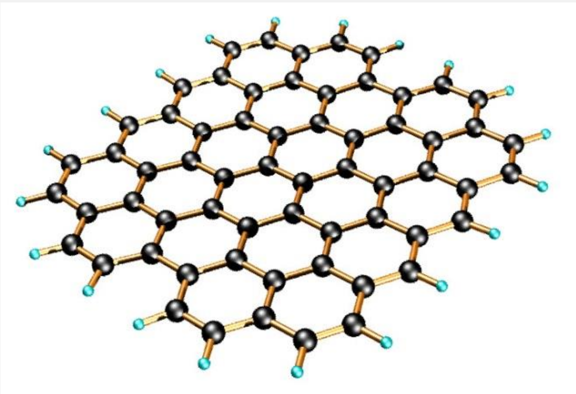
[6] This list is not exhaustive

improvement compared to a few years ago (De Volder et al., 2013). Moreover, the length of the tubes will have to increase considerably before a major impact beyond the laboratory will be possible. In addition, some health risks are associated with CNTs. One of the major synthesizing pathways of CNTs involves the use of metallic catalysts, which can have toxic effects. This is why in recent years synthesis pathways that do not use metals have been actively investigated (Tan et al, 2012). In addition, as CNTs are extremely small, they can easily penetrate and affect the human respiratory system. Health risks have been reported for both consumers and production workers (Kohler et al, 2008).

Graphene

The remarkable properties of carbon nanotubes, made of a rolled graphene sheet, have encouraged scientists to also explore the properties of graphene itself (Pautrat, 2011). Graphene is a flat sheet of carbon atoms of only one atom thick, about 0,34 nanometer (Figure 2.17). A major breakthrough took place in 2004 when researchers from the University of Manchester were able to isolate pure graphene sheets from graphite[7], the 'raw' material comprised of many layers of graphene stacked on top of one another, which can be found in everyday pencils. Since then, the number of publications related to graphene has exploded. Graphene has high strength, light weight and electrical properties that can exceed all metals and semiconductors currently known. As CNTs, graphene could be used as building blocks for smaller and faster responsive transistors to create more powerful and low energy use integrated circuits. Other potential applications include the use of graphene for coatings, nanoeletromechanical systems (NEMS), chemical sensors, and computer memory. There has been an explosion of ideas that suggest graphene for virtually every feasible use (Geim, 2009). Graphene is often called the plastic of the 21st century, referring to its wide range of potential applications. However, most applications are currently still far from commercialization, the study of grapheme is still a young field.

Figure 2.17: Structure of a single graphene sheet



Source: www.cnx.org

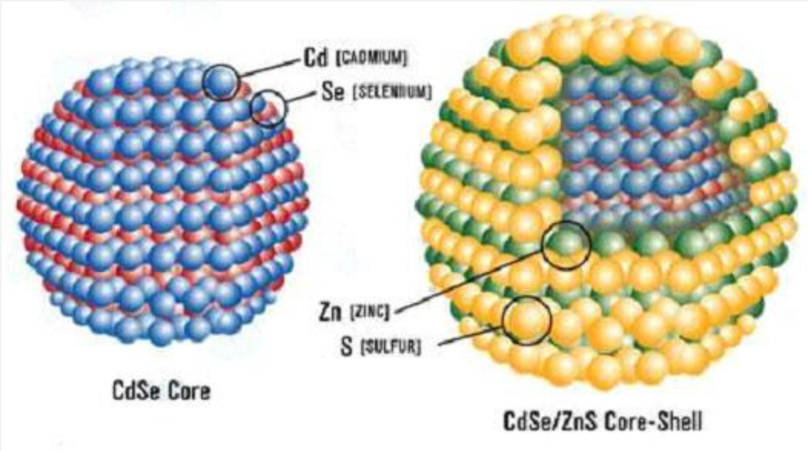
Despite the fact that the origins of graphene research lie in Europe, China and South Korea are leading in terms of number of graphene-related patents (CambridgeIP, 2013), followed by the US. In particular the company Samsung has built up a very solid expertise in this area, and has recently shown to be able to produce a graphene based flexible touchscreen (Technology Review, 2012). However, in this global race the European Union has made its intentions clear through the announcement of a 10-year, 1 billion euro Flagship research program aimed at developing graphene technology. This support is awarded to a consortium of nine partners, led by the Chalmers University (Sweden), which will later on be extended via an open call. The consortium partners include the University of Manchester, the University of Cambridge and Nokia (Graphene Flagship, 2013).

[7] The Nobel prize for physics for the year 2010 was awarded to Andre Geim and Konstantin Novoselov from the University of Manchester *"for groundbreaking experiments regarding the two-dimensional material graphene" (Nobel Prize Committee, 2010)*

Quantum dots

Quantum dots (QDs) are nanocrystals made of semiconductor material such as silicon, cadmium selenide, cadmium sulfide, or indium arsenide, with a diameter that typically ranges between 2 and 10 nanometer (see Figure 2.18). They are of particular interest due to their characteristic interaction with light: the ability to absorb and emit photons greatly depends on the size of the crystal. Given that this size can be well controlled in the production process, this creates possibilities for a number of interesting applications.

Figure 2.18: Structure of a Cadmium based quantom dot



Source: ObservatoryNano

QDs are a second area where nanotechnology has potential to contribute to solar energy applications. QD based photovoltaic cells (QDPVs) may surpass the theoretical efficiency limit of conventional solar modules due to the phenomenon of Multiple Exciton Generation (MEG) in which multiple electrons can be released by the absorption of one photon, whereas in regular solar panels this is only one electron per incoming photon. Hence, they can generate more electric current per unit of incoming light (Sengül & Theis, 2011). Moreover, they can be used to create 'tandem solar cells' or solar cells that can capture light of a broad range of wavelengths (see also PV cells of the third generation, described in section 2.3.2). By creating a thin film layer containing crystals that vary in size, light of various wavelengths can be captured. Studies have shown that QDPV modules may offer up to 87% conversion efficiency compared to the 31-33% limit of conventional solar cells (Conibeer et al, 2012). In addition, from a manufacturing point of view, QDPV cells could be produced in a cost-competitive way. Current research is focusing among others on the choice of semiconductor materials for this purpose (Sengül & Theis, 2011).

As mentioned in the section on photonics, light emitting diodes (LEDs) form a very promising new technology in the area of lighting, with the potential to reduce the energy consumption by at least a factor three compared to incandescent light. Yet, these LEDs are limited in the sense that they are not yet capable of high quality white light generation (unless when using rare earth metals, which is not an ideal). In this respect, QD integrated LEDs can offer a solution. These improved LEDs profit from narrow but precisely tuneable emission spectra of LEDs as well as their high photoluminescence quantum yields. Moreover, these QD integrated LEDs offer the possibility for adjusting their surface functionality, which allows unlimited design of functional composites and hybrid structures (Demir et al, 2011). Since the large scale QD synthesis has been successful in recent years (Sanderson, 2009), achieving the mass production of QD-LEDs with an extraordinary performance might be possible. However, there are still some aspects of QDs that need to be addressed. Currently many applications rely on the heavy metal cadmium, which should be avoided due to health risks. In addition, the compatibility with the silicon matrix typically used for LEDs still has to be improved. Despite this, it has been reported that some companies have already started to incorporate QDs in LEDs, be it not yet for large-scale general lighting. QD integrated LEDs have the potential to attain a dominant place in the lighting industry (Demir et al, 2011).

2.7. ADVANCED MANUFACTURING TECHNOLOGIES

2.7.1. Introduction

Advanced manufacturing technologies are required to produce high value marketable knowledge-based goods and the related services based on KETs. A world-class scientific knowledge in KETs that does not translate into goods and services is of little use to society. Advanced manufacturing technologies are therefore a strong enabling technology: they greatly influence the capability to commercialize products on a large scale, irrespective of how innovative the product itself may be. Therefore, equal efforts need to be invested in the development and deployment of advanced manufacturing technologies to create economic value from KETs (HLGAMT, 2010).

The ongoing evolution towards the manipulation of materials can only be sustained if manufacturing technologies enable to bring associated products to the market. There is a vast difference between demonstrating a concept in a small sample versus producing it in volume while still maintaining absolute control of the molecular composition, morphology, and properties. Working at the molecular scale requires analytical tools that analyze and simulate diverse processes with unprecedented scales of granularity, detail, fidelity, and complexity. Therefore, the ever growing trend towards miniaturization imposes strong challenges on the manufacturing side (STPI, 2010).

Advanced manufacturing technologies encompass a wide range of technologies that can be subdivided into different classes. First of all there are the 'pure' manufacturing techniques, enabling the physical conversion of material into the desired product. These pure production techniques can be applied specifically to a KET or have a broader coverage. In addition there are supporting techniques such as computer use for modeling and simulation of production process, and more 'soft' parts like innovations in the organization of the whole manufacturing process. In the next sections, we will focus on the pure manufacturing techniques: the first one (additive manufacturing) applies to many KETs, while the second and third relate particularly to micro- and nanoelectronics (respectively lithography and wafer size transitions).

2.7.2. Technological developments and applications

Additive manufacturing

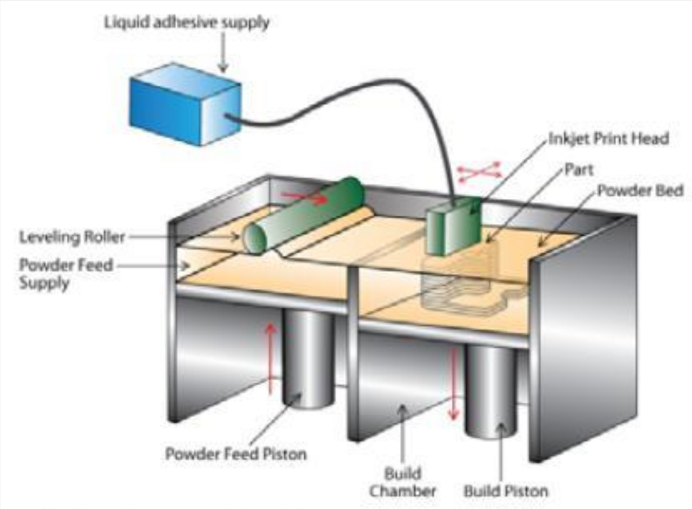
Additive manufacturing refers to a class of techniques in use since the mid-1980s that build solid parts by adding layers of a given material. Unlike the traditional "subtractive processes" that remove material from solid blocks to manufacture goods, additive manufacturing reduces waste as only the materials needed to produce a product are used. The process also reduces the need to maintain large inventories of component parts because they can be produced quickly upon request. The additive manufacturing industry, with about $1.2 billion in worldwide sales of systems, materials, and services in 2010, is relatively small but growing rapidly (Shipp et al, 2012).

A good and well known technique of additive manufacturing is 3D printing[8] (also known as inkjet printing, see Figure 2.19). Like a regular printer puts a layer of ink on a sheet of paper, the 3D printer deposits a binder on a powder bed that causes the powder to form together in the desired shape. This is repeated many times (with possible different shapes) such that all the different thin slices of created material can be put on top of each

[8] It should be emphasized here that additive manufacturing encompasses many other techniques, some of which bear a direct relationship to photonics as they involve the use of lasers in the manufacturing process.

other, to create a 3-dimensional structure. Digital production technologies, such as inkjet printing, have the potential to produce a variety of products on the same manufacturing line as the only thing that needs to vary are the shapes to create the layers, which is a digital input.

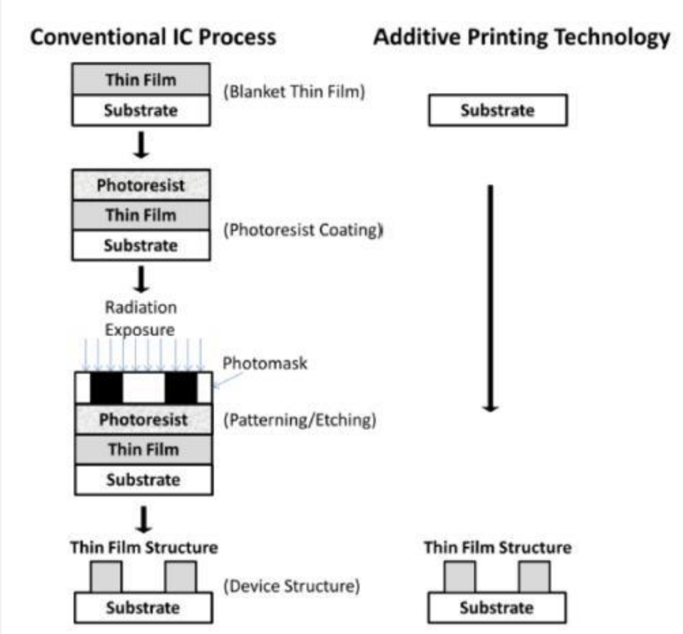
Figure 2.19: Illustration of the principle of 3D printing



Source: Shipp et al (2012)

In inkjet printing technique, the material loss is minimal, as shown in Figure 2.20 the example of integrated circuits. Due to an additive approach no functional material needs to be removed as in the masking process. The elimination of masking and etching steps alone results in several benefits like reduced material waste, energy consumption, and processing time and steps. In the all-additive approach, the materials are deposited with controlled location and geometries. Multiple materials (metal, dielectric, and semiconductor) can be deposited in the same process phase employing several printheads, thus eliminating several process steps. Furthermore, inkjet is a non-contact deposition method, which makes it applicable to a broad range of substrates (e.g. metals, ceramics, polymers, and silicon) with characteristic porosity and surface energy. The attainable line widths with a commercial drop-on-demand inkjet are approaching 20µm, while reports of finer line widths (~1µm) are already emerging (Joshi et al, 2012).

Figure 2.20: Comparison of subtractive IC processing and additive printing approach



Source: Joshi et al (2012)

In recent years significant progress has been made in the use of inkjet technology for printing diverse functional materials. Currently conductive, dielectric, and semiconductive inks are available for the development of a complete electronic system with a single inkjet printer. So far the printing of conductive metal inks has been investigated the most and has reached a certain degree of maturity. In these applications typically ink is used that is based on nanoparticles of metals such as gold, copper, silver and nickel that have good electrical properties (Kaija et al., 2010; Zhao et al., 2012). One concrete example of additive manufacturing that is commercially available today is the production of titanium alloys for medical and aerospace applications by the Swedish based company Arcam (Arcam, 2013).

The traditional subtractive production of these alloys is expensive and involves significant material losses. The US Navy and Defense Logistics Agency has identified several types of titanium alloys that have a long production time and could therefore be potential candidates for manufacturing by additive processes. In general, many military (including aircraft) systems use machinery beyond their lifetime, which requests the availability of a large number of spare parts. The production of these parts can take a long time, necessitating the build-up of vast inventories. Additive manufacturing could help resolve this problem by faster and on-demand production, which potentially even could happen at the place where they are needed, reducing transportation and logistics issues (Shipp et al, 2012).

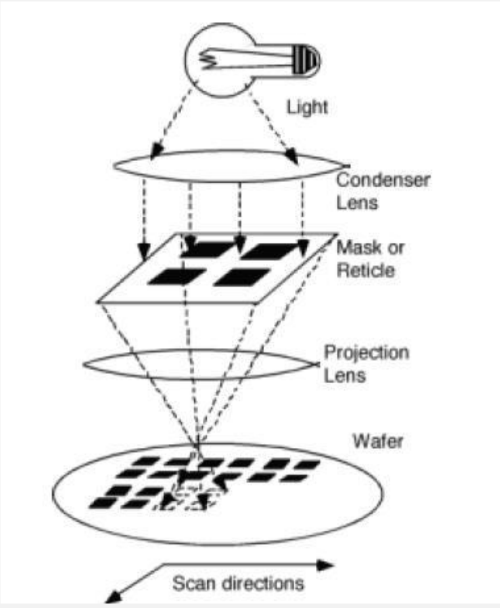
The early applications of additive manufacturing are restricted mostly to smaller parts, consumer products and medical components (that can nevertheless have complex geometry), while the realization of the production of larger parts is still difficult today. Consumer machines produce products that typically require less complexity and accuracy than those produced by industrial machines. Industrial applications of additive manufacturing will require process improvements and innovations to accelerate development of faster, more accurate machines to ensure quality control of products. While until recently, additive and subtractive manufacturing were viewed as mutually exclusive, a trend has emerged to combine both. For example, Boivie et al. (2011) report the development of a hybrid manufacturing cell which is a combination of a powder bed additive manufacturing metal system and a five axis milling machine with the primary objective of producing injection molding tooling inserts. Combinations like these allow reaping the benefits of the two sides of manufacturing, which is the main driver behind this integration effort. The combination of the two, also referred to as hybrid additive subtractive manufacturing, should greatly expand the application area of additive manufacturing and form one of the major points on the research agenda for the coming years (Joshi et al, 2012).

Lithography

As mentioned in the section on micro- and nanoelectronics, following Moore's law the trend of miniaturization in the semiconductor industry has led to a strong increase in performance and a decrease in the cost of chips. This has enabled the widespread use of micro- and nanoelectronics in everyday life. This evolution would not have been possible without major advanced in the manufacturing of integrated circuits. Major progress has been made through the use of lithography and through wafer size transitions.

The ever increasing performance/cost ratio of integrated circuits has been accomplished by scaling down transistor devices to ever-smaller dimensions. Optical lithography has been actively used to produce more and more dense integrated circuits (Socol, 2013). In photolithography, the surface of a wafer (a thin slice of semiconductor material used as substrate for production of ICs) is coated with a light-sensitive polymer (a 'photoresist'). Subsequently, light is sent through a mask that contains the desired pattern on to the photoresist-coated wafer. The material properties of a photoresist change when it is exposed to light, and as a consequence the material that was targeted by the light can be selectively removed from the wafer surface. Afterwards the wafer is chemically treated to engrave (etch) the exposure pattern in it. The process is repeated many times with different masks to form billions of complicated three-dimensional structures (such as transistors and interconnections) on the wafer (NRC, 2012). A schematic drawing of the lithography process is shown in Figure 2.21.

Figure 2.21: Schematic drawing of the lithography process



Source: Wilson (2007)

Photolithography has enabled manufacturers to increase transistor density (and thus the complexity of advanced chips) while lowering the cost per transistor. An important aspect in the advancement of photolithography is the minimum feature size (resolution) provided by the optical projection system that projects the mask image onto the wafer (that is, how close different elements can be put together). One way to improve this resolution is to use light from a lower wavelength. This strategy has been pursued extensively over the past years: in the early days light of a wavelength of 436 nm was used which evolved over several steps to the present state of the art into 193 nm technology. This technology can create feature sizes of only 22 nm (NRC, 2012; Li et al., 2013).

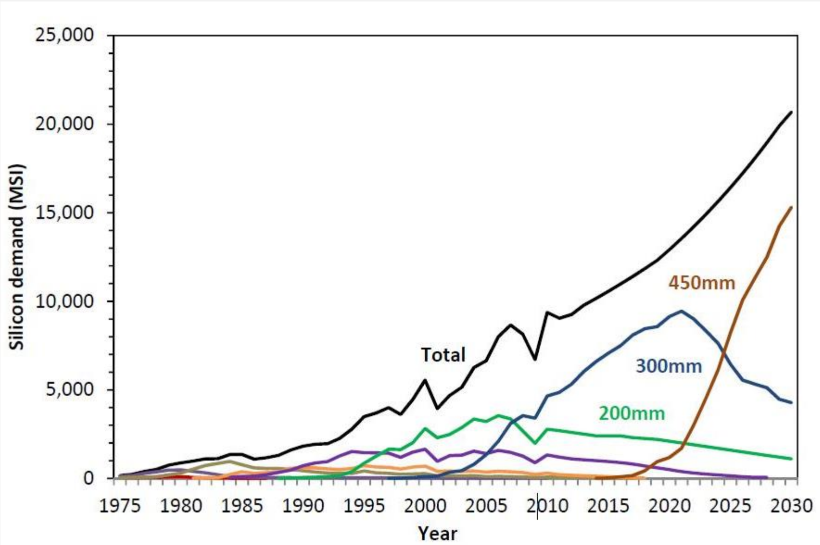
To improve the resolution even more, new options to use light with lower wavelengths are examined. The industry is working hard to develop extreme ultraviolet lithography, which uses UV light with a wavelength of only 13.5 nm by 2015. However, presently there is no source available with sufficient average power to enable high-volume manufacturing. Several types of lights sources are currently being investigated including laser produced plasma and discharge-produced plasma sources (NRC, 2012). The leading producer of lithography equipment, ASML, recently announced positive results for a preproduction EUV tool (ASML, 2012).

The use of lithography in the semiconductor is but one example of the use of photonics as production technology. Today it would be hard to think of modern production technologies not involving any form of laser use. Since the first carbon dioxide (CO_2) laser demonstrations in the 1960s, the use of laser systems in manufacturing has grown rapidly. Expanded applications of lasers throughout manufacturing have been driven by continuous innovation. One particular example is the area of micromachining, which involves very accurate handling of materials (for example, introducing slots in stainless steel smaller than 100 micrometer (NRC, 2012)). Lasers are used for high accuracy and high resolution micromachining purposes such as high precision surface micromachining as well as 3D internal structuring. Due to the ultrashort timescale and the ultrahigh laser intensity coupled to the electronic system, it is possible to obtain highly localized material ablation or modification, hence assuring high processing accuracy and cleanness (Cheng et al., 2013).

Wafer transition

The semiconductor industry has attempted to lower the manufacturing costs per microchip by increasing the area where chips are fabricated. This is known in the industry as a "wafer size transition" (Temponi et al, 2012). The underlying idea is that processing more silicon at a time results in more dies (integral pieces of silicon that form the basis of a chip) per wafer in a given production run, while the associated costs do not rise as quickly. For example, in the latest transition (from 200 mm to 300 mm wafer diameter size) the die throughput increased with 125% while equipment only cost rose by 30% (GlobalFoundries, 2011). This 300 mm diameter size has recently overtaken the 200 mm diameter in importance (see Figure 2.22). The expected next step is the switch to 450 mm diameter size, but this size is thought to become relevant only by 2020 (IC Knowledge, 2010).

Figure 2.22: World demand for silicon by wafer size



Source: IC Knowledge (2010)

A wafer transition does not occur without difficulties, as it poses numerous technical challenges. Wafer transitions are heavily capital intensive due to research and development costs, as well as the costs of building the fabrication facilities, infrastructure, equipment, and automation. In this respect, an increase in wafer sizes is much more disruptive to the industry than an ordinary process shrink (the miniaturization of the individual ICs).

This is illustrated by the development cost for the transition from 200 mm to 300 mm, which is estimated to lie around 11.6 billion dollar. The cost for the transition to 450 mm wafers is estimated to lie considerably higher, at around 20-40 billion dollar (Temponi et al, 2012). The transition costs are scaling up because higher automation complexity is required to handle larger, heavier, and more sensitive wafers (Singer, 2007).

Yet, the transition from 300 mm to 450 mm has become a certainty and 450mm factories will be in full production before the end of the decade. Given the large investments needed, it is not a surprise that it is the large players in the field who have committed to the new wafer size. Both Intel and TSMC have announced investment in 450mm factories (Reuters, 2012). In 2011 a R&D consortium working on the transition towards 450mm wafer size was founded by the CSNE Albany nanotech institute and leading companies Intel, TSMC, Samsung, GlobalFoundries and IBM (CNSE Albany, 2011). Recently, Intel, TSMC and Samsung announced an investment in the R&D program of ASML (a leading supplier of IC manufacturing equipment) to speed up the development of the 450 mm technology (ASML, 2012).

2.8. CONCLUSION

In the previous sections, technological developments and applications in all six KETs have been discussed. Some developments and applications are already commercialized, while the majority still needs (considerable) development and upscaling in order to reach the market.

For industrial biotechnology, several promising technological developments and applications have been identified like bio-based polymers and enzymes. With regard to the market potential, most platform chemicals need further optimization in order to be produced at economically interesting rates. Bio-based polymers such as bio-based plastics have a major market potential, but few applications have reached large scale production yet. Enzymes, such as carbohydrases, proteases and lipases, are increasingly used to perform chemical reactions in various industries. Emphasis is put on improving the performance and stability in industrial conditions of enzymes, next to a reduction of the production costs. In addition, biorefinery concepts can play an important role in the utilization and conversion of biogenic raw materials and residues.

Photonics is a key enabling technology that has technological developments and applications in many industries such as in the photovoltaics, communication, display and lighting industry. Photovoltaic solar panels have entered a third generation approach focused on lower costs and higher efficiency. In addition, research is being conducted in the area of concentrated solar power systems such as the parabolic trough concentrator. In the transportation of information arena, a huge challenge lies in overcoming crosstalk between different data sources in multiple mode/core fibers, next to a reduction of energy consumption. Also the rise of organic light emitting diodes (OLEDs) is promising as displays can be made thinner and less power consuming, while LEDs have the potential to reduce energy consumption in the area of lighting.

Micro- and nanoelectronics developments and applications have entered in almost all industries. They play a crucial role in the development of the information age. The introduction of multicore processors offers potential in enhancing efficiency as processing tasks can be well divided and delegated, but it poses major challenges on the software side. Also in the computer memory area, there are continuous developments to reduce either size or power consumption, and/or to enhance performance. In this regard, Resistive RAM and Spin Torque Ram are promising technologies for the future. The More than Moore trend entails promising applications in the area of continued integration of functionalities.

Advanced Materials are at the basis of multiple value chains and enable industrial innovation, as they are the building blocks of most physical products. The significance of lightweight materials is largely driven by their role in achieving greater energy efficiency as for example it takes less energy to accelerate a lighter object. Another promising area of research is focused on materials that are resistant to harsh conditions such as intermetallics.

Nanotechnology is key in many value chains as it can be used to realize smaller, quicker, more powerful, or more "intelligent" intermediates and systems components for products with significantly improved or even completely new functions (HLG Nano, 2010). Graphene and its rolled equivalent carbon nanotubes are both very promising materials that could serve for a variety of applications. Their thin carbon structure gives them light weight, high strength and excellent electrical properties. These properties have brought them at the forefront of scientific research across the globe. Quantum dots are also of interest because of their unique optical and electrical properties. However, as nanotechnology develops rapidly, caution is warranted regarding associated health risks.

Advanced manufacturing technologies enable technological innovations to be applied in various goods and services. It involves both pure manufacturing techniques and supporting techniques for modelling or simulation. Additive manufacturing entails promising applications such as 3D printing, as it allows straightforward manufacturing of complex geometries and uses only the material needed to produce a product, thereby reducing waste compared to the traditional subtractive process of removing material from solid blocks. In some applications it also reduces the need for large stocks. In addition, major progress has been realized in the use of lithography and wafer size transitions. The transition to 450 mm wafers will pose considerable challenges in the next years.

CHAPTER 3. MARKET SHARES IN TECHNOLOGY AND MARKET POTENTIAL FOR KETS

3.1. INTRODUCTION

In the background study of the 2010 European Competitiveness Report, market share calculations based on patent data and estimates of future market potential for KETs-based products and applications have been provided. The objective of this chapter is to provide an update of these calculations and estimates. The technology market shares are calculated based on the number of international patent applications. The patent activities are identified through IPC codes. The list of IPC codes deviates from the list that was used in the 2010 European Competitiveness Report as this list has been revised in a recent feasibility study for a KETs Observatory commissioned by DG Enterprise (Van de Velde et al., 2013).

Providing an update of the market potential for all six KETs, is not straightforward as KETs provide indispensable technology bricks that enable a wide range of product applications and hence have the ability to enable advances in all industries and sectors. The six KETs currently have applications in multiple industries such as the automotive, food, chemicals, electronics, energy, pharmaceuticals, construction, and telecommunication industry, and more applications in a variety of other industries are expected. In order to estimate the market potential of each KET, a literature review of existing studies, reports and reviews has been conducted[9]. For each KET, several (sub) markets have been selected in line with the KETs-based applications discussed in chapter 2.

3.2. MARKET SHARES IN TECHNOLOGY MARKETS

3.2.1. Introduction

An important measure to evaluate a country's position in KETs is its ability to produce new commercially relevant technological knowledge. A standard way to measure this ability is to look at patent data. Patent data have certain advantages when it comes to measuring technological performance in KETs. Patents represent new technological knowledge that has a certain potential for economic application. Each patent is linked to technological areas through an internationally standardised classification system (the International Patent Classification - IPC) which allows to relating patents to KETs.

Since patents are essential for the production of new technology and innovative products and processes, they are a commercial good which serves as an input to production and can be traded on technology markets (either through licensing or by selling and purchasing patent rights). In contrast to many other goods, most patents are produced and used in-house while only a small part is actually traded between firms (see Gambardella et al., 2007; Arora et al., 2002; Serrano, 2005; Lamoreaux and Sokoloff, 1999). Like for any other market, one can analyse the technology market performance of individual actors as well as for countries. In this report, for each country a market share in the technology market for each KET is calculated based on the number of international patent applications. International patent applications are patents that were applied at the European Patent Office (EPO) or through the so-called PCT (Patent Cooperation Treaty) procedure at the World Intellectual Property Organization. By using international patent applications (as opposed to applications at national patent offices such as the USPTO) one avoids a too strong home country bias for the country whose patent office is considered and excludes patents of low (expected) commercial value since an application at EPO or through PCT is comparatively costly.

[9] In selecting sources for this review, the growth rates provided by the High-Level Expert Group on KETs (see Figure 4.3) have been used as benchmark for the reliability of estimates. However, it should be kept in mind that the market potential of subgroups of products may differ substantially from the average of the whole KET (especially in the case of very young applications that currently represent only a small market). Estimates provided by organizations having an interest in inflating figures have been avoided, only in case where another independent source (HLEG KETs or other) provides comparable estimates such estimates have been included.

When calculating market shares based on patent counts, one should bear in mind certain limitations of patent count data (see Griliches, 1990; Moed et al., 2004). First, not all new technological knowledge needed for innovations is represented by patents while a number of patents is never be used for innovations. Secondly, the economic value represented by one patent can vary substantially. Thirdly, not all patents seek legal protection of new technological knowledge but some are used to block competitors' patenting activities or to disinform others about one's own technological strategy. For these reason, patents represent only a certain fraction of the technology market. There is a general agreement in technology research, however, that patent data accurately represent the main structures and development of technology markets (see OECD, 2012; Glänzel et al., 2004; Schmoch, 2009).

When examining technology market shares over time, one should also take into account that patent applications are linked to market developments and firms' regional commercialisation strategies (Frietsch and Schmoch, 2010). Since patent protection expires after some time, firms often apply for a patent only shortly before market introduction of the product that uses the patented technology. If market introduction is postponed due to unfavourable market conditions, patent activity can fall. For EPO/PCT patents, the attractiveness of regional markets can affect patent activity, too. Since EPO/PCT patents are mostly used to protect technology which is to be commercialised globally and/or in the European market, shifts in market attractiveness towards global/European markets can increase international patent activity while a gain in market attractiveness of other regional markets such as the North American or East Asian market may shift patent activity towards the patent offices in these markets.

Technology market shares are calculated using the most recent edition of the Patstat database published by EPO in April 2013. Patstat contains information on patents applied at the various national patent offices as well as international (EPO and PCT) patent applications. Patent data are available only with a considerable time lag after the underlying invention has been made. First, there may be a time lag between the invention and the patent application which is due to the process of preparing a patent file. Secondly, as mentioned above patent applications may be postponed in response to unfavourable market conditions. Finally, patent applications are disclosed only 18 months after the date of application. The time lag becomes even larger when one considers international patents since applicants may apply for patent protection in their home country first and seek international protection only some time after the initial application. When focussing on granted patents, time lags become even worth since patent examination may last a year or more. For this reason, the final year for which market shares can be calculated is 2010.

No weighting of patent application counts by patent value indicators such as patent citations or opposition for is applied for two reasons: First, such a procedure would add another time lag to our analysis since only older patents have a chance to be forward cited by other patents or to receive opposition. Secondly, the extent of forward citations and oppositions varies by national patent offices and will thus reduce comparability across regions. The market share is calculated for four regions as well as for individual European countries. The four regions considered are:

- Europe (all EU member states as well as Albania, Andorra, Bosnia-Herzegovina, Croatia, Iceland, Liechtenstein, Macedonia, Monaco, Montenegro, Norway, San Marino, Serbia and Switzerland)
- North America (the USA; Canada and Mexico)
- East Asia (Japan, China (incl. Hong Kong), South Korea, Singapore and Taiwan)
- Rest of World (all other countries)

Note that the sum of patents for the four regions does not equal the total number of EPO/PCT patents because of missing data on applicant countries. The share of EPO/PCT patents with unknown country of applicant rose from 0.0 percent in 2000 to 2.4 percent in 2010. In some KETs this share was very high in recent years, including industrial biotechnology (7.0 percent), micro-/nanoelectronics (6.0 percent) and AMT for other KETs (5.9 percent). For this analysis, it is assumed that the regional distribution of applicants with unknown country is the same as for applicants for which the country is known. The market share for each KET is hence calculated as the number of EPO/PCT patents originating from a certain country/region in a specific year over the total number of EPO/PCT patents (excluding patents with unknown country of applicant).

An important issue for determining market shares is how to assign patents to countries and regions. There are basically two options: by country of applicant or by country of inventor. In many patent analyses, inventor countries are used to assign a patent to a region. This is a valid approach when one wants to know in which region new technological knowledge has emerged. Assigning patents to country of applicants is a useful procedure if one wants to identify the regions that have economic control over the technological knowledge represented by patents. Following a prior study for the EU Competitiveness Report (Aschhoff et al., 2010), market shares are calculated based on applicant location (applying fractional counting in case one patent has applicants from more than one country/region). Patent applicants are not consolidated by company groups. This means that, for example, patents applied by European subsidiaries of North American companies are assigned to Europe, whereas applications of North American subsidiaries of European companies are counted as North American patents. Since many of the large international companies apply patents that have been invented outside their home market region by their regional subsidiaries, differences between the regional patterns that emerge based on country of applicants do not differ significantly from the pattern that would emerge when the analyses would be based on country of inventor.

3.2.2. Identifying KET Patents

Patent activities in the six KETs are identified through IPC codes. For each KET a list of IPC codes (including combinations of codes or the exclusion of codes in case of co-occurrence with other codes) is defined. This list is taken from a recent feasibility study for a KETs Observatory commissioned by DG Enterprise (van de Velde et al., 2013). This list started from an earlier list developed for the 2010 EU Competitiveness report and has been refined and further developed based on expert reviews and the results of various robustness checks (including free text search in patent abstracts). The list of IPC codes used for each KET is shown in Box 1.

When comparing this list with the list used for the 2010 EU Competitiveness Report (Aschhoff et al., 2010: 30), some deviations emerge. For nanotechnology, the definition remained virtually the same, though one IPC code has been added. For advanced materials, a few additional codes were added in order the better capture some new materials in the field of chemicals. For industrial biotechnology, the group of enzymes is now more defined in a more narrow way in order to reduce the amount of patents related to pharmaceutical applications to be counted as industrial biotechnology patents (though there is a strong technological link between red and white biotechnology in the field of enzymes). In micro-/nanoelectronics, testing and control of semiconductor devices was added to the list of IPC codes, as well as some smaller groups related to semiconductor material, amplifiers for semiconductors and printed circuits while apparatus for manufacturing printed circuits have been skipped since these are considered part of advanced manufacturing technologies. More substantial changes were made in the field of photonics. In this study, photonic applications in the field of measuring, optical recording and optical data transmission as well as electron-optical applications and photonics in the field of semiconductors are now covered more completely than in the previous study while a few codes have been skipped as a result of more detailed examination of patent abstracts (some photonic applications in microelectronics, electric arc lamps).

Box 1: IPC codes used to identify KETs (based on the 2012 edition of IPC)

Nanotechnology: B81C, B82B, B82Y

Photonics: F21K, F21V, F21Y, G01D 5/26, G01D 5/58, G01D 15/14, G01G 23/32, G01J, G01L 1/24, G01L 3/08, G01L 11/02, G01L 23/06, G01M 11, G01P 3/36, G01P 3/38, G01P 3/68, G01P 5/26, G01Q 20/02, G01Q 30/02, G01Q 60/06, G01Q 60/18, G01R 15/22, G01R 15/24, G01R 23/17, G01R 31/308, G01R 33/032, G01R 33/26, G01S 7/481, G01V 8, G02B 5, G02B 6 (excl. subclasses 1, 3, 6/36, 6/38, 6/40, 6/44, 6/46), G02B 13/14, G03B 42, G03G 21/08, G06E, G06F 3/042, G06K 9/58, G06K 9/74, G06N 3/067, G08B 13/186, G08C 19/36, G08C 23/04, G08C 23/06, G08G 1/04, G11B 7/12, G11B 7/125, G11B 7/13, G11B 7/135, G11B 11/03, G11B 11/12, G11B 11/18, G11C 11/42, G11C 13/04, G11C 19/30, H01J 3, H01J 5/16, H01J 29/46, H01J 29/82, H01J 29/89, H01J 31/50, H01J 37/04, H01J 37/05, H01J 49/04, H01J 49/06, H01L 31/052, H01L 31/055, H01L 31/10, H01L 33/06, H01L 33/08, H01L 33/10, H01L 33/18, H01L 51/50, H01L 51/52, H01S 3, H01S 5, H02N 6, H05B 33

Industrial biotechnology: C02F 3/34, C07C 29, C07D 475, C07K 2, C08B 3, C08B 7, C08H 1, C08L 89, C09D 11/04, C09D 189, C09J 189, C12M, C12P, C12Q, C12S, G01N 27/327 except for co-occurrence with A01, A61, C07K 14/435, C07K 14/47, C07K 14/705, C07K 16/18, C07K 16/28, C12N 15/09, C12N 15/11, C12N 15/12, C12N 5/10, C12P 21/08, C12Q 1/68, G01N 33/15, G01N 33/50, G01N 33/53, G01N 33/68, G01N 33/566, C12N 1/19, C12N 1/21, C12N 1/15, C12N 15/00, C12N 15/10, C12P 21/02

Advanced materials: B32B 9, B32B 15, B32B 17, B32B 18, B32B 19, B32B 25, B32B 27, B82Y 30, C01B 31, C01D 15, C01D 17, C01F 13, C01F 15, C01F 17, C03C, C04B 35, C08F, C08J 5, C08L, C22C, C23C, D21H 17, G02B 1, H01B 3, H01F 1/0, H01F 1/12, H01F 1/34, H01F 1/42, H01F 1/44, H01L 51/30, H01L 51/46, H01L 51/54

Micro- and nanoelectronics: B82Y 25, G01R 31/26, G01R 31/27, G01R 31/28, G01R 31/303, G01R 31/304, G01R 31/317, G01R 31/327, G09G 3/14, G09G 3/32, H01F 1/40, H01F 10/193, H01G 9/028, H01G 9/032, H01H 47/32, H01L, H01S 5, H03B 5/32, H03C 3/22, H03F 3/04, H03F 3/06, H03F 3/08, H03F 3/10, H03F 3/12, H03F 3/14, H03F 3/16, H03F 3/183, H03F 3/21, H03F 3/343, H03F 3/387, H03F 3/55, H03K 17/72, H05K 1

AMT for other KETs: B01D 15, B01D 67, B01J 10, B01J 12, B01J 13, B01J 14, B01J 15, B01J 16, B01J 19/02, B01J 19/08, B01J 19/18, B01J 19/20, B01J 19/22, B01J 19/24, B01J 19/26, B01J 19/28, B01J 20/30, B01J 21/20, B01J 23/90, B01J 23/92, B01J 23/94, B01J 23/96, B01J 25/04, B01J 27/28, B01J 27/30, B01J 27/32, B01J 29/90, B01J 31/40, B01J 38, B01J 39/26, B01J 41/20, B01J 47, B01J 49, B01J 8/06, B01J 8/14, B01J 8/24, B01L, B04B, B04C, B32B 37, B32B 38, B32B 39, B32B 41, B81C 3, B82B 3, B82Y 35, B82Y 40, C01B 17/20, C01B 17/62, C01B 17/80, C01B 17/96, C01B 21/28, C01B 21/32, C01B 21/48, C01B 25/232, C01B 31/24, C01B 9, C01C 1/28, C01D 1/28, C01D 3/14, C01D 5/16, C01D 7/22, C01D 9/16, C01F 1, C01G 1, C02F 11/02, C02F 11/04, C02F 3, C03B 20, C03B 5/24, C03B 5/173, C03B 5/237, C03B 5/02, C03C 21, C03C 29, C04B 11/028, C04B 35/622, C04B 35/624, C04B 35/626, C04B 35/653, C04B 35/657, C04B 37, C04B 38/02, C04B 38/10, C04B 40, C04B 7/60, C04B 9/20, C07C 17/38, C07C 2/08, C07C 2/46, C07C 2/52, C07C 2/58, C07C 2/80, C07C 201/16, C07C 209/82, C07C 213/10, C07C 227/38, C07C 231/22, C07C 249/14, C07C 253/32, C07C 263/18, C07C 269/08, C07C 273/14, C07C 277/06, C07C 29/74, C07C 303/42, C07C 315/06, C07C 319/26, C07C 37/68, C07C 4/04, C07C 4/06, C07C 4/16, C07C 4/18, C07C 41/34, C07C 41/58, C07C 45/78, C07C 45/90, C07C 46/10, C07C 47/058, C07C 47/09, C07C 5/333, C07C 5/41, C07C 51/42, C07C 51/573, C07C 51/64, C07C 57/07, C07C 67/48, C07C 68/08, C07C 7, C07D 201/16, C07D 209/84, C07D 213/803, C07D 251/62, C07D 301/32, C07D 311/40, C07D 499/18, C07D 501/12, C07F 7/20, C07H 1/06, C07K 1, C08B 1/10, C08B 17, C08B 30/16, C08C, C08F 2/01, C09B 41, C09B 67/54, C09D 7/14, C09J 5, C12M, C12S, C21C 5/52, C21C 5/54, C21C 5/56, C21C 7, C21D, C22B 11, C22B 21, C22B 26, C22B 4, C22B 59, C22B 9, C22C 1, C22C 3, C22C 33, C22C 35, C22C 47, C22F, C23C 14/56, C23C 16/54, C25B 9, C25B 15/02, C25C, C25D 1, C30B 15/20, C30B 35, C40B 60, D01D 10, D01D 11, D01D 13, D01F 9/133, D01F 9/32, D06B 23/20, D21H 23/20, D21H 23/70, D21H 23/74, D21H 23/78, D21H 27/22, F24J 1, F25J 3, F25J 5, F27B 17, F27B 19, F27D 19, F27D 7/06, G01C 19/5628, G01C 19/5663, G01C 19/5769, G01C 25, G01R 3, G11B 7/22, H01L 21, H01L 31/18, H01L 35/34, H01L 39/24, H01L 41/22, H01L 43/12, H01L 51/40, H01L 51/48, H01L 51/56, H01S 3/08, H01S 3/09, H01S 5/04, H01S 5/06, H01S 5/10, H05B 33/10, H05K 13, H05K 3

Source: Van de Velde et al. (2013)

Box 2: Definition of subfields by KET

Nanotechnology: **nano-biotechnology** (B82Y 5), **nano-electronics/magnetics** (B82Y 10, B82Y 25), **nano-analytics** (B82Y 15, B82Y 35), **nano-optics** (B82Y 20), **nano-materials** (B82Y 30), **nano-structures** (B81C, B82B, B82Y 40)

Photonics: **lighting** (F21K, F21V, F21Y, H01L 51/50, H01L 51/52, H05B 33), **measuring** (G01D 5/26, G01D 5/58, G01D 15/14, G01G 23/32, G01J, G01L 1/24, G01L 3/08, G01L 11/02, G01L 23/06, G01M 11, G01P 3/36, G01P 3/38, G01P 3/68, G01P 5/26, G01Q 20/02, G01Q 30/02, G01Q 60/06, G01Q 60/18, G01R 15/22, G01R 15/24, G01R 23/17, G01R 31/308, G01R 33/032, G01R 33/26, G01S 7/481, G01V 8), **devices** (G02B 5, G02B 6 (excl. subclasses 1, 3, 6/36, 6/38, 6/40, 6/44, 6/46), G02B 13/14, G03B 42, G03G 21/08, G06E, G06F 3/042, G06K 9/58, G06K 9/74, G06N 3/067, G08B 13/186, G08C 19/36, G08C 23/04, G08C 23/06, G08G 1/04), **laser** (G11B 7/12, G11B 7/125, G11B 7/13, G11B 7/135, G11B 11/03, G11B 11/12, G11B 11/18, H01S 3, H01S 5), **electron-optics** (G11C 11/42, G11C 13/04, G11C 19/30, H01J 3, H01J 5/16, H02N 6), **semiconductors** (H01J 29/46, H01J 29/82, H01J 29/89, H01J 31/50, H01J 37/04, H01J 37/05, H01J 49/04, H01J 49/06, H01L 31/052, H01L 31/055, H01L 31/10, H01L 33/06, H01L 33/08, H01L 33/10, H01L 33/18)

Industrial biotechnology: **proteins/acids** (C07K 2, C08B 3, C08B 7, C08H 1, C08L 89, C09D 11/04, C09D 189, C09J 189), **enzymes** (C12M, C12P, C12Q, C12S), **others** (C02F 3/34, C07C 29, C07D 475, G01N 27/327)

Advanced materials: **layers** (B32B 9, B32B 15, B32B 17, B32B 18, B32B 19, B32B 25, B32B 27), **compounds** (C01B 31, C01D 15, C01D 17, C01F 13, C01F 15, C01F 17, C03C, C04B 35), **macro-scale** (C08F, C08J 5, C08L), **alloys** (C22C), **coatings** (C23C), **electronics** (H01F 1/0, H01F 1/12, H01F 1/34, H01F 1/42, H01F 1/44, H01L 51/30, H01L 51/46, H01L 51/54), **others/nano-materials** (B82Y 30, D21H 17, G02B 1, H01B 3)

Micro- and nanoelectronics: **testing/amplifiers/nano** (B82Y 25, G01R 31/26, G01R 31/27, G01R 31/28, G01R 31/303, G01R 31/304, G01R 31/317, G01R 31/327, H03B 5/32, H03C 3/22, H03F 3/04, H03F 3/06, H03F 3/08, H03F 3/10, H03F 3/12, H03F 3/14, H03F 3/16, H03F 3/183, H03F 3/21, H03F 3/343, H03F 3/387, H03F 3/55, H03K 17/72), **semiconductors** (G09G 3/14, G09G 3/32, H01L), **devices** (H01F 1/40, H01F 10/193, H01G 9/028, H01G 9/032, H01H 47/32, H01S 5, H05K 1)

AMT for other KETs: **materials** (B01D 15, B01D 67, B01J 10, B01J 12, B01J 13, B01J 14, B01J 15, B01J 16, B01J 19/02, B01J 19/08, B01J 19/18, B01J 19/20, B01J 19/22, B01J 19/24, B01J 19/26, B01J 19/28, B01J 20/30, B01J 21/20, B01J 23/90, B01J 23/92, B01J 23/94, B01J 23/96, B01J 25/04, B01J 27/28, B01J 27/30, B01J 27/32, B01J 29/90, B01J 31/40, B01J 38, B01J 39/26, B01J 41/20, B01J 47, B01J 49, B01J 8/06, B01J 8/14, B01J 8/24, B32B 37, B32B 38, B32B 39, C01B 17/20, C01B 17/62, C01B 17/80, C01B 17/96, C01B 21/28, C01B 21/32, C01B 21/48, C01B 25/232, C01B 31/24, C01B 9, C01C 1/28, C01D 1/28, C01D 3/14, C01D 5/16, C01D 7/22, C01D 9/16, C01F 1, C01G 1, C03B 20, C03B 5/24, C03B 5/173, C03B 5/237, C03B 5/02, C03C 21, C03C 29, C04B 11/028, C04B 35/622, C04B 35/624, C04B 35/626, C04B 35/653, C04B 35/657, C04B 37, C04B 38/02, C04B 38/10, C04B 40, C04B 7/60, C04B 9/20, C07C 17/38, C07C 2/08, C07C 2/46, C07C 2/52, C07C 2/58, C07C 2/80, C07C 201/16, C07C 209/82, C07C 213/10, C07C 227/38, C07C 231/22, C07C 249/14, C07C 253/32, C07C 263/18, C07C 269/08, C07C 273/14, C07C 277/06, C07C 303/42, C07C 315/06, C07C 319/26, C07C 37/68, C07C 4/04, C07C 4/06, C07C 4/16, C07C 4/18, C07C 41/34, C07C 41/58, C07C 45/78, C07C 45/90, C07C 46/10, C07C 47/058, C07C 47/09, C07C 5/333, C07C 5/41, C07C 51/42, C07C 51/573, C07C 51/64, C07C 57/07, C07C 67/48, C07C 68/08, C07C 7, C07D 201/16, C07D 209/84, C07D 213/803, C07D 251/62, C07D 301/32, C07D 311/40, C07D 499/18, C07D 501/12, C07F 7/20, C07H 1/06, C08C, C08F 2/01, C09B 41, C09B 67/54, C09D 7/14, C09J 5, C21C 5/52, C21C 5/54, C21C 5/56, C21C 7, C21D, C22B 11, C22B 21, C22B 26, C22B 4, C22B 59, C22B 9, C22C 1, C22C 3, C22C 33, C22C 35, C22C 47, C22F, C23C 14/56, C23C 16/54, C25B 9, C25B 15/02, C25C, C25D 1, C30B 15/20, C30B 35, C40B 60, D01D 10, D01D 11, D01D 13, D01F 9/133, D01F 9/32, D06B 23/20, D21H 23/20, D21H 23/70, D21H 27/22, F24J 1, F25J 3, F25J 5, F27B 17, F27B 19, F27D 7/06, H01S 3/09, H01S 5/04), **biotechnology** (C02F 11/02, C02F 11/04, C02F 3, C07C 29/74, C07K 1, C08B 1/10, C08B 17, C08B 30/16, C12M, C12S), **photonics** (G11B 7/22, H01S 3/08, H01S 5/10, H05B 33/10), **microelectronics** (H01L 21, H01L 31/18, H01L 35/34, H01L 39/24, H01L 41/22, H01L 43/12, H01L 51/40, H01L 51/48, H01L 51/56, H05K 13, H05K 3), **instruments** (B01L, B04B, B04C, B81C 3, D21H 23/74, G01C 19/5628, G01C 19/5663, G01C 19/5769, G01C 25, G01R 3), **others** (B82B 3, B82Y 35, B82Y 40, B32B 41, D21H 23/78, F27D 19, H01S 5/06)

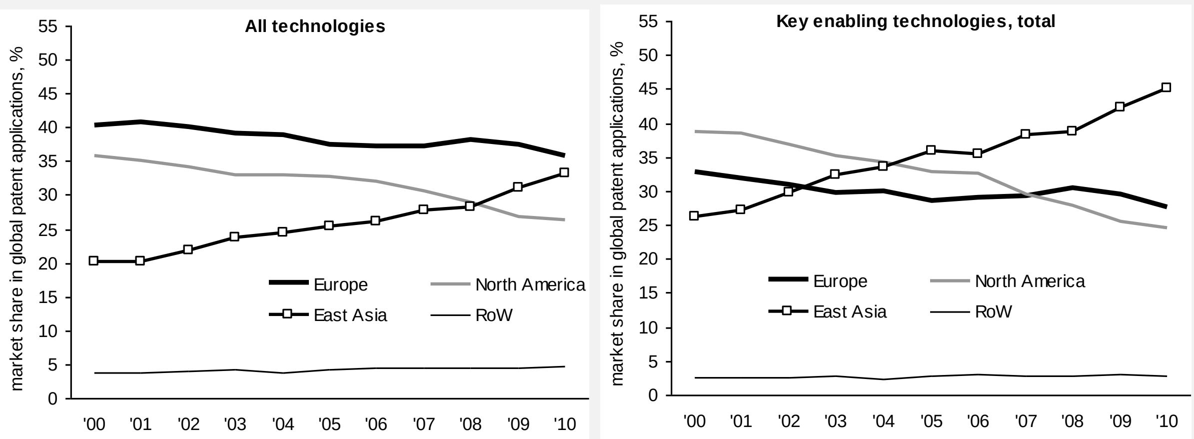
The most fundamental change refers to advanced manufacturing technologies, however. In the earlier study, advanced manufacturing technologies focused on automation, robotics and the use of advanced information technology in mechanical engineering. These advanced manufacturing technologies can be employed in any manufacturing sector, though an implicit focus was on sectors that process materials (such as metal working, plastics, wood and paper processing, manufacture of non-metallic mineral products) or assemble materials and components to complex products (such as manufacture of vehicles, electronics, optical or electrical equipment, machinery and the like). For the present study, following the new communication of the EU Commission on KETs (EU Commission, 2012) a different definition of advanced manufacturing technologies was applied that focuses on process technology which is needed to manufacture products in any of the other five KET areas. Since most of the other KETs areas are concerned with the development of new materials (which is true for advanced materials as well as industrial biotechnology and nanotechnology and also applies to major parts of technological development in micro-/nanoelectronics and photonics), manufacturing technology for these KETs areas is often linked to apparatus for performing chemical processes and treating basic materials. In order to clearly distinguish the result in this report from the results presented in the EU Competitiveness Report 2010 on advanced manufacturing technologies, this report will use "AMT for other KETs" as the name for this KET.

Market shares of each KET are further separated into subfields based on IPC codes. Box 2 lists the subfields within the other five KETs and the IPC codes used to define each subfield.

3.2.3. Market Shares by KET

Before presenting the results on market shares for each KET, it is important to keep in mind the general trends in international patenting over the past decade. Across all technologies (i.e. for the sum of all international patents), the market share of East Asia increased continuously from 20 to 33 percent. Losses in market shares are reported for Europe (down from 40 to 36 percent) and, even stronger, North America (down from 36 to 26 percent). The rest of the world (RoW) gained some market shares (from 4 to 5 percent). For KETs, trends are similar. East Asia increased its market share in technology markets from 2000 to 2010 by almost 20 percentage points. In 2010, 45 percent of all KET patents were applied by organisations from East Asia. Europe lost 5 percentage points and had a market share in 2010 of 28 percent. The largest loss is reported for North America (down 15 percentage points to 24 percent). The RoW reports a stable market share of 3 percent throughout the period under consideration.

Figure 3.1: Market share for all patents and KET patents (EPO/PCT) 2000-2010 by region of applicant



Source: EPO: Patstat, ZEW calculations

When interpreting changes in market shares, one should also bear in mind the underlying trends in total patenting activity. The number of international (EPO/PCT) patent applications (excluding applications with unknown country of origin) increased by 23 percent between 2000 and 2010. While patent applications from North America declined (-9 percent), European applicants raised their number of patent applications by 10 percent. By far the largest increases are reported for East Asia (+103 percent). RoW applicants increased their patent output by 51 percent. With respect to KET patenting, the increase in the number of international patent applications between 2000 and 2010 (+7 percent) was lower than for all fields of technology. Both North America (-32 percent) and Europe (-10 percent) cut back their patent output while East Asian applicants reported a growth rate of 85 percent, and RoW of 19 percent.

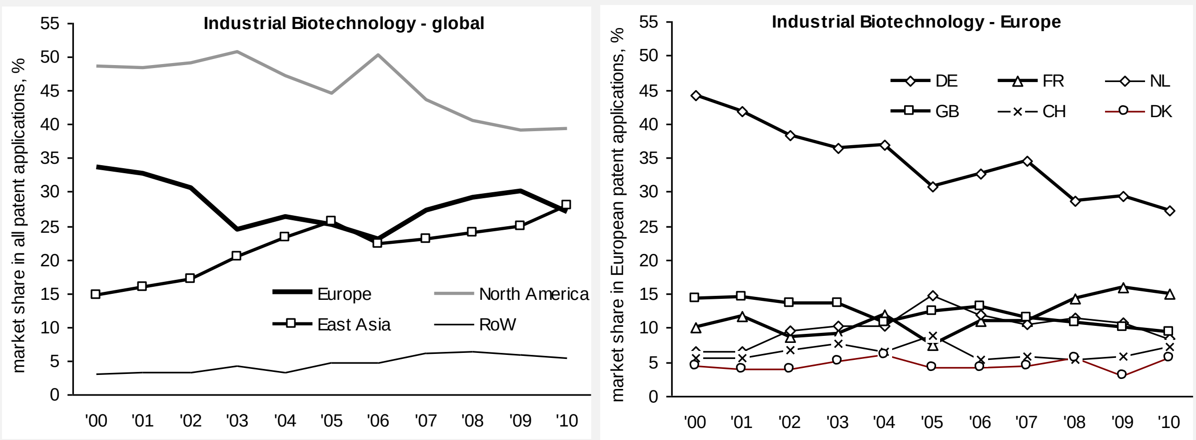
3.3. INDUSTRIAL BIOTECHNOLOGY

3.3.1. Technology market share

International patent applications in the field of industrial biotechnology show a decreasing trend over the past ten years. Globally, the number of patents fell by 33 percent between 2000 and 2010. Europe and North America report the same reduction (-46 percent). East Asia and RoW increased the number of international patent applications in industrial biotechnology by 28 and 14 percent, respectively. As a consequence, market shares of Europe and North America are declining. Nevertheless, North America is still the region with the highest market share in 2010 (39 percent). Europe lost its second position in 2010 though its market share in this year (27 percent) was above the low level reported for the mid 2000s (23 percent in 2006). East Asia gained in market shares and contributed 28 percent to the global patent output in industrial biotechnology in 2010. The RoW countries show increasing market shares until 2008, but no further growth afterwards, contributing 5 percent to total patenting in industrial biotechnology in 2010.

In Europe, Germany gradually lost market shares which went down from 44 percent (2000) to 27 percent (2010). France gained market shares and replaced the UK as second largest European patent producer in industrial biotechnology by 2008. The Netherlands showed high market shares in the mid-2000s (ranking second in 2005 with a European market share of 15 percent) but clearly lost ground in the past years. Switzerland and Denmark hold position 5 and 6 in European patenting in the field of industrial biotechnology.

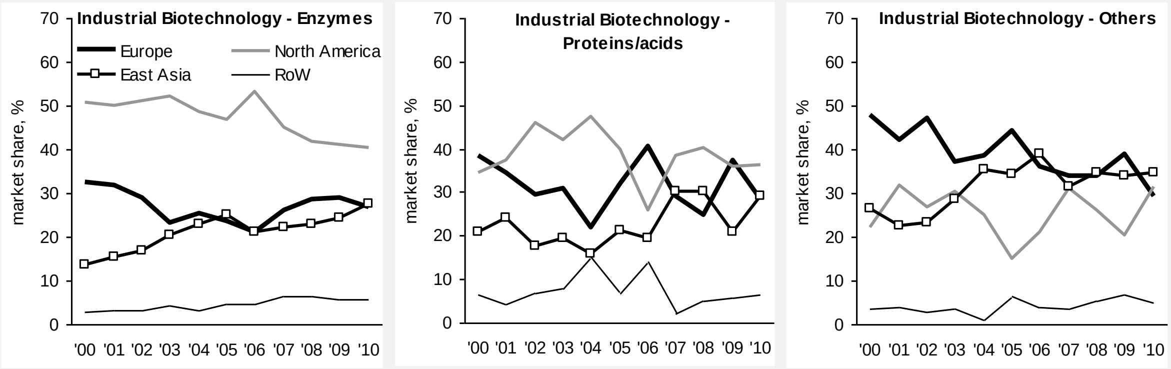
Figure 3.2: Market shares in international patents in the KET field of Industrial Biotechnology 2000-2010 (percent)



Source: EPO: Patstat, ZEW calculations

The main subfield in industrial biotechnology patenting is enzymes, which account for 90 percent of all EPO/PCT patent applications in this KET. Consequently, the development in this subfield basically mirrors the one for the entire KET. The other two subfields do not show clear trends but rather an erratic development which reflects the low absolute number of patent applications per year. North America tends to show higher market shares in the subfield of proteins and acids while Europe has the highest market share in most years in the others category.

Figure 3.3: Market shares in international patents in the KET field of Industrial Biotechnology 2000-2010, by subfields (percent)



Source: EPO: Patstat, ZEW calculations

3.3.2. Market potential

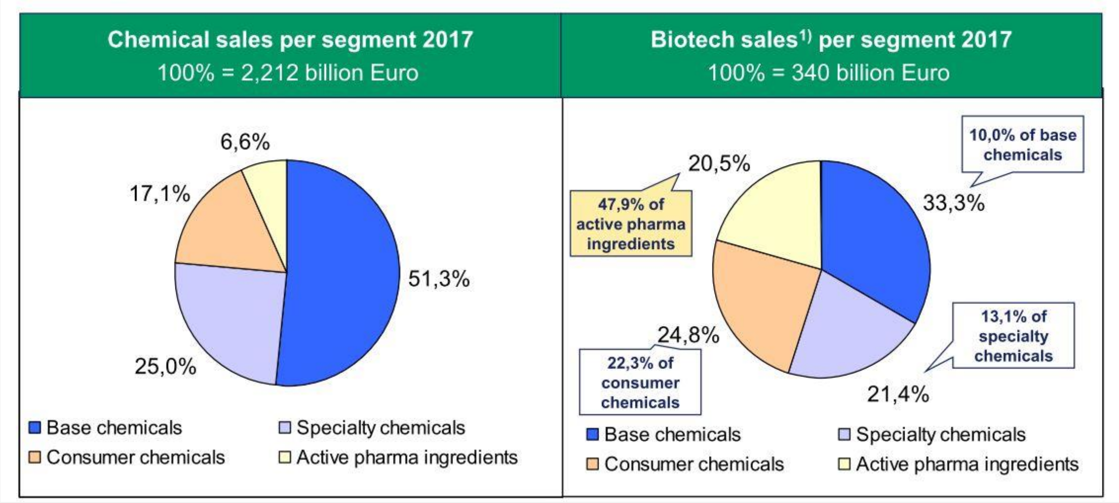
Industrial biotechnology is used in the production of chemicals and derived biomaterials. The use of biotechnology for chemical production has increased over the past decade and is likely to continue to increase, driven by rising energy costs, new chemical legislation and increasingly stringent environmental regulations (OECD, 2009).

According to Festel Capital, the sales of products made by biotechnological processes in 2007 was around 48 billion Euro or 3.5% of total chemical sales, while they predicted the sales of products made by biotechnological processes to be around 340 billion Euro or 15.4% of total chemical sales in 2017[10]. Based upon their research, they predict the most important sub-segments in 2017 to be active in pharma ingredients and polymers & fibers, compared to pharma ingredients and cosmetics in 2012 and 2007[11].

[10] http://www.oecd.org/sti/biotech/44776744.pdf

[11] http://www.oecd.org/sti/biotech/44776744.pdf

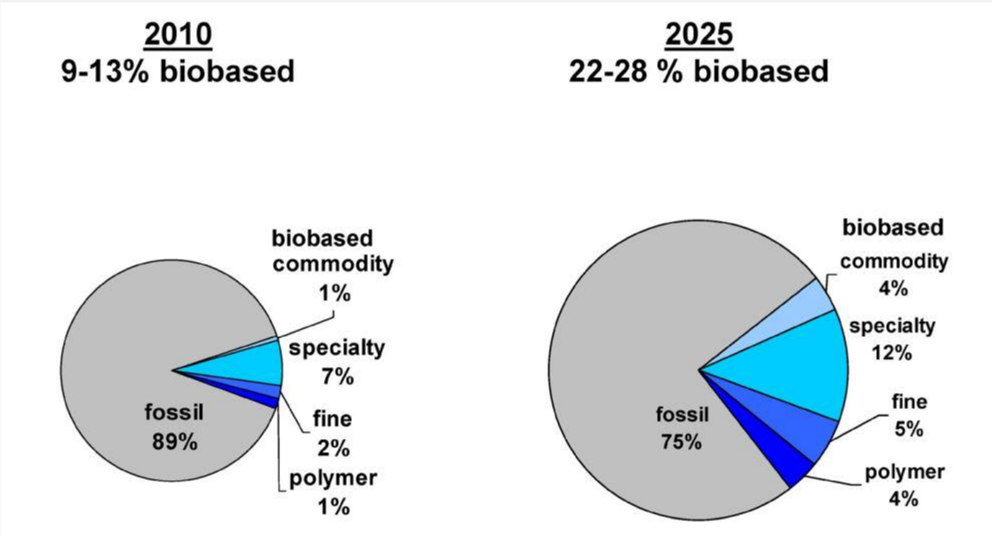
Figure 3.4: Sales of products made by biotechnological processes in 2017



Source: Festel Capital (2010)

Other sources depart from a market share of 9% to 13% in 2010 and predict a further growth to 22% to 28% in 2025. Especially in the area of polymers and bulk chemicals, a large growth is expected to take place.

Figure 3.5: The expected growth of bio-based chemicals

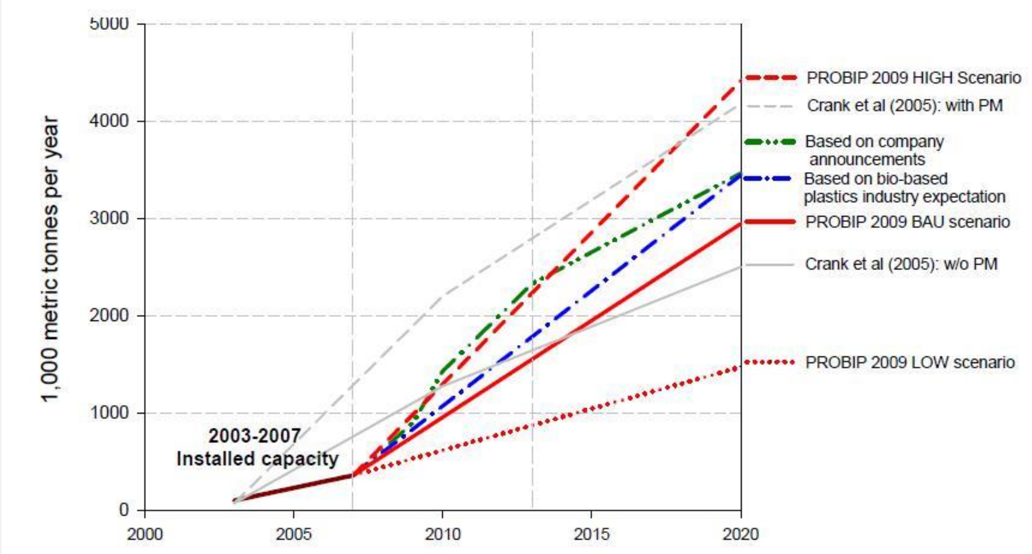


Source: Kircher (2012)

Bio-based polymers

Bio-based polymers form a very promising emerging application of biotech that has high potential to substitute for petroleum-based polymers (see section 2.2.2). Even in low and business as usual scenario's studied by Shen et al. (2009), there is considerable growth to be expected over the next 10 years. Also the prospects of companies and the industry association indicate that production is expected to increase strongly between 2010 and 200. The most important representatives will be starch plastics, PLA, bio-based PE and PHA (Shen et al., 2009).

Figure 3.6: Projections for installed bioplastics production capacity



Source: Shen et al., 2009

Biofuels

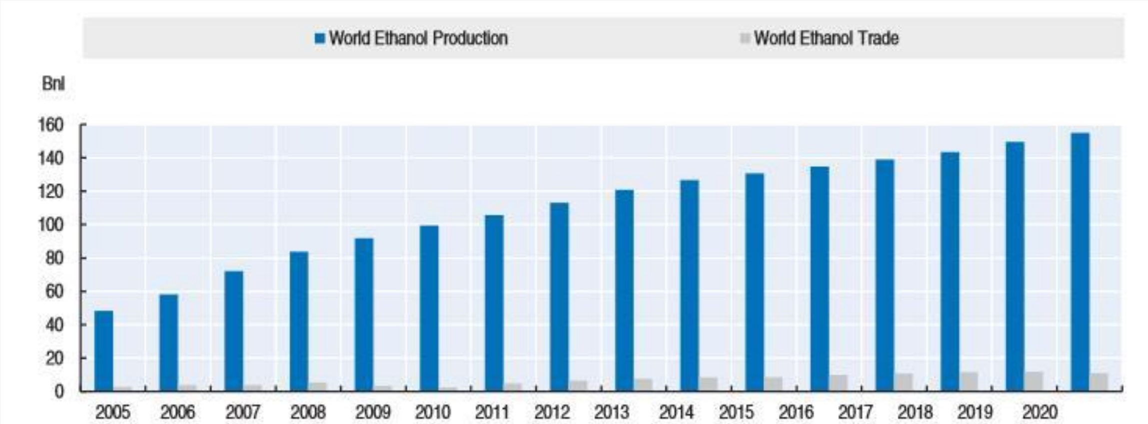
World biofuel production is covered largely by three major regions, as the US, Brazil, and Europe account for 87% of global production[12]. The US produced 48% of the world's 2011 biofuel total, mostly in the form of corn ethanol. Brazil produced 22.4%, primarily as sugarcane ethanol. However, ethanol production in Brazil has been flat to declining in recent years due to disappointing sugarcane harvests. The third major biofuel producing region is the EU, which is the leading biodiesel-producing region in the world. The EU was responsible for 16.5% of global biofuel production. Other than the US and Brazil, the only other countries producing more than 3% of the global biofuel total were Germany (4.8%) and Argentina (3.8%). The OECD-FAO Agricultural Outlook 2008–2017 predicts that the US and Brazil will maintain their position as largest ethanol producers, while China, India, Thailand and several African countries are expected to expand their ethanol production significantly .

The OECD (Organisation for Economic Co-operation and Development) and UN FAO food agency project that global ethanol production will increase steadily, realizing about 50% growth in total over the period 2010-2020. Biodiesel production is about to double over the same time period (Figure 3.7 and Figure 3.8). Pike research, a cleantech market intelligence firm, also estimate steady growth till 2016, but then rapid production increases between 2017 and 2021 as a result of higher oil prices, emerging mandates, new feedstock availability, and advanced technologies[13]. They project the total global biofuel production to reach 65.7 billion gallons per year (BGPY) by 2021, while they expect ethanol to maintain its dominance over the industry, with nearly 50 BGPY compared to biodiesel's 16.2 BGPY.

[12] BP Statistical review of world energy June 2012

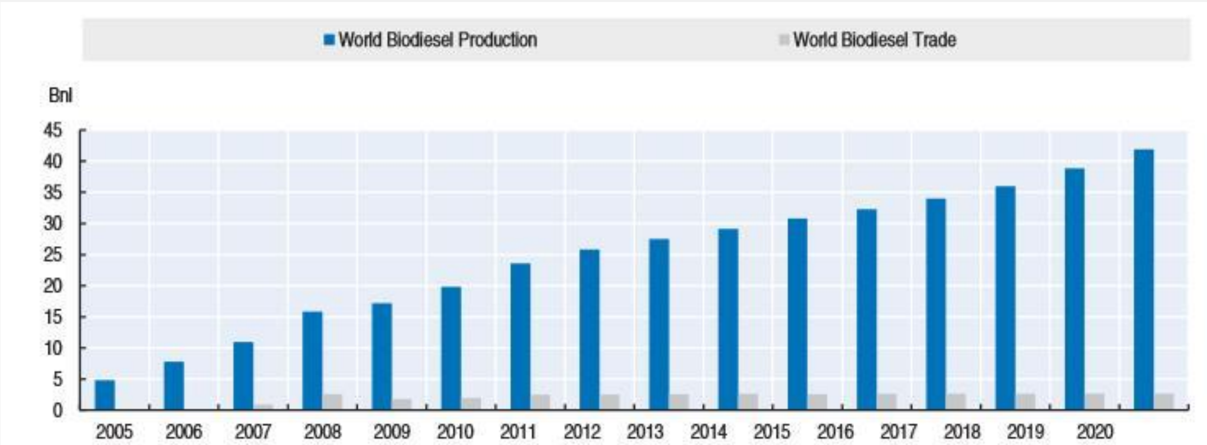
[13] http://cleantechnica.com/2012/02/20/report-global-biofuels-market-could-double-to-185-3-billion-by-2021/

Figure 3.7 World ethanol production and trade, 2005- 2020



Source: OECD-FAO Agricultural outlook 2011-2020

Figure 3.8: world biodiesel production, 2005-2020



Source: OECD-FAO Agricultural outlook 2011-2020

The production of advanced biofuels (second and third generation biofuels) has reached 685-689 million gallons in 2012 and is predicted to have a production capacity of 1.6 to 2.6 billion gallons by 2015 (see Figure 3.9). The industry is moving from the demonstration phase into the commercial production phase as new facilities are being built to accommodate the increase in demand.

Figure 3.9: Advance biofuel capacity by fuel type for 2012 and 2015

ADVANCED BIOFUEL CAPACITY
IN MILLIONS OF GALLONS/YEAR

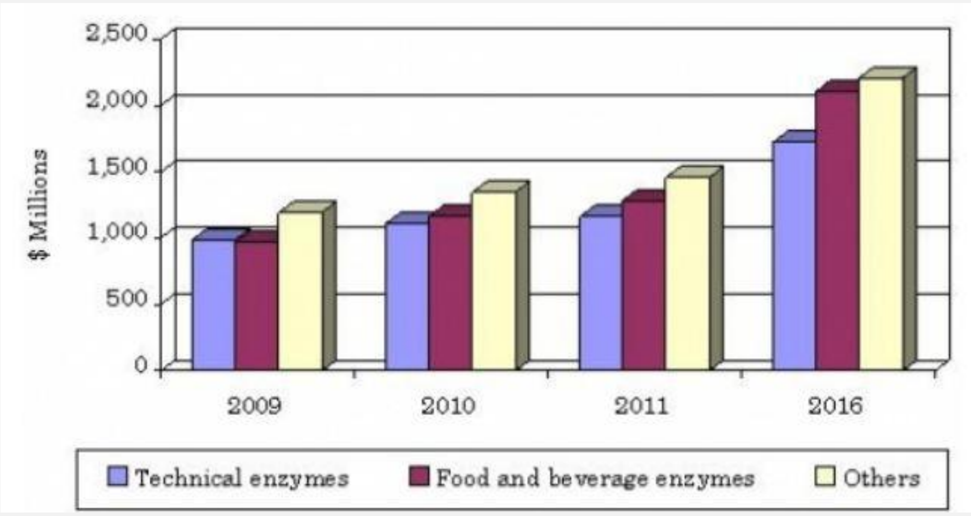
	# Companies		2012 Capacity		2015 Capacity	
	LOW	HIGH	LOW	HIGH	LOW	HIGH
Jet Fuel	1	6	0.1	0.1	23.1	150.0
Biodiesel	91	91	564.0	564.0	877.0	877.0
Butanol	1	4	19.0	19.5	56.0	370.5
Ethanol	24	35	14.2	14.2	337.2	512.2
Adv. Diesel	5	9	75.1	75.4	248.4	300.8
Adv. Gasoline	4	7	2.4	3.0	52.4	113.0
Fuel flexible	1	11	11.0	13.3	11.0	312.6
Biocrude	2	2	0	0	1.1	1.1
TOTAL	**129**	**165**	**685.8**	**689.6**	**1,606.2**	**2,637.2**

Source: Environmental entrepreneurs (2012)

Enzymes

The global market for industrial enzymes is forecasted to reach US$3.74 billion by the year 2015[14]. Important factors that are driving the market include new enzyme technologies endeavoring to enhance cost efficiencies and productivity, and growing interest in substituting petroleum-based products with products based on biomass. BCC projects the industrial enzymes market to grow to $6 billion by 2016[15]. Major growth is expected to be realized in the segment of food and beverage enzymes and technical enzymes (see Figure 3.10). Two segments with high growth potential are carbohydrases and lipases.

Figure 3.10: Global revenue of industrial enzymes market



Source: BCC Research (2011a)

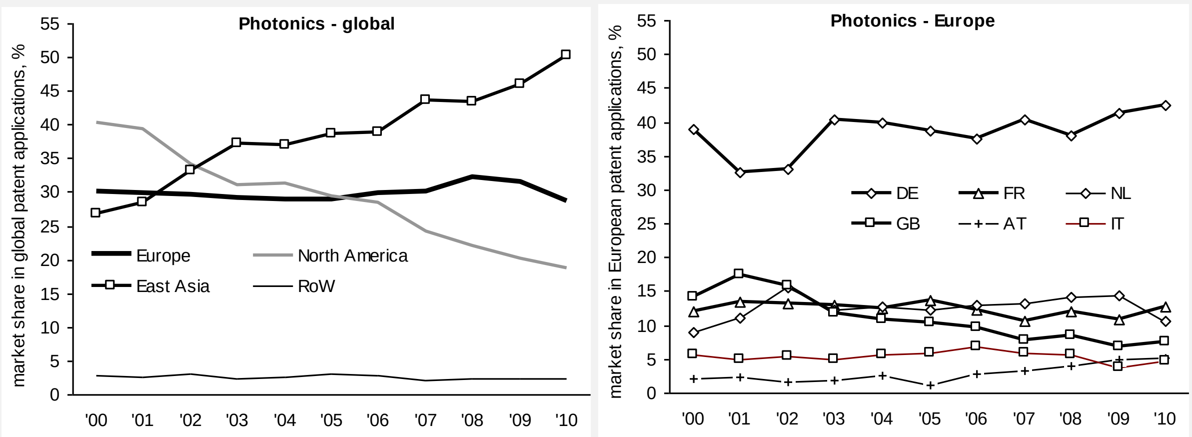
[14] http://www.prweb.com/releases/industrial_enzymes/proteases_carbohydrases/prweb8121185.htm
[15] http://www.bccresearch.com/report/enzymes-industrial-applications-markets-bio030g.html

3.4. PHOTONICS

3.4.1. Technology market share

Over the past ten years, East Asia gained significantly in technology market shares in the field of Photonics. Since 2003, East Asian organisations are the largest group of applicants of Photonics patents and were able to strengthen their position continuously, rising their market share from 27 percent in 2000 to 50 percent in 2010. North American applicants lost their leading position which they held in the early 2000s. Their market share fell from 40 percent (2000) to 19 percent in 2010. Europe did significantly better, its market share increased until 2008 when it reached 32 percent. In 2009 and 2010, Europe's contribution to photonics patenting went down, however, to 29 percent. Countries from outside the three main regions slightly lost market shares.

Figure 3.11: Market shares in international patents in the KET field of Photonics 2000-2010 (percent)



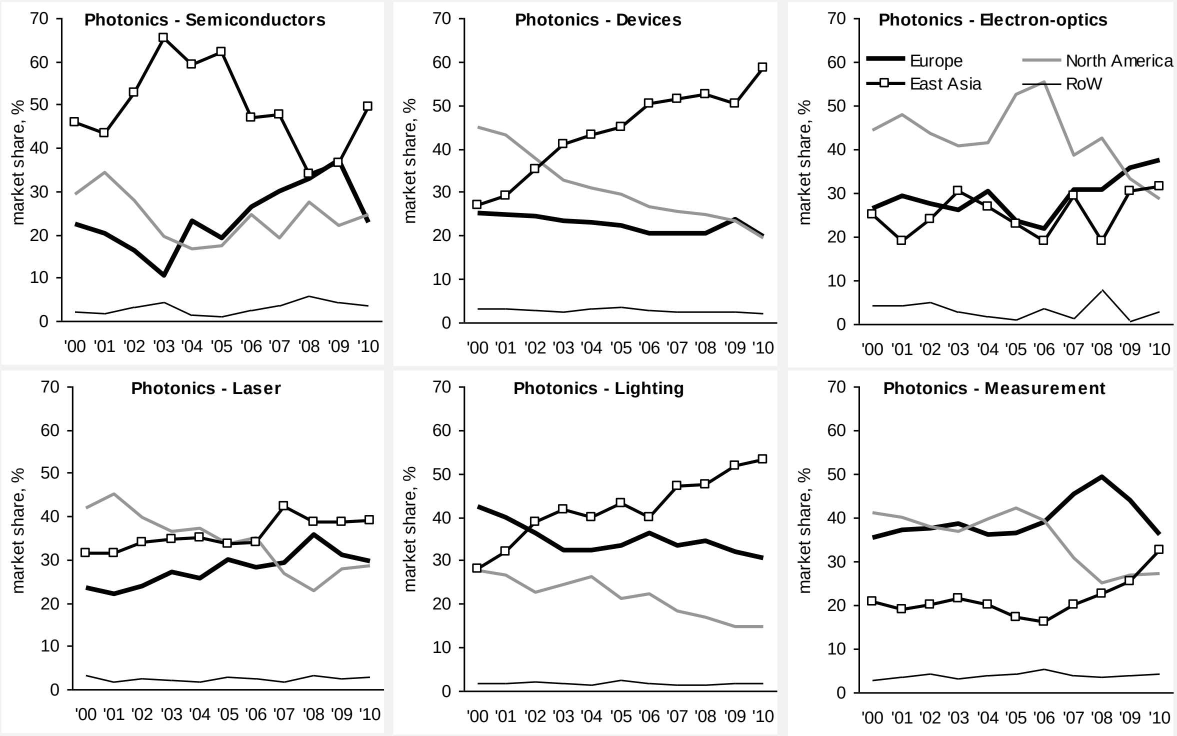
Source: EPO: Patstat, ZEW calculations

Changes in market shares in the field of Photonics took place against the background of an expanding patent activity. The total number of international patent applications grew from 2000 to 2010 by 25 percent, which is almost four times the rate for all KET patents, and equals the growth rate of patenting across all fields of technology.

Within Europe, Germany further strengthened its position as the main producer of new technological knowledge in photonics over the past decade. Its share in total European patent applications was 43 percent in 2010, compared to 33 percent in 2001/02. Among the other five main European applicant countries (as for 2010: France, the Netherlands, UK, Austria and Italy), the Netherlands and UK lost market shares while the France and Italy were able to hold their position within Europe. Austria recently increased patenting in photonics and replaced Switzerland from the top-6 patent producers in Europe.

The general trend in technology market shares in photonics can also be found in the two largest subfields, devices and lighting. The growing market share of East Asia and the strong loss in market shares of North America in the field of photonics devices took place against the background of declining patent activity in this subfield. In 2010, East Asia was clearly the leading region in this subfield of photonics patenting with a market share of 59 percent. Patenting in the field of lighting strongly increased over the past ten year in all three regions with largest growth rates reported for East Asia which held a share in global patenting of 53 percent. From 2003 to 2010, Europe was able to maintain a market share of about a third while North America further lost position. In the third largest subfield -laser- both Europe and East Asia slightly gained market shares at the expense of North America.

Figure 3.12: Market shares in international patents in the KET field of Photonics 2000-2010, by subfields (percent)



Source: EPO: Patstat, ZEW calculations

In the subfield of measuring applications, Europe is the leading patent producer since 2007, though its market share felt from 49 percent in 2008 to 36 percent in 2010. From 2007 onwards, East Asia is constantly increasing its patent output and overtook North America as second largest patent producer in this subfield in 2010. In the two smallest subfields in terms of the number of patent applicants -electron-optics and semiconductor applications- Europe improved its position in global technology markets over the past decade. In electron-optics, Europe holds the largest market share in 2010 (38 percent). One should note, however, that patenting activity in this subfield is strongly declining in all regions. In semiconductor applications, the opposite trend emerges, with increasing patent output in all regions, though at a still low absolute number of patents. In this subfield, Europe gained in market shares until 2009 primarily at the expense of East Asia, but patenting by European applicants strongly felt in 2010.

3.4.2. Market potential

The photonics industry is expected to grow strongly in the coming years. The global market for photonic components and systems is currently worth more than £250bn and is forecasted to exceed £400bn by 2017[16]. The European technology platform Photonics21 estimates the market size to reach €480 billion in 2015, including an estimated annual growth rate of 8 to 10%.

Solar photovoltaic

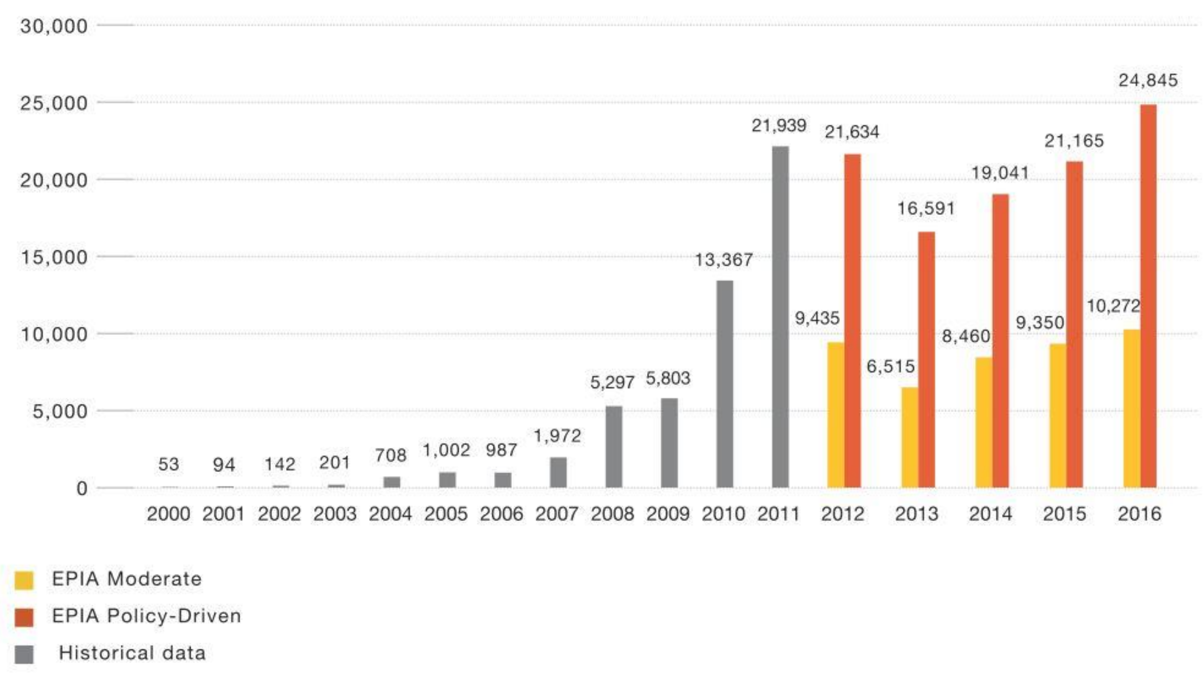
Solar photovoltaic (PV) is the third most important renewable energy in terms of globally installed capacity, following hydro and wind power. The growth rate of PV reached almost 70% in 2011, more than 69 GW have been installed globally which can produce 85 TWh of electricity per year[17]. In terms of global cumulative installed

[16] http://www.innovateuk.org/_assets/enablingtechnologies_strategywebfinal.pdf

[17] Global market outlook for photovoltaics until 2016, EPIA, May 2012

capacity, Europe leads the way with more than 51 GW installed as of 2011, the majority being located in Italy and Germany. This represents about 75% of the world's total PV cumulative capacity. Next in the ranking are Japan (5 GW) and the USA (4.4 GW), followed by China (3.1 GW) which reached its first GW in 2011[18]. Figure 3.13 and Figure 3.14 show projections for the solar PV market for two scenarios (pessimistic and optimistic) for the EU and the global annual market. As can be seen, in the EU the short term demand is not expected to reach the peak of 2011; however this situation is projected to improve in the coming years. At world level significant market growth is expected till 2016, illustrating the large untapped potential of many countries. The estimates at world level of the market research company IHS lie between the moderate and policy driven scenario projections, with an estimated installed capacity of about 55 GW in 2016[19].

Figure 3.13: European annual market scenarios until 2016

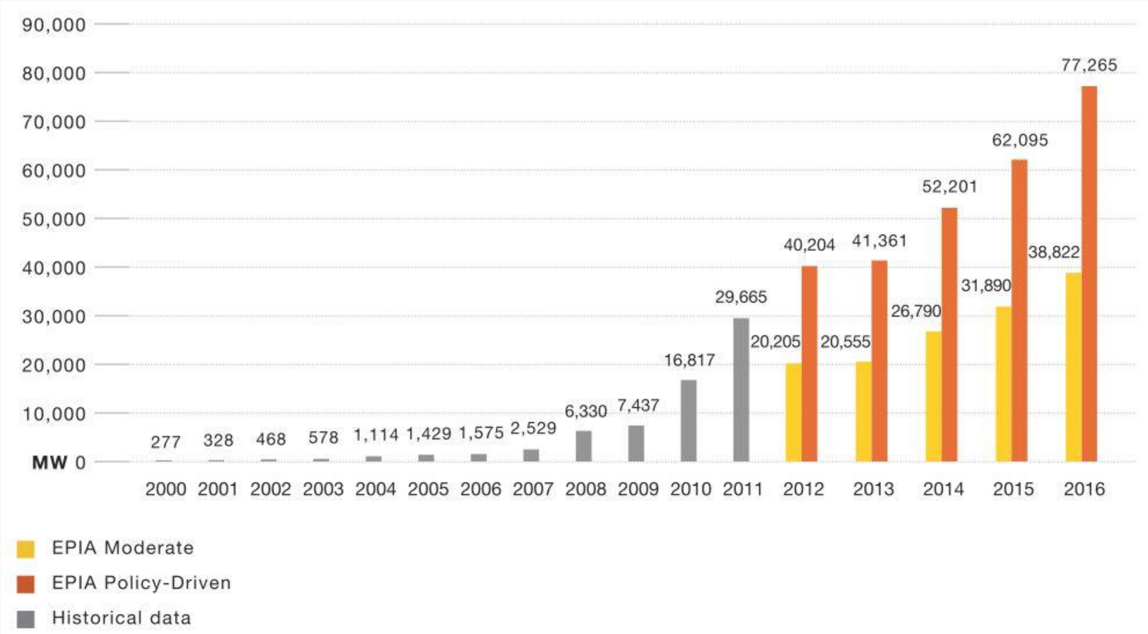


Source: Global market outlook for photovoltaics until 2016, EPIA, May 2012

[18] Global market outlook for photovoltaics until 2016, EPIA, May 2012

[19] http://cleantechnica.com/2013/02/05/solar-pv-installations-hit-32-gw-in-2012-35-gw-projected-for-2013-according-to-ihs/

Figure 3.14: Global annual market scenarios until 2016



Source: Global market outlook for photovoltaics until 2016, EPIA, May 2012

LEDs

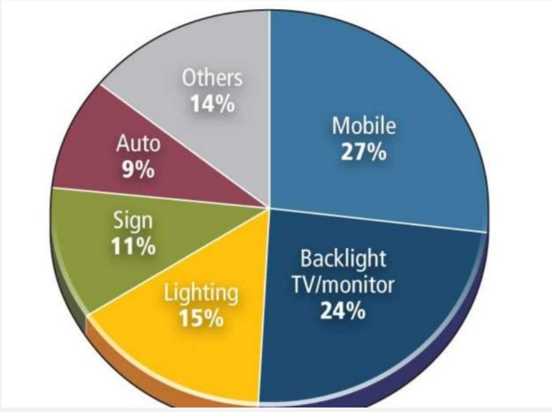
By 2020, LEDs are expected to take around 95% of the market share of light bulbs, which is currently estimated at €11 billion per annum[20]. The expected growth in the market demand for LEDs will be driven by product substitution rather than overall market growth[21]. Other application areas of LEDs are mobile applications including mobile phone, notebooks and tablets, TV and monitor backlights, sign and automotive lighting (see Figure 3.15). Japan accounts for the greatest portion of overall LED component revenues (30%) followed by Korea (26%), Taiwan and Southeast Asia (19%)[22].

[20] J.P. Morgan Cazenove, "Electrical engineering and semiconductor equipment: Winners and losers in a radically changing lighting market driven by LED", March 2010

[21] Photonics Technologies and Markets for a Low Carbon Economy

[22] http://ledsmagazine.com/features/9/3/2

Figure 3.15: Revenue from packaged LEDs by application in 2011

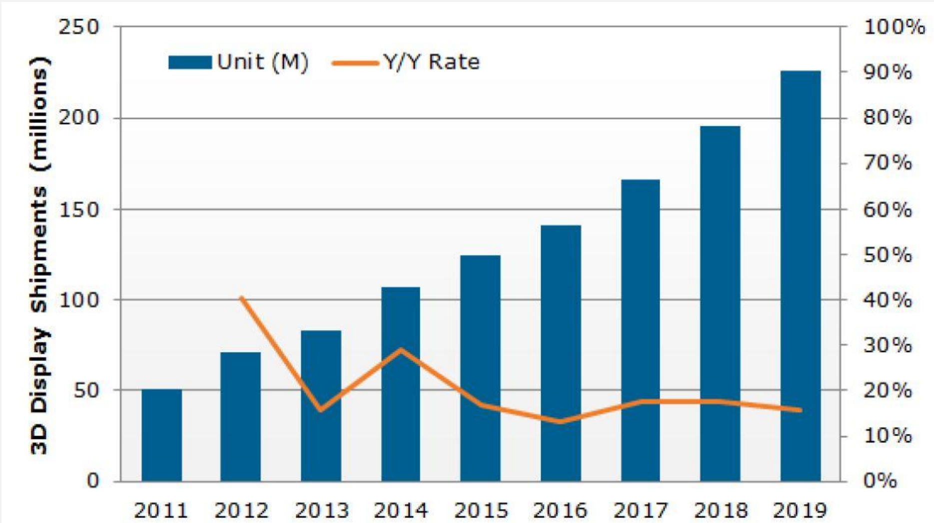


Source: http://ledsmagazine.com/features/9/3/2

Displays

The global display applications' market is expected to reach $164.244 billion by 2017 at an estimated CAGR of 3.1% from 2012 to 2017[23]. Conventional flat panel displays are increasingly taken over by the demand for flexible displays. Application areas for display are consumer electronics, home appliances, automotive, industrial and healthcare segments. The LCD dominated global display market was valued at over €90 billion in 2011[24]. The 3D display market is set to grow from 50.8 million units and $13.2 billion in revenue in 2011, to 226 million units and $67 billion in revenue in 2019 worldwide (see Figure 3.16). In the 3D display market, 3D televisions are expected to create the largest revenue stream with anticipated growth from 25 million units in 2011 to approximately 180 million units in 2019[25].

Figure 3.16: Shipment Forecast for 3D-ready Devices



Source: NPD DisplaySearch 2012 3D Display Technology and Market Forecast Report

[23] http://www.marketsandmarkets.com/Market-Reports/display-market-925.html

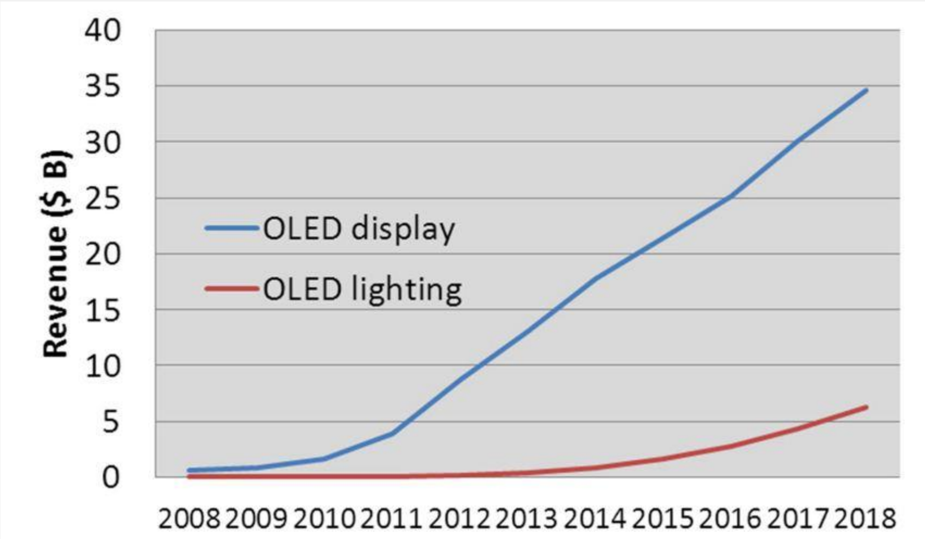
[24] Global TV trends in the flat panel display market, DisplaySearch, November 2010

[25] NPD DisplaySearch, 3D Display Technology and Market Forecast Report, 2012

OLED

The global OLED displays market is expected to reach $25.9 billion by 2018 from $4.9 billion in 2012 growing at a CAGR of 31.7% from 2012 to 2018[26]. Mobile phones are the largest end use application and accounted for 71% of the total OLED displays market in 2012, but the share of OLED TV displays are expected to surpass the shares of mobile phone displays by 2015. The current market for OLED lighting technologies is around $1 billion but this is expected to increase significantly over the next 5 to 10 years. Market values of over €$ billion are estimated for 2018[27]. The revenues from OLED displays are expected to be larger than OLED lighting; mounting up to $34 billion by 2018 (see Figure 3.17).

Figure 3.17: OLED display and lighting revenues



Source: DisplaySearch OLED Lighting in 2009 and Beyond: The Bright Future and Q1'12 Quarterly OLED Display Shipment and Forecast Report

Optical communication

The optical communication industry is experiencing a recovery from the economic downturn. In 2010 and 2011, the sales of data communication systems is picking up again. For 2010, growth estimates are put at 16%, 17%, 25%, and 22% for transceiver, Ethernet, Fibre Channel, and 10 Gbit/s DWDM transceiver modules, respectively[28]. The worldwide market for communications (telecom and datacom) lasers is estimated to be $1.95 billion for 2010 with 14.1% growth in 2011 to $2.22 billion[29]. While Europe is experiencing a decline in demand, the construction of optical communication is at its peak in China.

3.5. MICRO-/NANOELECTRONICS

3.5.1. Technology market share

East Asia is the largest producer of international micro-/nanoelectronics patents since 2002. Its market share is gradually increasing over time. In 2010, 56 percent of global patent output in this KET originated from East Asia. North America and Europe are both losing market shares. In 2010, North America reported a market share of 23

[26] OLED Displays Market - Global Industry Analysis, Market Size, Share, Growth And Forecast, 2012 – 2018, Transparency Market Research

[27] http://www.semiconwest.org/sites/semiconwest.org/files/docs/Jennifer%20Colgrove_Display%20Search.pdf

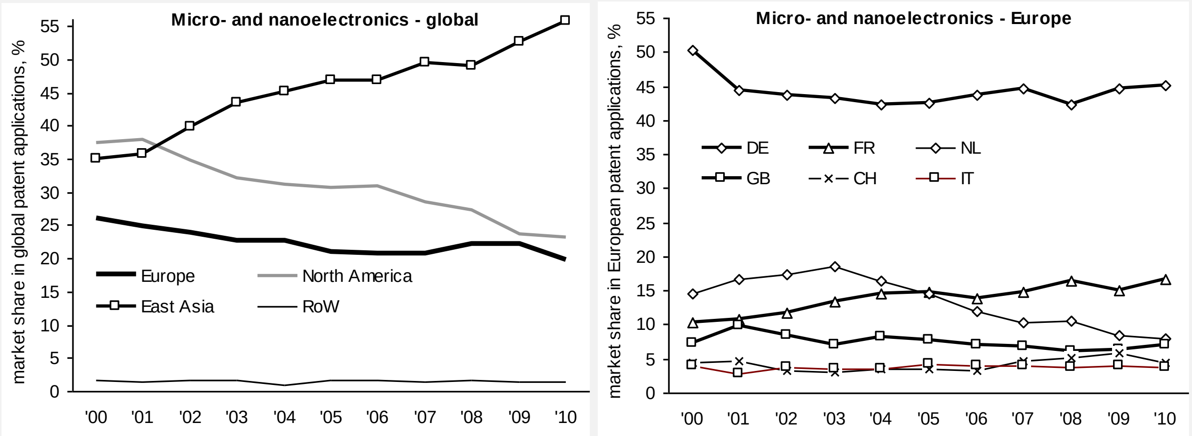
[28] http://www.lightcounting.com/news/092910.pdf

[29] http://www.laserfocusworld.com/articles/2011/01/annual-review-and-forecast-skies-may-be-clearing-but-fog-still-lingers.html

percent, while the figure for Europe was 20 percent. Countries from RoW are of no importance in the technology market for micro-/nanoelectronics, with a market share of 1 to 2 percent only.

Dynamics in micro-/nanoelectronics patenting are high. Global patent output grew by 35 percent from 2000 to 2010. The number of patent applications by European applicants in 2010 was 2 percent higher than in 2000, while applicants from North America reported a 17 percent lower figure for 2010 as compared to 2000. Dynamics are highest for East Asian countries which increased their patent output by 116 percent within a ten-year period.

Figure 3.18: Market shares in international patents in the KET field of Micro- and Nanoelectronics 2000-2010 (percent)

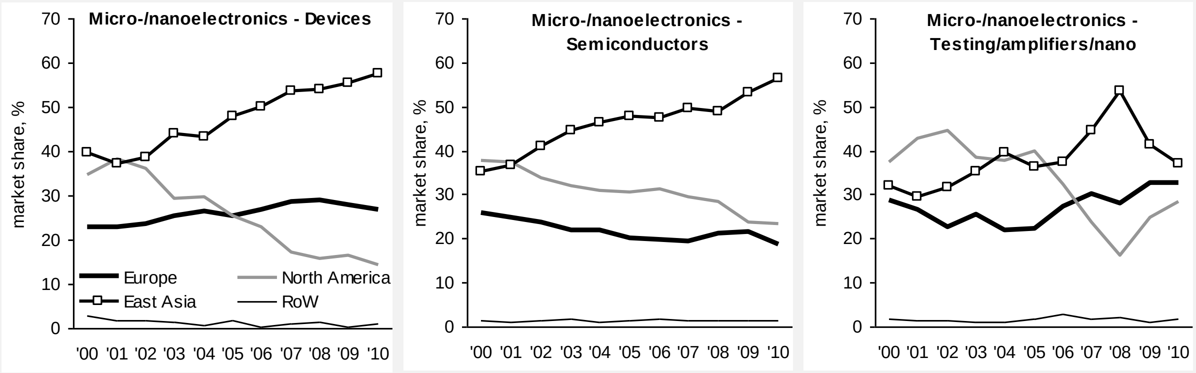


Source: EPO: Patstat, ZEW calculations

In Europe, Germany is clearly the largest patent producer in micro-/nanoelectronics and maintained a European market share of 42 to 45 percent throughout 2001 to 2010. France increased its European market share from 10 percent (2000) to 17 percent (2010) while the Netherlands lost position two in Europe. The Dutch market share within Europe declined from 19 percent in 2003 to 8 percent in 2010. The UK is the fourth largest producer of micro-/nanoelectronics patents in Europe, followed by Switzerland and Italy.

Patent statistics allow for a separation of micro-/nanoelectronics into three subfields, devices, semiconductors, and others, which primarily include testing applications, amplifiers and nanoelectronics. The largest subfield is semiconductors, and trends in market shares are very much the same as those for micro-/nanoelectronics in total. In the field of devices, North America shows a very strong decline in its market share over the past ten years and is now only third while Europe was able to increase its share in global patent output in this subfield. In the third subfield, trends are less clear. While East Asia increased its market share until 2008, it reported decreasing patent output in 2009 and 2010 (which is not due to an undercoverage of nanoelectronics patents but driven by patenting in the area of testing applications). Europe increased its market share in this subfield and now holds position two.

Figure 3.19: Market shares in international patents in the KET field of Micro- and Nanoelectronics 2000-2010, by subfields (percent)



Source: EPO: Patstat, ZEW calculations

3.5.2. Market potential

The global market for the semiconductor industry has increased significantly from $ 25 billion in 1985 to $299.5 billion in 2011[30]. This growth is driven by the increasing need for microelectronic devices and smart sensors in intelligent products, such as smart phones, tablets, car driver assistance systems, energy management systems, smart grid, networked sensors, etc. From a total investment of €28bn in microelectronics in 2007, only 10% was made in the EU compared to 48% in Asia. Europe's semiconductor market share has declined from 21% to 16% since 2000[31].

Since 2008, the worldwide production of semiconductors by region has remained relatively stable at 69% in Asia, 18% in America and 13% in Europe[32]. However, a production migration has taken place from Japan to South-eastern Asia. China is the largest market for semiconductors based on the concentration of major Electronic Manufacturing Services in Asia-Pacific.

After the economic crisis in 2009, the semiconductor market recovered quickly and global sales reached a record high in 2010. While billings fell by 11% from 2007's peak to 2009's trough, sales then recovered by a remarkable 33% from 2009 to 2010, a pace never before achieved which compensated more than previous losses[33]. PWC estimates the semiconductor market to grow with an average CAGR from 2010 to 2015 of 7.4% for the overall market.

The World Semiconductor Trade Statistics (WSTS) estimates that the world semiconductor market in 2012 will be $290 billion, down 3.2% from 2011, followed by a recovery of positive 4.5% growth to $303 billion in 2013 (Figure 3.20)[34]. Their forecast is at the low end compared to forecasts from other organizations (see Figure 3.21). Semiconductor Intelligence forecasts 7.5% in 2013 and 12% in 2014.

---

[30] Semiconductor Industry Association

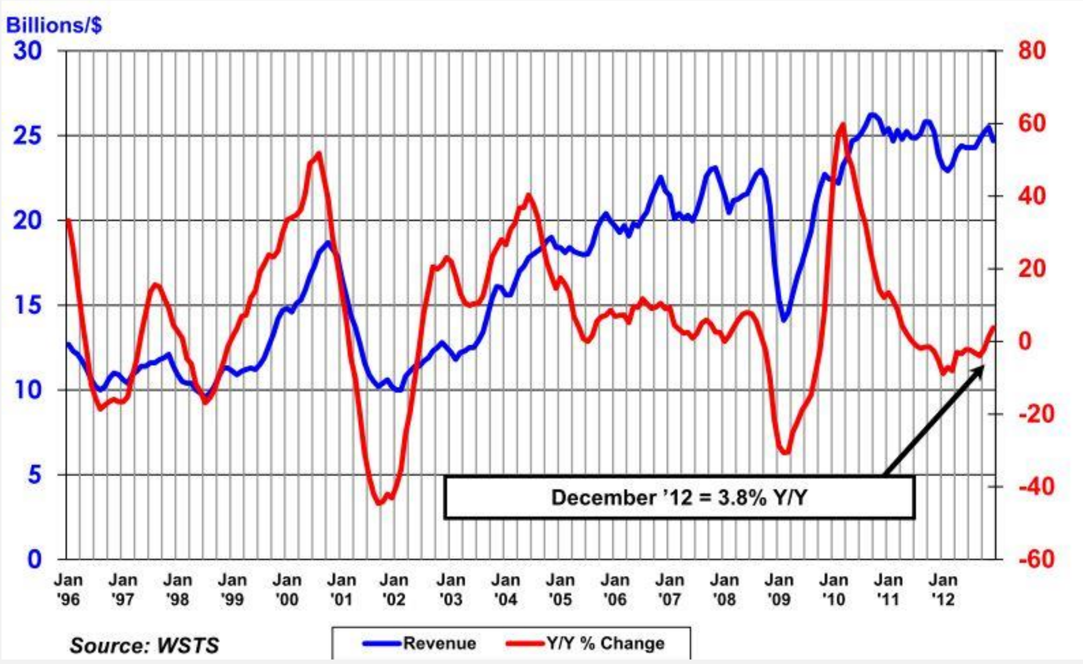
[31] http://www.silicon-europe.eu/

[32] Quebec's microelectronic industry directory 2012

[33] Faster, greener, smarter – reaching beyond the horizon in the world of semiconductors, PWC, 2012

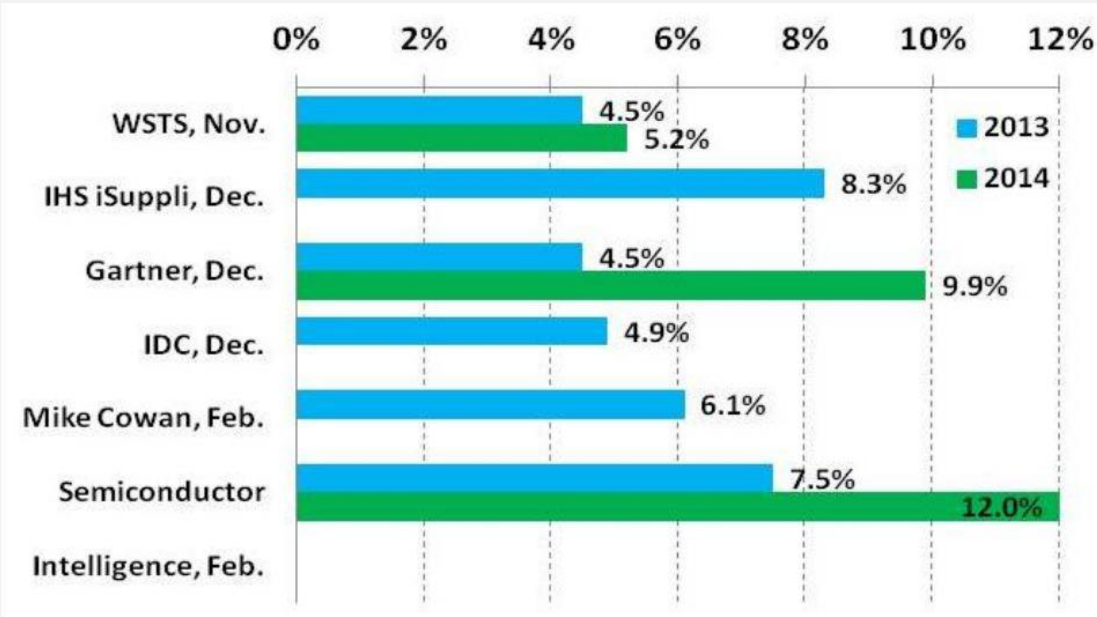
[34] WSTS forecast, November 2012

Figure 3.20: Worldwide semiconductor revenues



Source: http://www.semiconductors.org/clientuploads/GSR/December%202012%20GSR%20table%20and%20graph%20for%20press%20release.pdf

Figure 3.21: Semiconductor market forecasts



Source: http://www.semiconductorintelligence.com/

The semiconductor sector is linked to various application markets including data processing (including personal computers, laptops, servers and tablets); communications (including fixed-line telephone systems, broadband internet, mobile phones, smartphones and more); consumer electronics (television sets, music players, gaming consoles and household appliances); automotive (comprising both light vehicles and trucks); and industrial (including infrastructure, rail services, the military, fossil and regenerative energy, smart grids, etc.)[35]. The automotive and industrial application markets show the highest growth rates (Figure 3.22), while the consumer electronics market exhibit the lowest growth rate.

Figure 3.22: Growth rate of global semiconductor application markets

	CAGR 2009–2015	CAGR 2010–2015
Data processing	11.2%	6.9%
Communications	10.1%	7.0%
Consumer electronics	6.6%	3.3%
Automotive	20.0%	15.8%
Industrial	15.7%	8.9%
Total	11.3%	7.4%

Source: Faster, greener, smarter – reaching beyond the horizon in the world of semiconductors, PWC, 2012

Microprocessor

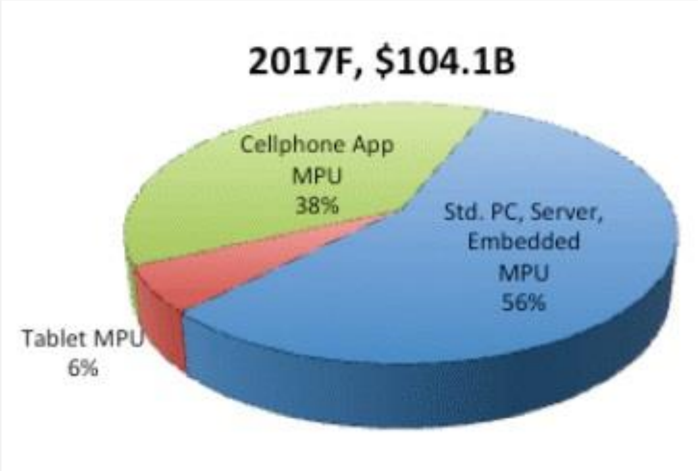
According to IC Insights, worldwide processor sales are expected to regain strength in 2013 and grow 12 percent to $65.3 billion after rising just 5 percent in 2012 to $58.2 billion. The slow growth in 2012 is attributed to weakness in the personal computer part of the market and global economic uncertainty[36]. The strongest growth is expected for microprocessor units (MPU) especially in the area of tablet computers and smartphones. Tablet processor sales are expected to grow 50 percent in 2013 to nearly $3.4 billion from about $2.3 billion in 2012, when revenues surged by 60 percent. Cell phone application processor sales are forecast to increase 28 percent in 2013 to $17.0 billion from $13.3 billion in 2012, when revenues climbed by 41 percent[37].

[35] Faster, greener, smarter – reaching beyond the horizon in the world of semiconductors, PWC, 2012

[36] http://www.eetimes.com/design/microcontroller-mcu/4405323/Processor-market-to-surf-tablet-wave-in-2013

[37] http://www.eetimes.com/design/microcontroller-mcu/4405323/Processor-market-to-surf-tablet-wave-in-2013

Figure 3.23: Global microprocessor sales by type



Source: IC Insights

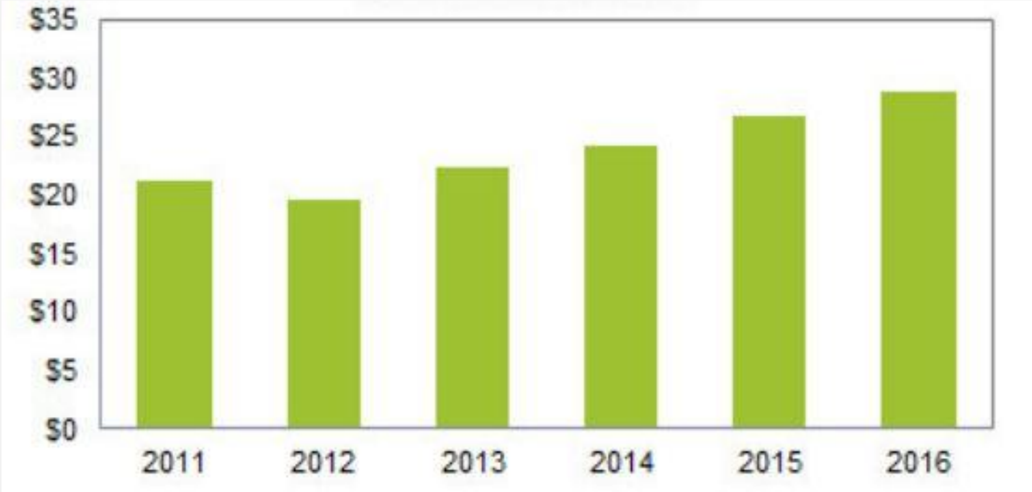
Computer memory

The total flash memory market will grow 2 percent to $30.4 billion by end 2012, while the DRAM market will decline from $31.2 billion to $28 billion, causing the flash memory market, including NAND and NOR, to surpass the DRAM market for the first time[38]. This is caused by the fact that DRAM is mostly used in PCs while flash memory is used in smartphones, media tablets, and other personal media devices (see also section 2.4.2). The flash memory market is expected to take over the lead from DRAM in the next five years. IC Insights forecasts NAND flash sales to increase 14 percent annually from 2012-2017, growing to $53.2 billion at the end of the forecast period, while the DRAM market is forecast to grow 9 percent over the same time[39].

More particular on the NAND flash memory market, it was indicated that the global NAND flash memory market revenue fell 7 percent in 2012 as disappointing Ultrabook sales negated the impact of surging demand from Apple Inc. for its iPhone line[40]. NAND industry revenue fell to $19.7 billion in 2012, down from $21.2 billion in 2011. Revenue, however, will pick up in 2013 and rise to $22.4 billion after last year's stumble, and then continue to expand during the next few years (see Figure 3.24). Apple's iPhone line in 2012 was the largest single consumer of NAND, helping to increase demand for the memory from the smartphone market due to its high-memory density, combined with high-volume shipments[41].

[38] http://www.digikey.com/supply-chain-hq/us/en/articles/semiconductors/flash-memory-market-surpasses-dram-for-the-first-time/1468
[39] http://www.digikey.com/supply-chain-hq/us/en/articles/semiconductors/flash-memory-market-surpasses-dram-for-the-first-time/1468
[40] IHS iSuppli Data Flash Market Tracker Report from information and analytics provider
[41] http://www.isuppli.com/Memory-and-Storage/News/Pages/Despite-Surging-Demand-from-Apple-NAND-Market-Contracts-in-2012-as-Ultrabooks-Disappoint.aspx

Figure 3.24: Worldwide NAND industry revenue forecast (in $ billions)



Source: IHS iSuppli Research, January 2013

MEMS

The Semiconductor Industry Association estimates the market for MEMS at $8 billion in 2011, demonstrating a grow rate of 15.5%, compared to 0.8% for the whole semiconductor market[42]. The MEMS industry saw double-digit growth in 2012, is valued at more than $10 billion, and is on track to double in market value by 2015[43]. The MEMS industry is expected to see a steady, sustainable double digit growth for the next six years, with 20% compound average annual growth in units and 13% growth in revenues, to become a $21 billion market by 2017 (see Figure 3.25). This growth will be realized through emerging MEMS devices and existing MEMS devices that will expand into new markets.

[42] Quebec's microelectronic industry directory 2012

[43] http://www.eetimes.com/electronics-news/4404150/MEMS--mics--and-impressive-growth

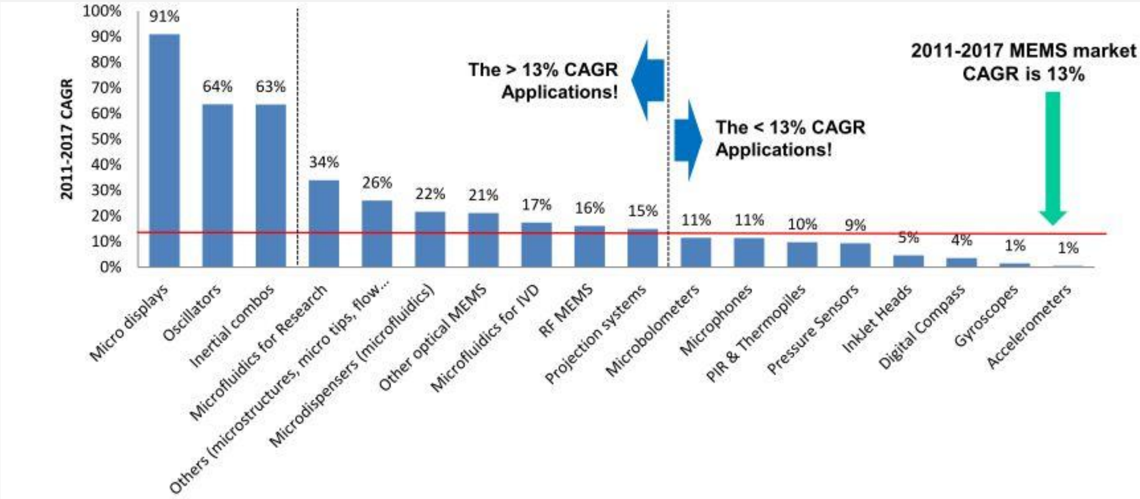
Figure 3.25: MEMS market forecast

Source: Yole Développement, (2012a)

The MEMS applications with the largest growth rate are micro displays, oscillators and inertial combos (see Figure 3.26). The global microdisplays market is expected to reach $995.0 million by 2016 from just about $250 million in 2011 at a CAGR of 31.82% from 2011 to 2016[44]. The use of these displays in the head mounted displays (used in the military and the medical field) will indirectly help the microdisplays market to increase. The market size of crystal oscillators in 2013 is expected to be $2,033.67 million and expected to reach $2,719.00 million by 2018, at an estimated CAGR of 6.0%[45]. In terms of volume, the unit shipments for crystal oscillators are expected to be 1544.74 million in 2013 and are forecast to reach 2,297.16 million by 2018, at an estimated CAGR of 8.3% from 2013 to 2018[46]. Inertial combos are expected to jump from very tiny volumes currently to penetrate some 40% of the $2.7 billion consumer inertial market and more than 12% of the $1.1 billion automotive inertial market by 2016[47].

[44] http://www.marketsandmarkets.com/Market-Reports/micro-displays-market-430.html
[45] http://www.prweb.com/releases/2013/2/prweb10465654.htm
[46] http://www.marketsandmarkets.com/PressReleases/crystal-oscillator.asp
[47] http://www.reuters.com/article/2012/02/08/idUS95947+08-Feb-2012+BW20120208

Figure 3.26: CAGR ranking by devices



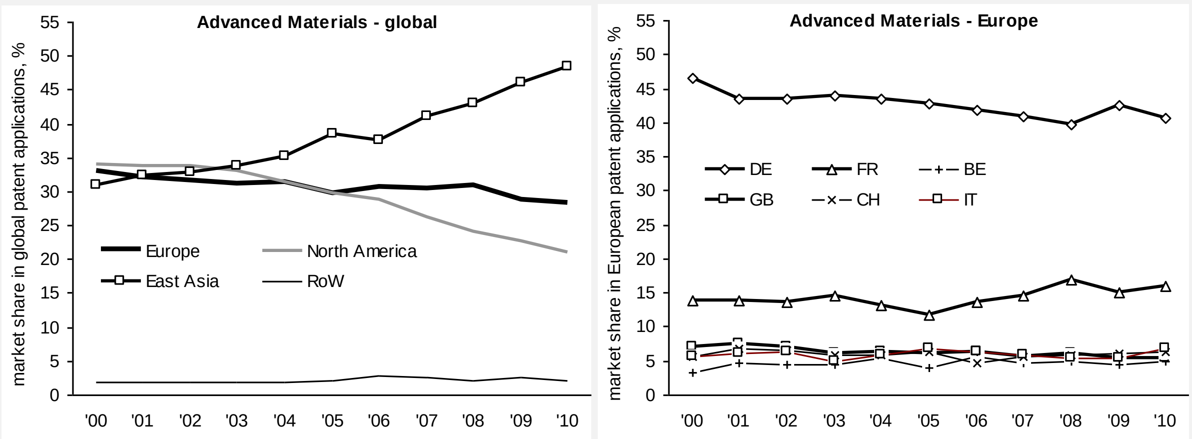
Source: Yole Développement (2012a)

3.6. ADVANCED MATERIALS

3.6.1. Technology market share

East Asia is constantly increasing its market share in international patenting in the field of advanced materials. In 2010, 48 percent of all advanced materials patents originated from East Asia, compared to 28 percent from Europe and 21 percent from North America. North America's market share is declining much faster than the European one. Changes in market shares emerged against the background of low patent dynamics in advanced materials. Global patent output felt by 4 percent between 2000 and 2010. In Europe and North America, the number of international patent applications in advanced materials is declining from year to year whereas patent output grew in East Asia (+51 percent) and the rest of the world.

Figure 3.27: Market shares in international patents in the KET field of Advanced Materials 2000-2010 (percent)

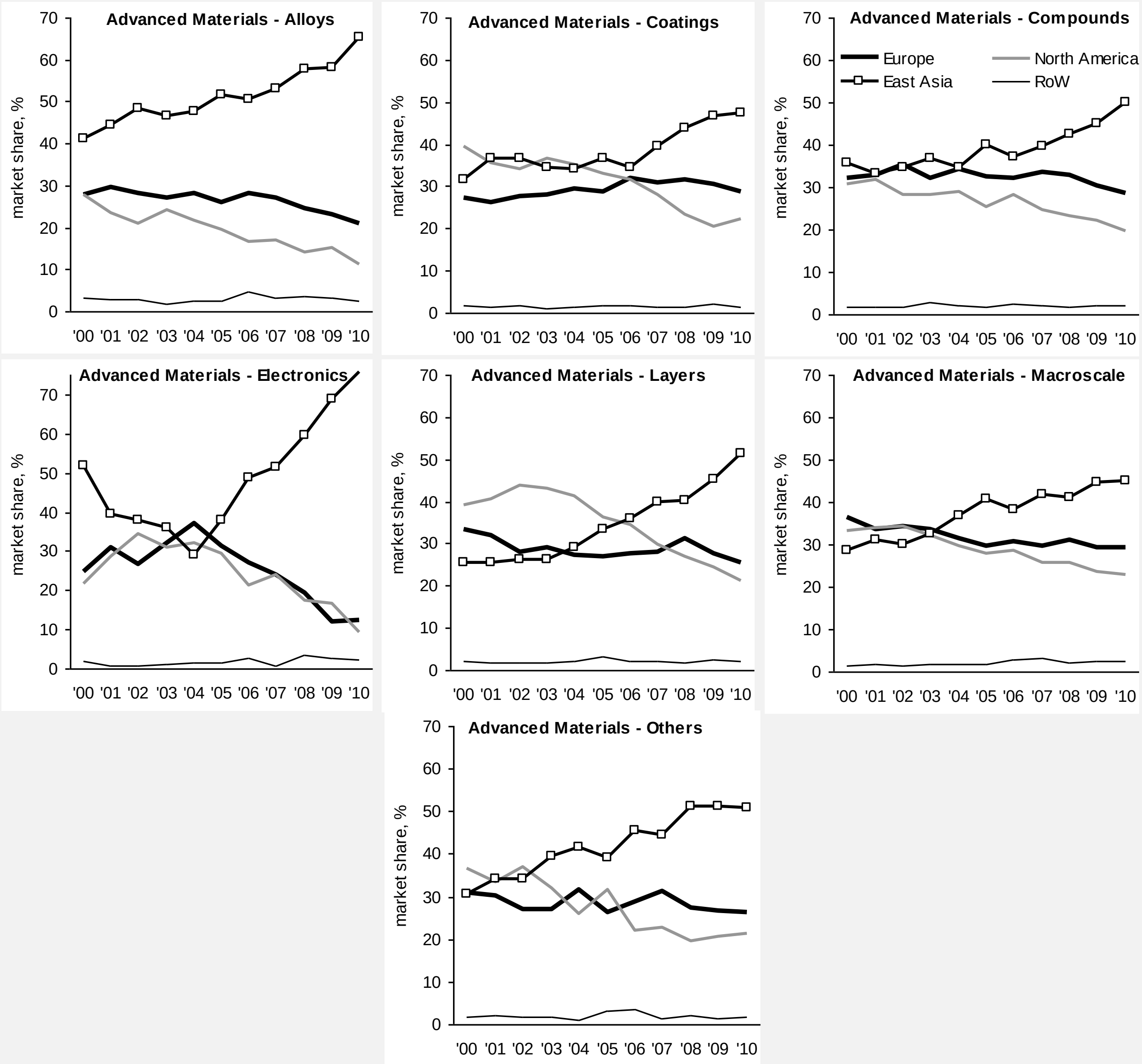


Source: EPO: Patstat, ZEW calculations

Within Europe, market shares of countries with the highest numbers of advanced materials patents are rather stable over time. Germany is still responsible for more than 40 percent of European patent output in this KET, followed by France (16 percent in 2010), Italy, Switzerland, the UK and Belgium. The Netherlands held rank three in advanced materials patenting in Europe until 2008, but decreased its patent activities considerably since then.

The main trends of regional market shares in advanced materials patenting can be found in all seven subfields. East Asia is gaining importance in each subfield, with the highest increases in market shares in the two smallest subfields, alloys and advanced materials for electronics. North America lost markets shares more rapidly than Europe and held position three among the three large regions in all six subfields by 2010. Europe reports falling market shares in the majority of subfields. In coatings, however, market shares in the second half of the 2000s were slightly above the level in the first half of the decade. In compounds and layers, losses in market shares by European applicants were rather modest.

Figure 3.28: Market shares in international patents in the KET field of Advanced Materials 2000-2010, by subfields (percent)



Source: EPO: Patstat, ZEW calculations

3.6.2. Market potential

Advanced materials tend to outperform other conventional materials with their superior properties such as toughness, hardness, durability and elasticity. The scope of advanced materials research is very broad in nature and so are its potential applications. While some advanced materials are already well known like polymers, metal alloys, ceramics, semiconductors, composites and biomaterials, other advanced materials like carbon nanomaterials, activated carbon, titanium, are becoming increasingly important[48].

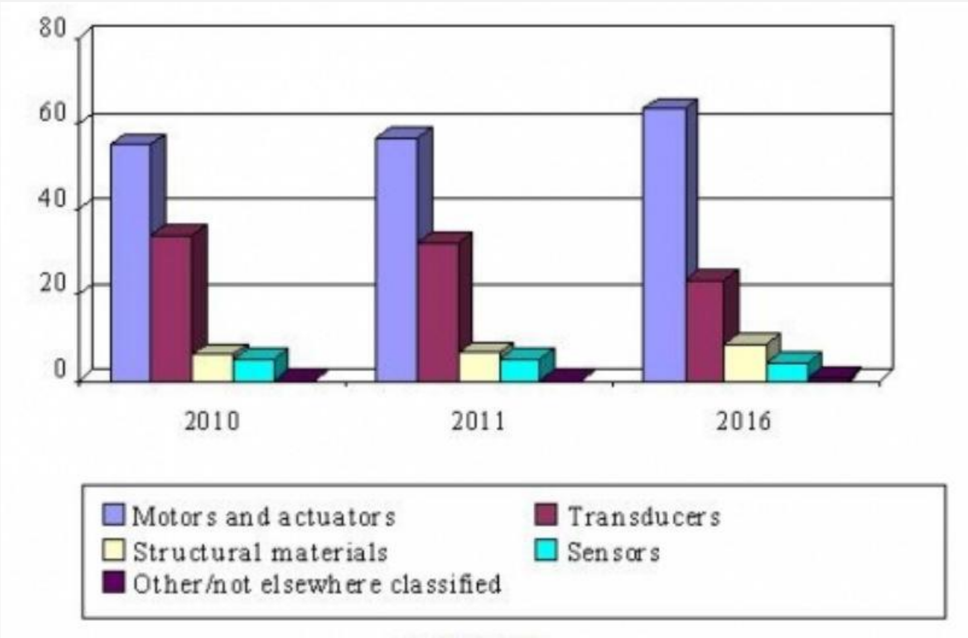
Smart materials

The 'smart' materials are a class of materials that respond dynamically to electrical, thermal, chemical, magnetic, or other stimuli from the environment. These materials are incorporated in a growing range of products, enabling these products to alter their characteristics or otherwise respond to external stimuli. The market for

[48] http://www.marketsandmarkets.com/advanced-material-market-research-12.html

these materials was estimated at about $19.6 billion in 2010 and it expected to approach $22 billion in 2011 and pass $40 billion by 2016, a compound annual growth rate (CAGR) of 12.8% between 2011 and 2016[49]. While smart materials can be used across a range of sectors, food and drink, healthcare and cosmetics together comprise 90% of the current market. In the submarket of food and beverages, MarketsandMarkets estimates the global market for active and smart packaging technology to grow to $23.474 million in 2015, at an estimated CAGR of 8.2% from 2010 to 2015[50]. Visiongain obtains a more conservative estimate and predicts the demand for active, intelligent and smart (AI&S) packaging to rise by around 8% per year to reach $17.23 billion by 2016 and by an average of 7.7% annually to be worth $24.65 billion by 2021[51]. They forecast the US to be the largest AI&S national packaging market to be worth $3.6 billion by 2021, followed by Japan ($2.36 billion) and Australia ($1.69 billion). In Europe, Germany is forecasts to be worth $1.4 billion, followed by the UK ($1.27 billion)[52].

Figure 3.29: Global market forecast for smart materials (% of total market)



Source: BCC Research (2012)

Advanced materials and devices used in renewable energy systems

The global market for advanced materials and devices used in renewable energy systems was $18.2 billion in 2010; it is projected to approach $22.3 billion in 2011 and it will further grow to $31.8 billion in 2016 increasing at a compound annual growth rate (CAGR) of 7.4%[53]. In 2010, emerging market countries consumed $876 million worth of advanced materials and devices used in the production of renewable energy systems. The market is projected to grow to $925 million in 2011 and nearly $1.3 billion in 2016, a CAGR of 6.9% over the next 5 years[54].

[49] http://www.bccresearch.com/report/smart-materials-technologies-markets-avm023d.html
[50] http://www.marketsandmarkets.com/PressReleases/smart-packaging-market.asp
[51] http://www.foodproductiondaily.com/Packaging/Global-market-for-active-and-intelligent-packaging-to-double-by-2021-report
[52] http://www.foodproductiondaily.com/Packaging/Global-market-for-active-and-intelligent-packaging-to-double-by-2021-report
[53] http://www.bccresearch.com/report/advanced-materials-devices-renewable-energy-egy053c.html
[54] http://www.environmental-expert.com/news/global-advanced-materials-and-devices-for-renewable-energy-market-356499/view-comments

Figure 3.30: Renewable energy consumption of advanced materials and devices by type (%)

Type of Material/Device	2010	2011	2016
Electromechanical and electronic devices	46.3	38.3	56.4
Photovoltaic materials and devices	46.1	54.2	31.1
Composites	5.7	5.9	9.3
Reflective materials	1.7	1.4	2.6
Other materials	0.2	0.2	0.6
Total	100.0	100.0	100.0

Source: BCC Research (2012)

Lightweight materials

Lightweight materials are increasingly being used in the transportation industry as reducing weight is one of the most important ways of reducing fuel consumption and improving the performance of transportation equipment. The total global consumption of lightweight materials used in transportation equipment was 46.7 million tons/$95.5 billion in 2010. This market is expected to reach 67.7 million tons/$125.3 billion by 2015, increasing at a compound annual growth rates (CAGRs) of 7.7% in tonnage terms and 5.6% in value terms between 2010 and 2015[55].

Value added materials

Value added materials (VAMs) are a group of advanced materials that have strategic importance for economic growth, industrial competitiveness and address the Grand Challenges of our times. Their market potential is estimated to be €1 trillion by 2050[56]. Figure 3.31 shows the market shares by sector, pointing to the importance of the environment and ICT sector. In the environmental-related markets for VAMs, growth will be driven by the energy-efficient technologies and the carbon capture technologies[57]. VAMs in the ICT sector are expected to grow substantially in the coming years with an average CAGR of 5%. Figure 3.32 gives an overview of the share of detailed materials markets in the ICT sector.

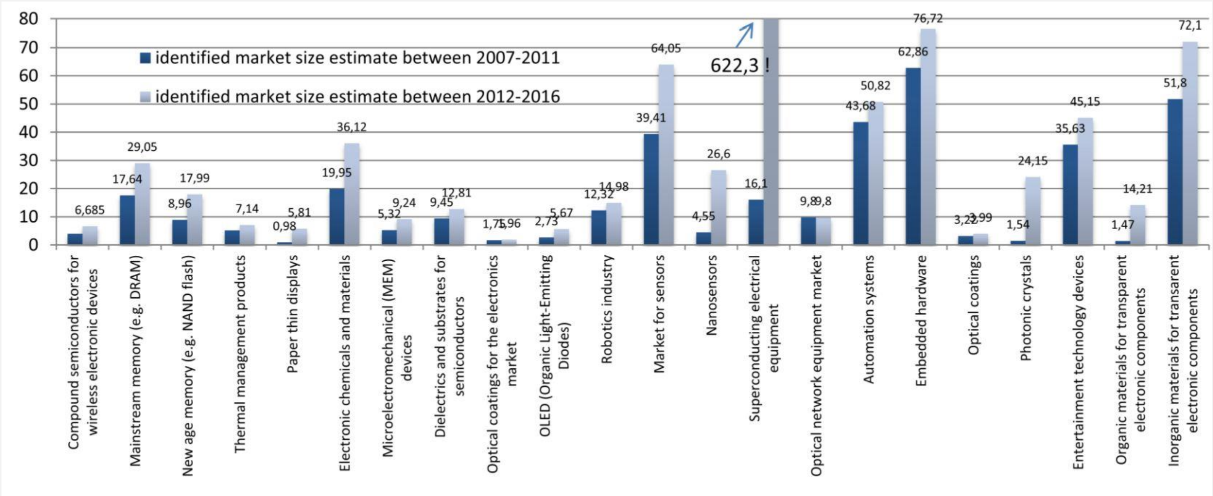
Figure 3.31: VAMs market share by sector

	2008	2015	2020	2030	2050
Energy	7,1	14,3	18,9	37,0	175,7
Transport	9,6	13,1	15,8	24,3	52,6
Environment	24,6	38,2	48,0	86,8	352,2
Health	27,0	32,1	37,4	55,0	115,2
ICT	29,6	38,8	46,6	70,7	152,2
Others / Cross-cutting	3,6	13,5	19,3	42,2	250,8
Total projected value of identified VAMs markets	**101,7**	**150,0**	**186,1**	**316,0**	**1098,6**

Source: Oxford research AS
Note: Unit= billion Euro.

55 http://www.bccresearch.com/report/lightweight-materials-ransportation-avm056b.html
56 Bridging the innovation gap for energy materials, EMIRI, 2012
57 http://ec.europa.eu/research/industrial_technologies/pdf/technology-market-perspective_en.pdf

Figure 3.32: ICT-related markets for VAMs



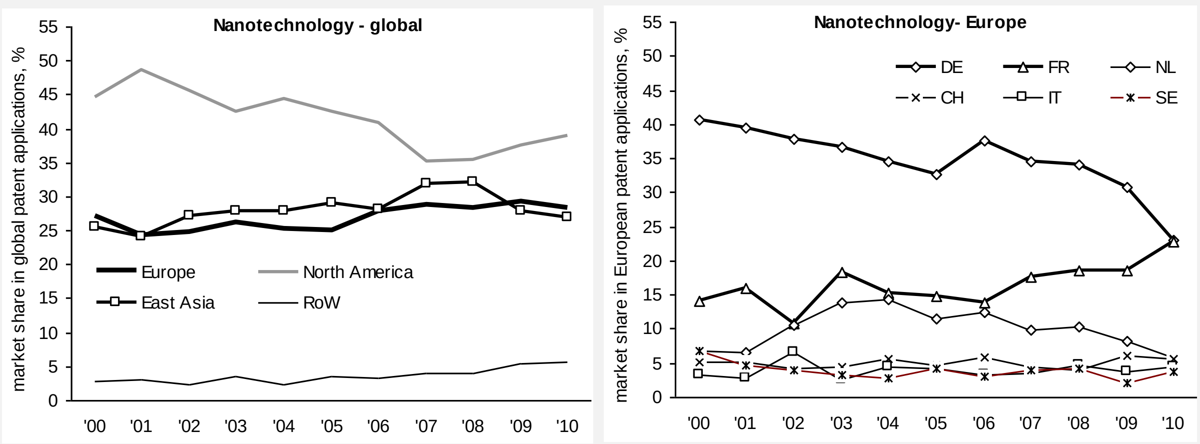
Source: Oxford Research AS

3.7. NANOTECHNOLOGY

3.7.1. Technology market share

Trends in technology market shares in the field of nanotechnology significantly diverge from the general trends in KETs patenting. North America is still the most important patent applicant, reporting a market share of 39 percent in 2010. While North America's market share in nanotechnology patenting was decreasing until 2007 (down to 35 percent), this trend changed in 2008. Europe and East Asia report a similar market share over the entire period. The East Asian contribution to total nanotechnology patenting was above that of Europe in most years within the past decade, though in recent years, Europe shows a slightly higher market share (2010: 28 percent; East Asia: 27 percent). The total number of nanotechnology patents grew by 31 percent between 2000 and 2010. All regions report growing nanotechnology patent output.

Figure 3.33: Market shares in international patents in the KET field of Nanotechnology 2000-2008 (percent)



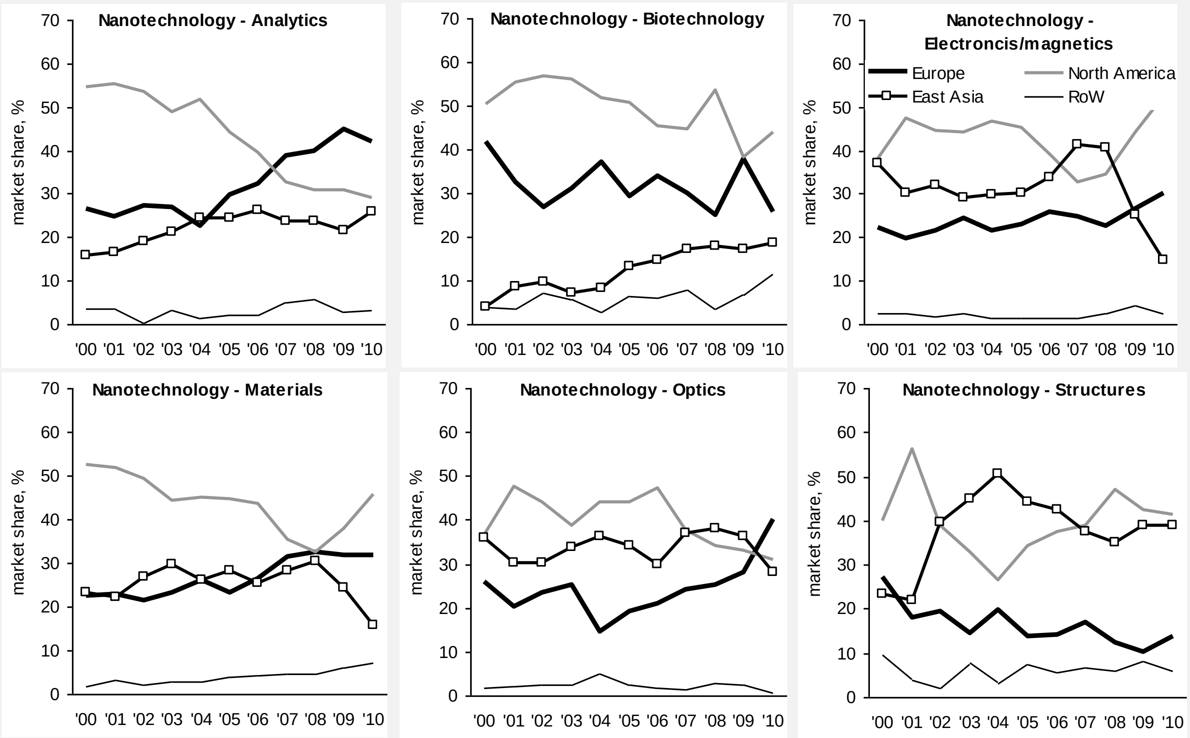
Source: EPO: Patstat, ZEW calculations

Within Europe, Germany lost market shares over the past decade, from 41 percent in 2000 to 23 percent in 2010. At the same time, France could substantially increase its nanotechnology patent output and gained market shares, catching-up to Germany in 2010. The market share of the Netherlands dropped from 14 percent in 2004 to 6 percent in 2010 while the UK was able to maintain its share in European patent production in nanotechnology at around 10 percent. Switzerland produced about 5 percent of European nanotechnology patents over the entire period. Italy recently increased its market share.

North America reports falling market shares in three subfields (nano-analytics, nano-biotechnology, nano-optics) and rather stable ones in the three other subfields (nano-materials, nano-electronics, nano-structures). Europe shows increasing market shares in nano-analytics, nano-electronics, nano-materials and nano-optics while its contribution to patenting is decreasing in nano-structures and rather stable in nano-biotechnology. In two subfields, nano-analytics and nano-optics, Europe is reporting the highest market share among the three regions. In nano-materials, Europe could catch-up to North America by 2008, but was not able to further increase its share in total patent output in this subfield in the two years following, while North America strongly increased its market share in this subfield in 2009 and 2010.

East-Asia is gaining market shares in only two subfields of nanotechnology, nano-analytics and nano-biotechnology. Still, in both subfields East Asia only holds position three among the three main regions. In nano-electronics, East Asia was the largest patent producing region in 2007 and 2008 but substantially reduced its patent output in 2009 and 2010, falling behind North America and Europe. In the subfield of nano-structures, the number of patent applications by East Asian organisations strongly increased in the early 2000s but stayed behind the dynamics in North America since 2005. East Asia's market share in the subfield of nano-materials clearly felt in 2009 and 2010 which may be associated with the falling patent output in nano-electronics. In nano-optics, market shares of East Asia are rather stable over time.

Figure 3.34: Market shares in international patents in the KET field of Nanotechnology 2000-2008, by subfields (percent)



Source: EPO: Patstat, ZEW calculations

3.7.2. Market potential

Nanotechnology has many applications in various industry segments like electronics, cosmetics and defense. The global market for nanotechnology was valued at nearly \$20.1 billion in 2011 and should reach \$20.7 billion in 2012[58]. Total sales are expected to reach \$48.9 billion in 2017 after increasing at a five-year compound annual growth rate (CAGR) of 18.7%.

The US is the most prominent market and accounted in 2011 for an estimated share of around 35% of the global nanotechnology market[59]. The US is expected to remain a major player although several developing economies such as, China, Korea, India, and Brazil have started to catch up. Table 3.1 provides an overview of the market potential for several nanotechnology applications.

[58] http://www.bccresearch.com/report/nanotechnology-market-applications-products-nan031e.html

[59] http://www.marketresearch.com/corporate/aboutus/press.asp?view=3&article=1944&g=1

Table 3.1 - Market potential of nanotechnology

Market/Product	*Current*	*Projected*	*CAPR*	*Source*
Nano Materials				
Nanomaterials, total	9 Bn. $ (2009)	20 Bn. $ (2015)	15 %	BCC 2010
Nanostructured metal oxids, metall powders, metall particles, nano tubes, macro molecules, quantum dots, mineralic nano materials	3,6 Mrd $ (2013)	34 Bn. $ (2025)	20 %	Freedonia 2010
Carbon Nano Tubes	167 Mio. $ (2010)	1 Bn. $ (2014)	56 %	BCC 2010
- SWCNT	1 Mio. $ (2010)	70 Mio. (2014)	189 %	
- MWCNT	161 Mio. $ (2010)	865 Mio. (2014)	52 %	
Polymer Nanocomposites	460 Mio. $ (2009)	1,4 Bn.$ (2014)	27 %	BCC 2010
- Nanoceramics filled composites	48 Mio. $ (2009)	145 Mio. $ (2014)	25 %	
- Nano-layer silicats composites	227 Mio. $ (2009)	692 Mio. $ (2014)	20 %	
- Other Nanopolymer composites (filler material CNT, metal nanoparticles, Nanobiocomposites)	185 Mio. $ (2009)	835 Mio. $ (2014)	35 %	
Nano adhesives (biomimetic adhesives, medical adhesives)	257 Mio. $ (2010)	1,2 Bn. $ (2015)	36 %	BCC 2010
Elektro-active polymeres (electroconductive polymere, organic conductors and semiconductors)	n.a.	2,8 Bn. $ (2014)	n.a.	MarketsandMarkets 2011
Metal oxide nano powder	2,9 Bn. $ (2009)	9,8 Bn. $ (2017)	16 %	Future Markets 2010
- Titan dioxide nano powder	360 Mio. $ (2009)	1,5 Bn. $ (2017)	20 %	Future Markets 2010
Nanocoat silicats (for fire protection and barrier for gas diffusion)	202 Mio. $ (2009)	291 Mio $ (2015)	6 %	Future Markets 2010
Aerogels	n.a.	1 Bn. $ (2015)	n.a.	Global Industry Analysts 2010
Quantum dots	67 Mio. $ (2010)	670 Mio. $ (2015)	59 %	BCC 2011
Metal colloides	200 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Gold bioconjugate	100 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Nano fibres	80 Mio. $ (2010)	334 Mio. $ (2017)	23 %	Future Markets 2010
UV hardening nanocomposite coatings varnishes	100 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Reactive nano films	2 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
long-time stable nano-optimised pating agents	100 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Nano Coatings				
Nano coatings total	3,6 Bn. $ (2010)	17,9 Bn. $ (2015)	38 %	BCC 2010

Market/Product	*Current*	*Projected*	*CAPR*	*Source*
Nano coatings total	2,4 Bn. $ (2009)	13 Bn. $ (2016)	27 %	Nanoposts.com 2010
Self-cleaning antibacterial nano coatings	764 Mio. $ (2010)	2,1 Bn. $ (2015)	22 %	Future Markets 2011
Anticorrosive nano coatings	352 Mio. $ (2010)	879 Mio. $ (2015)	20 %	Future Markets 2011
Antifog-Beschichtungen	300 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
photocatalytic coatings	1 Bn. € (2010)	n.a.	n.a.	VDI TZ 2011
photocatalytic coatings	848 Mio. $ (2009)	1,7 Bn. $ (2014)	14 %	BCC 2010
Controlled-released coatings and encapsulation	600 Mio. $ (2010)	1 Bn. $ (2015)	11 %	BCC 2010
Diamant-based coatings	905 Mio. $ (2010)	1,7 Bn. $ (2015)	13 %	BCC 2010
ceramic high-performance coatings (NAFTA only)	1,4 Bn. $ (2009)	2 Bn. $ (2014)	7 %	BCC 2010
- Thermic extruding	953 Mio. $ (2009)	1,4 Bn. $ (2014)	8 %	
- PVD	183 Mio. $ (2009)	260 Mio. $ (2014)	7 %	
- CVD	183 Mio. $ (2009)	220 Mio. $ (2014)	4 %	
- others (sol-gel)	75 Mio. $ (2009)	100 Mio. $ (2014)	6 %	
Sol-Gel-coatings für for textiles, metals, construction	50 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Nanoporose ant-ireflex coatings	400 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Nano analytikcs				
Microscopy total (optical, TEM, SEM)	1,7 Bn. $ (2009)	3,1 Bn. $ (2014)	13 %	BCC 2009
Microscopy euqipment	374 Mio. $ (2009)	513 Mio. $ (2014)	7 %	BCC 2009
Elecron microscopy	328 Mio $ (2010)	589 Mio. $ (2015)	12 %	Future Markets 2011
Nano structuring				
Equipment for wafer structuring	62 Bn. $ (2008)	90 Bn. $ (2014)	6 %	iRAP 2009
Nanotools (Nanomanipulators, near field optics, nano lithografy, nano imprint)	2,6 Bn. $ (2009)	6,8 Bn. $ (2015)	3 %	BCC 2010
PVD coating units	9 Bn. $ (2009)	14,8 Bn. $ (2014)	11 %	BCC 2010
MBE units	30 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Equipment for processing nano probes (reactive etching, SIMS, ion stream beating, FIB, CMP)	848 Mio. $ (2009)	1,2 Bn. $ (2015)	6 %	Future Markets 2010
Piezoelectric Actors and motors	6,6 Bn. $ (2009)	12,3 Bn. $ (2014)	13 %	iRAP 2010
- Nanometer precision actuators, positioning	3,2 Bn. $ (2009)	6 Bn. $ (2014)	13 %	

Market/Product	*Current*	*Projected*	*CAPR*	*Source*
- Cameras, microskopy lences/mirrors/optics	2,8 Bn. $ (2009)	5,2 Bn. $ (2014)	13 %	
- Other applications (fuel injection, micro pumps, printing cartridges, robotics)	587 Mio. $ (2009)	1,1 Bn. $ (2014)	13 %	
Health				
Nano-biotechnology applications in medicine (drug delivery, imaging, anti-microbiotics)	19,3 Bn. $ (2010)	29,7 Bn. $ (2015)	9 %	BCC 2011
Drug delivery technologies	n.a.	13 Bn. $ (2018)	n.a.	Espicom Business Intelligence 2009
- Established products (approved transporters such as liposomes, polymere particles, dendrimeres)	n.a.	10,2 Bn. $ (2018)	n.a.	
- New products (tissue specific, theranostics)	n.a.	2,8 Bn. $ (2018)	n.a.	
Nano coatings in medicine	115 Mio. $ (2010)	380 Mio $ (2015)	27 %	Future Markets 2010
Biochips (DNA, protein analyses, agent research)	2,6	6	18 %	BCC 2010
- DNA chips	1,3	2,7	15 %	
- Microfluidic chip labs	0,8	2,1	21 %	
- Protein chips	0,3	0,8	20 %	
- Newly developed biochips (glykomics, tissue analysis)	131	265	15 %	
Electronics				
Transparente elektronics	76,4 Bn. $ (2010)	123 Bn. $ (2015)	10 %	BCC 2010
- organic materials (organic semiconductors)	2,3 Bn. $ (2010)	20,1 Bn. $ (2015)	60 %	
- anorganic materials (ITO, mixed oxides, CNT)	74 Bn. $ (2010)	103 Bn. $ (2015)	7 %	
Semiconductor memories	46 Bn. $ (2009)	79 Bn. $ (2014)	11 %	BCC 2010
- DRAM	25 Bn. $ (2009)	41 Bn. $ (2014)	10 %	
- NAND Flash	13 Bn. $ (2009)	26 Bn. $ (2014)	15 %	
- Others (MRAM, PC-RAM, FeRAM, NRAM)	8 Bn. $ (2009)	12 Bn. $ (2014)	8 %	
Optics				
LED	5,1 Bn. $ (2009)	5,4 Bn. $ (2010)	6 %	Strategies unlimited 2010
Nano-photonic componentc (nano-LED, OLED, holographic memories, amplifiers, switches, photonic cristalls, plasmonics)	110 Mio. $ (2009)	3,6 Bn. $ (2014)	101 %	MarketsandMarkets.com 2009
Energie				
Nano-optimised batteries	169 Mio. $ (2009)	1,1 Bn. $ (2013)	46 %	iRAP 2009
Nano-optimised photovoltaic	68 Mio. $ (2010)	820 Mio. $ (2017)	43 %	Future Markets 2010
Nano-optimised fuel cells and hydrogen technology	2 Bn. $ (2008)	n.a.	n.a.	iRAP 2009

Market/Product	*Current*	*Projected*	*CAPR*	*Source*
Membran electrode units for fuel cells	600 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Supercondensers	275 Mio. $ (2009)	713 Mio. $ (2014)	21 %	iRAP 2010
Micro energy harvesting	80 Mio. $ (2009)	1,3 Bn. $ (2014)	74 %	iRAP 2010
Superconduction	2 Bn. $ (2010)	3,4 Bn. $ (2015)	11 %	BCC 2010
Superconduction in electrical engineering	23 Mio. $ (2010)	889 Mio. $ (2015)	107 %	
High-temperature superconductor wires	4 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Catalyser for electrical engineering	4 Bn. $ (2010)	6 Bn. $ (2015)	8 %	BCC 2010
Thermovoltaic cells	1 Bn. € (2010)	n.a.	n.a.	VDI TZ 2011
Membran electrode units for electroysis	50 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Environmental technologies				
Nanotechnology in environmental technologies, total	2 Bn. $ (2009)	21,8 Bn. $ (2014)	62 %	BCC 2009
Nanotechnology for water treatment	1,4 Bn. $ (2010)	2,2 Bn. $ (2015)	10 %	BCC 2010
- Nano and ultrafiltration membranes	1,4 Bn. $ (2010)	2,1 Bn. $ (2015)	9 %	
- Nanomaterial based membranes	45 Mio. $ (2010)	112 Mio. $ (2015)	20 %	
Ceramic filtering membranes	23 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Nano fibers fasern and non-wovens for technical filtration	100 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Nano optimised water filters	100 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
Catalysts for environmental technologies	12,3 Bn. $ (2010)	14,6 Bn. $ (2015)	6 %	BCC 2010
Packaging				
Nano-optimised packaing in pharmaceuticals	3,8 Bn. $ (2009)	8,1 Bn. $ (2014)	16 %	iRAP 2010
Nano-optimised packaing in food and beverages	4,2 Bn. $ (2009)	7,3 Bn. $ (2014)	12 %	iRAP 2009
Electronics in packaing (RFID, OLED, sensors)	n.a.	7,7 Bn. $ (2020)	n.a.	IDTechEx 2010
Nano-optimised paper production	3,2 Bn. $ (2010)	3,7 Bn. $ (2015)	3 %	BCC 2010
- Carbon nano tubes	8,3 Mio. $ (2010)	19,3 Mio. $ (2015)	18 %	
- Nano-layer silicates	1,9 Bn. $ (2010)	2,1 Bn. $ (2015)	2 %	
- Nano starch	600 Mio. $ (2010)	700 Mio. $ (2015)	3 %	
Construction				
Nano coatings in construction	130 Mio. $ (2010)	400 Mio. $ (2015)	21 %	Future Markets 2010

Market/Product	*Current*	*Projected*	*CAPR*	*Source*
Automotive				
Nano-optimized components and fabrics (e.g. polymer composites, sensors, batteries, ...)	246 Mio. $ (2010)	888 mio. $ (2015)	29 %	Future Markets 2010
Nanocoating in automotive applications (e.g. anti-corrosion, anti-bacterial, ...)	125 Mio. $ (2010)	310 Mio. $ (2015)	20 %	Future Markets 2011
Sensors				
MR sensor chips	100 Mio. $ (2010)	n.a.	n.a.	VDI TZ 2011
micro sensors	5,9 Bio. $ (2011)	12 Bio. $ (2016)	15 %	BCC 2011
- MEMS sensors	3,2 Bio. $ (2011)	6,5 Bio. $ (2016)	16 %	
- Nano sensors	6,5 Mio. $ (2011)	38 Mio. $ (2011)	43 %	
Textiles				
Nanosilver in textiles	50 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011
UV protection of textiles	10 Mio. € (2010)	n.a.	n.a.	VDI TZ 2011

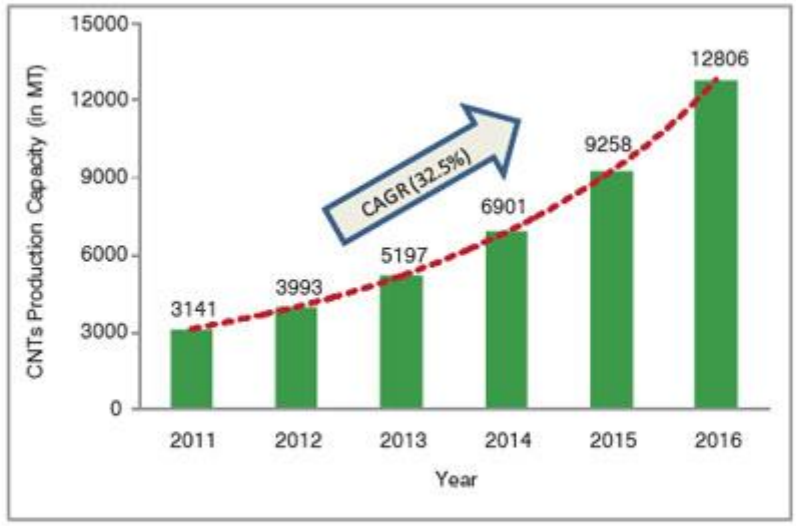
Source: Table was composed by Nano.DE-Report 2011

Carbon nanotubes

The global financial crisis has severely impacted the entire nanotechnology value chain, including nanointermediates, nanomaterials and nanocomposites[60]. In 2011, carbon nanotubes accounted for a 28% market share of overall nanomaterials demand[61]. In terms of production capacity, Asia-Pacific leads, followed by North America and the European Union. Carbon nanotubes witnessed a considerable decline during 2008-2009 but are taking up again. In addition, growing demand (particularly in Europe), advancements in manufacturing and purification methods, and commercialization of new products are expected to drive growth over the coming years. The global market for carbon nanotubes is forecast to reach $7.72 billion by the year 2015[62]. Other sources forecast the carbon nanotubes industry to grow to $1.1 billion by 2016 at a CAGR of 10.5%, expecting to production capacity to exceed 12.800 metric tons in 2016 (see Figure 3.35).

[60] http://www.prweb.com/releases/carbon_nanotubes/nanotechnology/prweb4482634.htm
[61] http://www.nanowerk.com/spotlight/spotid=23118.php
[62] http://www.prweb.com/releases/carbon_nanotubes/nanotechnology/prweb4482634.htm

Figure 3.35: Five years forecast for global carbon nanotubes market

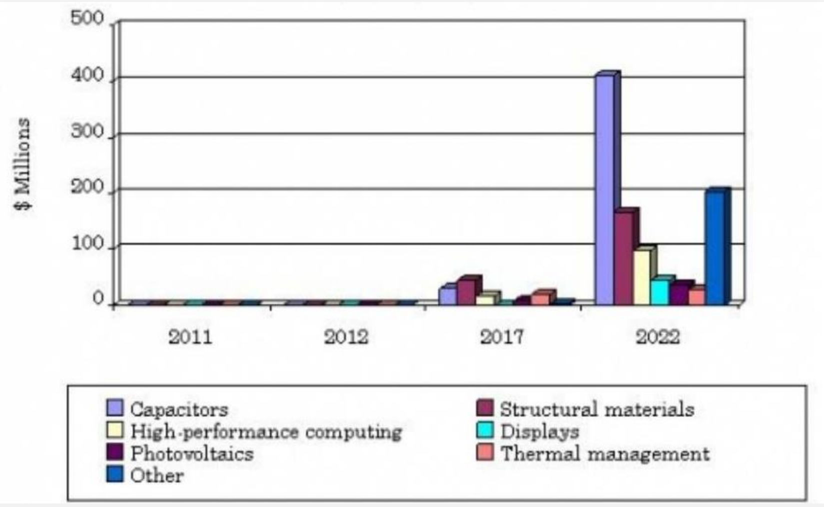


Source: Global carbon nanotubes market (forthcoming), Center for Knowledge Management of Nanoscience and Technology (CKMNT)

Graphene

The global market for graphene-based products is projected to reach $122.9 million in 2017 and $986.7 million in 2022, increasing at a five-year compound annual growth rate (CAGR) of 51.7% (Figure 3.36). The segment made up of capacitors is projected to be the largest segment in 2022. Capacitors are expected to increase from $31 million in value in 2017 to $410 million in 2022, a CAGR of 67.6%[63]. Others sources obtain a more conservative estimate of $100 million in 2018[64] or an annual growth of 40%, reaching $216 million in 2020[65].

Figure 3.36: Global market for graphene-based products ($ millions)



Source: BCC Research (2011b)

[63] http://www.bccresearch.com/report/graphene-technologies-applications-markets-avm075b.html

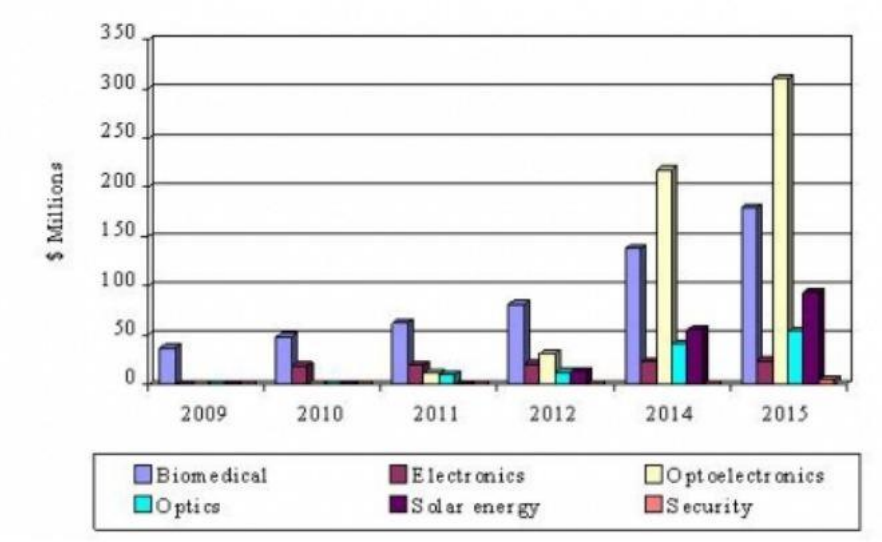
[64] http://www.electroiq.com/articles/sst/2012/11/idtechex-forecasts-a-usd100-million-graphene-market-in-2018.html

[65] http://www.luxresearchinc.com/news-and-events/press-releases/147.html

Quantum dots

The global market for Quantum Dots, which in 2010 is estimated to generate $67 million in revenues, is projected to grow over the next 5 years at a compound annual growth rate (CAGR) of 58.3%, reaching almost $670 million by 2015, representing a tenfold increase[66]. MarketsandMarkets estimate the total market for quantum dots to reach $7480.25 million by 2022, at a CAGR of 55.2% from 2012 to 2022[67]. The US has a leading position in the quantum dots technology market, followed by Europe and Asia-Pacific.

Figure 3.37 : Global market revenue for quantum dots in promising market sectors



Source: BCC Research (2011c)

[66] http://bccresearch.blogspot.be/2011/06/global-market-for-quantum-dots-to-grow.html
[67] http://www.prweb.com/releases/quantum-dots-qd/market/prweb9814298.htm

3.8. ADVANCED MANUFACTURING TECHNOLOGIES

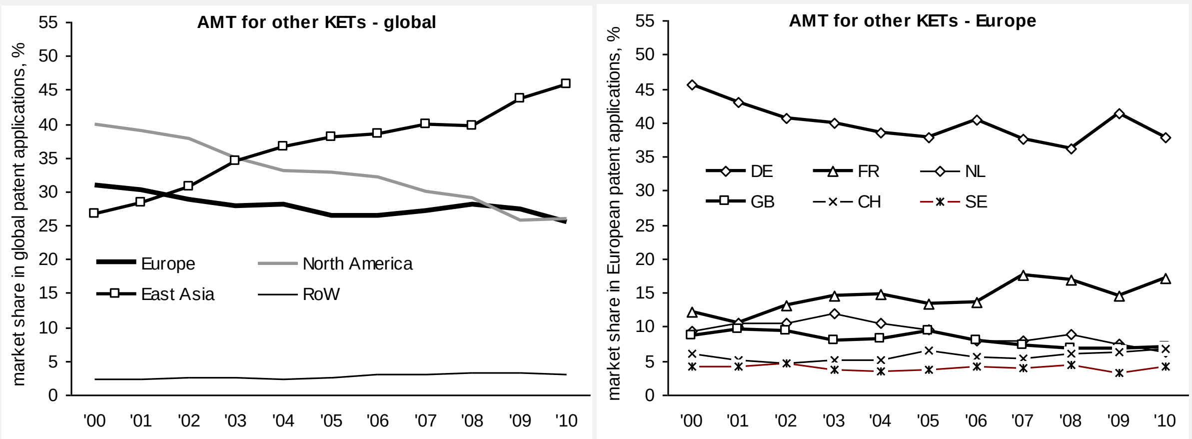
3.8.1. Technology market share

Trends in markets shares for AMT for other KETs are quite similar to those for micro-/nanoelectronics. and advanced materials since many patents classified as 'AMT for other KETs' patents relate to these two KETs (and a significant fraction of patents overlap between 'AMT for other KETs' on the one hand, and micro-/nanoelectronics. and advanced materials on the other). East Asia is producing the highest number of patents in the field of 'AMT for other KETs' (market share in 2010: 46 percent), while Europe and North America share position 2 (with about 25 percent each). North America's contribution to the global patent output in 'AMT for other KETs' felt stronger (from 40 percent in 2000) than Europe's share (2000: 31 percent). The RoW countries increased their market share marginally between 2000 and 2010, contributing 3 percent to global patent output in 2010.

Patent dynamics in this KET are low. The total number of international patent applications in 2010 was 9 percent below the 2000 figure. Declining patent output in Europe (-25 percent) and North America (-41 percent) are contrasted with significant increases in East Asia (+57 percent) and RoW (+11 percent).

In Europe, Germany lost market shares, but is still the largest patent producer in this KET, holding a European market share of 38 percent in 2010. France follows second, contributing 17 percent to European patent output in 'AMT for other KETs' in 2010. The Netherlands fell to rank 5, overtaken by the UK and Switzerland in 2010. Sweden was the sixth largest patent producer in Europe in this KET in 2010, ousting Italy to rank 7.

Figure 3.38: Market shares in international patents in the KET field of AMT for other KETs 2000-2010 (percent)

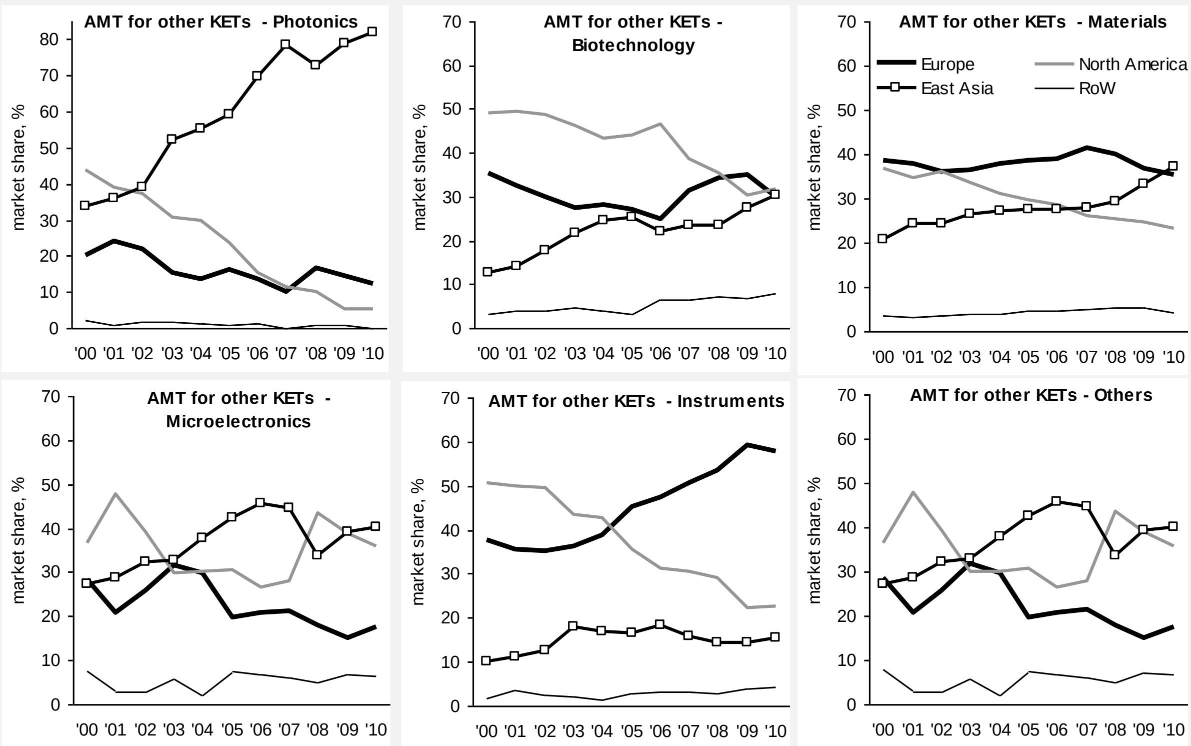


Source: EPO: Patstat, ZEW calculations

Most patents in 'AMT for other KETs' can be assigned to a subfield that is related to one of the other five KETs. There are also some patents, however, which represent a type of general purpose AMT and which can be used to produce different types of KETs or KET-based products. One group of these patents are classified in the subfield 'instruments' which includes technology for scientific instruments. Another group relates to controlling technology. This group is merged with the very small group of AMT patents related to nanotechnology into the subfield 'others'. The market share increase of East Asia in 'AMT for other KETs' is primarily due to the subfields of photonics, microelectronics and materials. In all three subfields, East Asian applicants hold the largest market share by 2010 and increased its contribution to global patent output significantly. In the subfields of photonics, more than 80 percent of all EPO/PCT patents in 2010 originated from East Asia. North American applicants, who had the highest market share in 2000/01 with more than 40 percent, contributed only 5 percent to total patenting in 2010. Europe could maintain its low market share at around 15 percent. In the subfield of microelectronics, North American did not lose ground at the same pace and are still ahead of Europe. In advanced materials, Europe had the highest market share until 2009 but was overtaken by East Asia in 2010.

Trends are somewhat different in the subfield of biotechnology. Europe reports a stable market share of about 35 percent, though this figure recently felt to 30 percent in 2010. North America shows a declining market share while East Asia has been catching up. In 2010, the three main regions had similar market shares of around 30 percent. The RoW contributed 10 percent to global patent output and show an upwards trend. The three most important countries in this group are India, Israel and Australia. A completely different picture emerges for the subfield 'instruments'. Here, Europe is clearly the leading producer of patents and could increase its market share, substantially from 35 percent in 2002 to 58 percent in 2010. East Asian applicants are not very active in this subfield and do not show an upwards trend for their market share. In the 'other' subfield, annual fluctuation in market shares is high due to a low absolute number of patents. The general trend suggests increasing market shares for East Asia at the expense of Europe while North America could maintain its share.

Figure 3.39: Market shares in international patents in the KET field of AMT for other KETs 2000-2010, by subfields (percent)



Source: EPO: Patstat, ZEW calculations

3.8.2. Market potential

Manufacturing is an essential step to bring technological innovations to the market. Most products and services have a manufacturing process behind it. The global manufacturing economy is estimated to be £6.5 trillion[68]. In the 2013 Global Manufacturing Competitiveness Index, China was found to be the most competitive manufacturing nation, followed by Germany, the US, India and South Korea. Five years from now, the report predicts China to maintain the first ranking, followed by India, Brazil, Germany and the US[69]. It is not straightforward to find detailed information on market estimates for advanced manufacturing technologies as they have many applications in multiple industries.

[68] A landscape for the future of high value manufacturing in the UK, Technology Strategy Board, 2012

[69] Global manufacturing competitiveness index 2013, Deloitte

Additive manufacturing

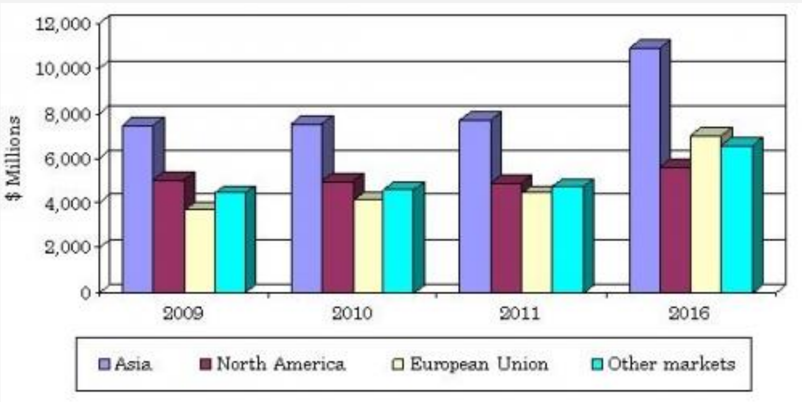
Additive manufacturing is a layer-by-layer technique of producing three-dimensional (3D) objects directly from a digital model. With markets including prototyping, tooling, direct part manufacturing, and maintenance and repair, the industry has grown significantly to $1.3B of materials, equipment, and services in 2010[70]. The additive manufacturing market, including consumer products, business machines, medical, and aerospace industries, is expected to grow at a CAGR of 13.5% from 2012 to 2017 to reach $3,471.9 million by 2017[71]. Other sources estimate additive manufacturing to reach $3.1 billion worldwide by 2016 and $5.2 billion by 2020[72].

Robotics

In 2011, BBC Research estimated the global market for robots and robot-related products to grow to nearly $22 billion in 2011 and $30 billion by 2016, a compound annual growth rate (CAGR) of 6.7% between 2011 and 2016 (see Figure 3.40). In their recent report published in February 2013, they forecast that this value will rise at a five-year compound annual growth rate (CAGR) of 5.9% between 2013 and 2018, when it's expected to surpass $29 billion. The Asian market is expected to demonstrate the largest growth in the coming years, while growth in the European Union is anticipated to be concentrated in the latter part of the forecast period, when robotic development initiatives now being undertaken on an EU-wide basis will result in commercialized products[73].

The industrial robotics market was worth $8.5 billion in 2011. Asia is leading the market with a market share of 56%, while Europe represents almost 1/3 of the global industrial robotics market[74]. The US is catching up as the Obama administration supports the automation & robotics industry. In the service robotics market, the market value reached $3.6 billion in 2011 for professional use and $0.636 billion for personal use. Europe is a major player in the professional service robotics market.

Figure 3.40: Demand for robots



Source: BCC Research (2011d)

3.9. CONCLUSION

The analysis of market shares in technology markets for KETs revealed a steady strengthening of East Asia as the main producer of new technological knowledge in KETs. In the past ten years, East Asian organisations increased their share in total patent activity in each of the six KETs. In four KETs -photonics, advanced materials, micro-/nanoelectronics, AMT for other KETs- East Asia was the most important patent producer by 2010. At the

70 Additive Manufacturing: Status and Opportunities, IDA, 2012

71 http://www.prweb.com/releases/additive-manufacturing/medical-devices-market/prweb10291367.htm

72 http://www.forbes.com/sites/tjmccue/2012/03/27/3d-printing-industry-will-reach-3-1-billion-worldwide-by-2016/

73 http://www.digitalmanufacturingreport.com/dmr/2013-03-01/bbc_research:_robotics_market_to_top_$29b_in_2018.html

74 Robotics in Europe, INNOECHO, March 2013

beginning of the 2000s, North America held the leading position in all six KETs. Industrial biotechnology and nanotechnology are the only two KET areas that still show North America as the region with the largest market share by 2010. While North America lost market shares in all six KETs, Europe performed relatively better. In Photonics and nanotechnology, European market shares stayed stable during the past decade. In the other four KETs, losses in market shares were less severe compared to North America.

One should note that trends in KET patenting are very similar to the overall trend in international patenting which shows an increasing share of East Asia and a declining contribution by North America while Europe reports moderate losses in market shares. The main difference with respect to KETs is the higher pace of market share gains by East Asia, resulting in a leading position of this region. For overall international patenting, Europe still held the highest market share in 2010.

Within Europe, Germany and France were the main producers of KET patents in 2010 in each of the six KETs. While Germany maintained its dominating position during the past ten years, France increased its market share within Europe in all six KETs. The UK and the Netherlands both show decreasing market shares.

A more disaggregated analysis at the level of subfields within each KETs reveals that Europe is leading KET patenting in some subfields and was able to gain market shares. In Photonics, European strengths are in the fields of measurement and electron-optics as well as lasers. In nanotechnology, Europe is the leading patent producer in nano-analytics and has increased its market share in nano-materials. In micro- and nanoelectronics, Europe could maintain its market share in the field of devices and shows an increasing market share in the small area of testing and amplifiers. In AMT for other KETs, Europe has a very high market share in the subfield of instruments and was able to maintain its share in the global technology output of AMT for biotechnology and materials production.

The analysis of the market potential of KETs reveals that substantial growth is expected in all six KETs in the coming years. Depending upon the particular KET, growth potential of 10 to 20% is expected in the coming years. For particular submarkets, the growth potential is even larger. The position of Europe with regard to market size differs for the various KETs, but in general the increasing importance of Asia and the higher pace of market share gains can also be witnessed here.

CHAPTER 4. VALUE CHAIN ANALYSIS OF KETS-BASED PRODUCTS

4.1. INTRODUCTION

In this chapter, the value chain of two promising KETs-based products is analysed and discussed. First, a motivation is provided for the selection of these two particular KETs-based products, namely the lipase enzymes and the accelerometer. Next, a more detailed analysis of the value chain of lipase enzymes and the accelerometer is provided. The information and analyses given are based on expert interviews, articles, new sites and market estimation reports. The methodology used to analyse the value chain is the same methodology as adopted in the feasibility study for an EU monitoring mechanism on KETs.[75] The analysis points out that EU firms play an important role in essential parts of the value chain although the exact proportions of value added captured by EU firms could not be retrieved[76].

4.2. SELECTION OF KETS-BASED PRODUCTS FOR VALUE CHAIN ANALYSIS

The results of the literature review are used to support the choice for the two KETs-based products that will be the subject of the value chain analysis in this chapter. Various Communications and reports published by the European Commission in order to select a KETs-based product have been consulted as well. A KETs-based product in two different KETs has been chosen, in order to illustrate the value chain decomposition for two different KETs.

The economic importance and growth potential of the particular KETs-based product has been the main selection criterion. In addition, for the selection at the product level, it was taken into account whether a given product constitutes a relatively new application versus being well established. The value chain analysis aims to focus on upcoming products that are driven by technological innovation, as to analyse how the EU performs in developing and marketing new high technology products in the KETs area and how EU future policy can support this process further. The final selection resulted in the choice of enzyme class lipases in industrial biotechnology and the accelerometer in micro- and nanotechnology.

In the next paragraphs, the selection process is described in more detail (see also Figure 4.1). First the choice for a particular KET is discussed, followed by the choice for a particular product segment within the chosen KET, and finally the choice for the actual product within the chosen KET segment is discussed and motivated.

Figure 4.1: Different steps in the selection of KETs-based products for the value chain analysis

Source: IDEA Consult

4.2.1. Lipase enzymes

A first KET that has been selected is industrial biotechnology. The reason for selecting this KET is the fact that bio-based products are identified as one of the six priority action lines in the Communication "A stronger European Industry for Growth and Economic Recovery". In addition, the Commission underscores the

[75] http://ec.europa.eu/enterprise/sectors/ict/files/kets/final_report_kets_observatory_en.pdf

[76] A major difficulty here is the possibility to estimate the value added of the selected KETs-based product in the total product range of a company. For example, in the case of foundries, no information is disclosed on the share of the accelerometer production versus the total production. Moreover, this share tends to alter over time particularly to rapid shifts in market demand. As in both selected KETs-based products, large companies are involved, it is important to have information on the share of the KETs-based product in total revenue in order to provide reliable information on the value added capture by EU firms. Due to confidentiality reasons, this information is hardly/not disclosed.

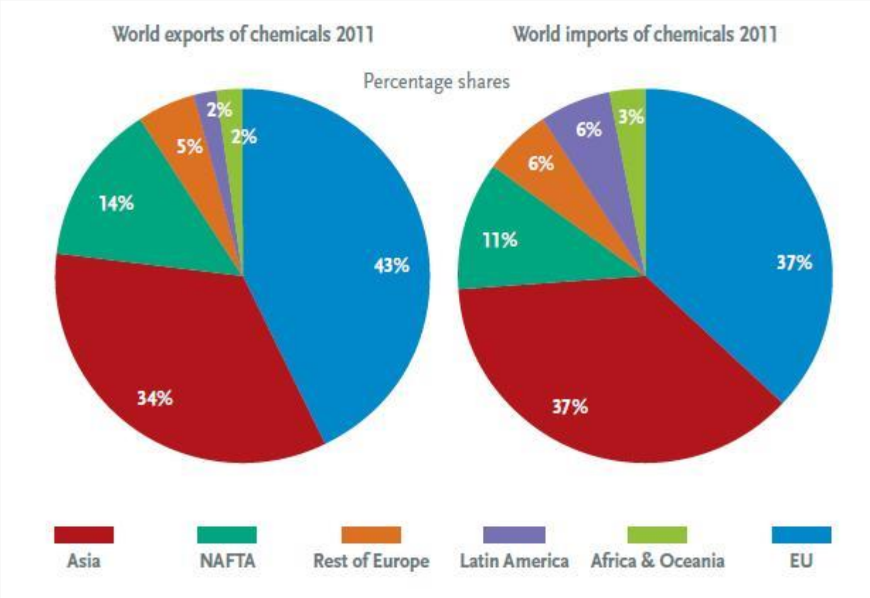
importance of the bio-based economy in the Communication "Innovating for Sustainable Growth: A Bioeconomy for Europe".

Within industrial biotechnology, enzymes have been selected as a product segment. Enzymes are one of the major promising growth areas in industrial biotechnology. They enable a broad range of applications and provide several advantages over traditional chemistry including high selectivity, less energy use and mild reaction conditions. They are a valuable complement to regular microbial fermentation, e.g. in cases where the microorganisms themselves are not wanted or cannot function in the reaction mixture. The market for enzymes has grown rapidly over the past decade, and both households and industry are becoming more and more dependent on enzymatic catalysis. Even so, there remains a vast untapped potential in the enzyme market (Sarrouh et al, 2012). The market for industrial enzymes amounted up to 3.3 billion dollar in 2010, and is expected to grow to 4.4 billion dollar by 2015, a compound annual growth rate (CAGR) of 6% over the 5-year forecast period (BCC market research, 2011a).

Two enzyme classes that are considered to have the highest growth potential belong to the group of hydrolases, namely carbohydrases and lipases (Global Industry Analysts, 2012). These two enzyme classes have been screened as potential products for the value chain analysis. Carbohydrases are a wide class of enzymes catalyzing breakdown of sugar polymers. They have been used for many years in the paper/pulp, food, and detergent industry; and more recently also for first generation biofuels. As previously described, a major new application is developing for carbohydrases, namely the use of cellulases for second generation biotechnology. However, this application is still too immature to be reflected in an analysis (only a minority of companies have started to produce next generation cellulase on a commercial scale since 2-3 years). Therefore, an analysis of carbohydrase enzymes would involve mostly traditional applications of this enzyme class. Since this is not fully in line with the purpose of the value chain analysis, this option was not pursued.

The second group that was screened, lipase enzymes, has traditionally been used in detergents, where they remove fat and oily stains. In addition, they are increasingly used in the food industry, where they are used among others in applications involving dairy, baking, etc. In recent years, lipases have also received more attention as they are not only capable of hydrolyzing (cleaving) lipids, but also of catalyzing synthesis of a range of new molecules (biocatalysis). This has opened up a whole new range of possibilities including production of basic chemicals, specialty chemicals, pharmaceuticals, cosmetics and biodiesel. Lipases are among the most versatile and flexible biocatalysts for organic synthesis (they are highly compatible with organic solvents), and therefore the most frequently used enzyme family in this area. They are penetrating various parts of the chemical industry, which is traditionally one of Europe's most competitive industries, accounting for 23.4% of world production and 43% of world exports in 2011 (Cefic, 2012). Europe represents about 40% of global trade in chemicals (defined as total exports plus total imports), and is able to realize a significant trade surplus, illustrating its competitive position (Figure 4.2). Lipases have the potential to positively impact this industry both in terms of competitiveness as well as environmental friendliness (high societal relevancy) as they allow reactions under 'mild' conditions, use less energy, and produce less unwanted side-products. Therefore, this KETs-based product is selected to analyse the position of the EU in the value chain of this upcoming class of promising enzymes.

Figure 4.2: World exports and imports in chemicals, 2011



Source: Cefic, 2012

4.2.2. Accelerometer

In Figure 4.3 the expected market size for micro- and nanotechnology is estimated to be $300 billion in 2015, with an expected compound annual growth rate of 13%. Micro- and nanoelectronics provide the knowledge and technologies that generate some 10% of GDP (HLG MNE, 2011). It has enabled the rise of the information age and impacted deeply our everyday lives, and is expected to continue to do so in the future. Seen the importance and impact of this KET, it was decided to also select a KETs-based product in micro- and nanotechnology.

Figure 4.3: Estimate global market potential of KETs

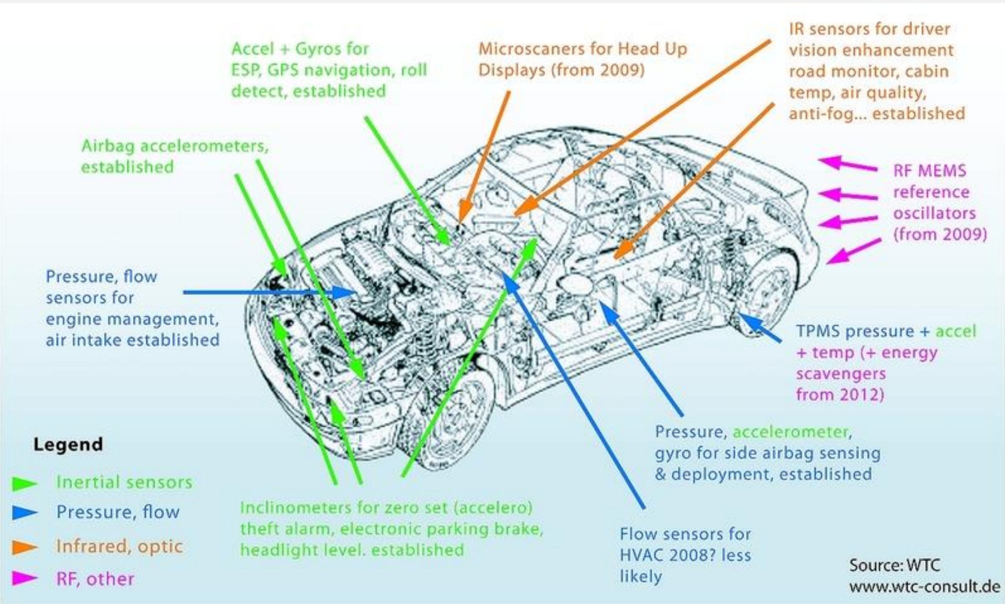
	Current market size (~2006/08) USD	Expected size in 2015 (~2012/15) USD	Expected compound annual growth rate
Nanotechnology	12 bn	27 bn	16%
Micro and nanoelectronics	250 bn	300 bn	13%
Industrial biotechnology	90 bn	125 bn	6%
Photonics	230 bn	480 bn	8%
Advanced Materials	100 bn	150 bn	6%
Advanced Manufacturing systems	150 bn	200 bn	5%
TOTAL	832 bn	1282 bn	

Source: High-Level Expert Group on Key Enabling Technologies, Final Report

Within this KET, Europe is leading in More-than-Moore and still at a state of the art level in More Moore (HLG MNE, 2011). Seen the increasing importance of More-than-Moore applications, it was decided to select a KETs-based product in More-than-Moore and more specifically in the segment of Micro Electro Mechanical systems (MEMS). MEMS are products elementary for many types of interactions of electronics with the outside world, and provide a good example of the continued integration of digital and non-digital functions over time, namely the More than Moore (MtM) trend. This integration has enabled strong growth of MEMS over the past years and their use in a wide range of applications. The More than Moore trend is a major evolution with potential for radical innovations in the microelectronics field, and it is expected that the relative weight of the MtM component in the industry will increase over time (ITRS, 2010).

To illustrate the variety of MEMS that exist today, Figure 4.4 provides an overview of the different functions MEMs fulfil in an automobile context, where they were originally introduced. As can be seen, they serve many purposes including measuring several state variables (pressure, motion), security (airbags), navigation (GPS), as well as many others. Gradually MEMS have been used also in other areas such as consumer electronics (Ryhänen, 2010). With regard to the future it can be seen in Figure 2.13 that the MEMS constitute a strong growing market with a projected compound annual growth rate of 13% over the coming years, to reach more than 20 billion dollars in 2017. Strong growth in the MEMS segment is thought to come particularly from microfluidics and inertial sensors (Yole Development, 2012). One example of these fast growing inertial sensors is the accelerometer[77], which is the chosen KETs-based product for further analysis.

Figure 4.4: Overview of MEMS applications in automobiles



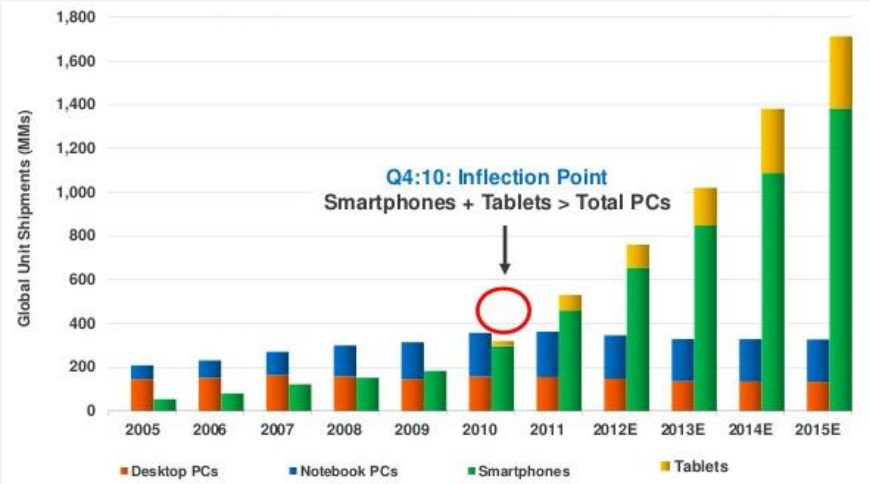
Source: WTC-Consult

The accelerometer is a motion sensor, measuring the acceleration of a given object. It was first introduced on a large scale in automotive applications, but in recent times it has found its way into many consumer electronics applications. In mobile devices such as smartphones, they are key sensors as they enable gesture recognition, user interface control, activity monitoring, and hard disk protection. Other consumer electronics applications include measuring of motion in gaming and sports applications. The accelerometer has been one of the important sensors in the evolution towards more ‘intelligent’ consumer electronics, that is, devices becoming increasingly aware of the environment and the conditions of the device (Rÿhanen, 2010). The trend towards mobile and intelligent consumer electronics has been growing strongly over the past years, and has outpaced the growth in more traditional segments such as personal computers (Figure 4.5). With regard to the future, it is expected that mobile devices sales will expand spectacularly. The value added that can be captured in the microelectronics industry will increasingly move towards mobile, intelligent applications. As the accelerometer is representative of two major evolutions in MNE (the trend towards mobile, intelligent devices and the integration of

[77] Note that in **Error! Reference source not found.**, the growth of the accelerometer is not only captured under the class ‘accelerometer’ itself, but also under the class ‘combo’s’, which refers to a combination of several inertial sensors

heterogeneous functions), we selected this KETs-based product to analyse the position of the EU in the value chain of this product.

Figure 4.5: Global Unit shipments of personal computers, tablets and smartphones for 2005-2015 (E=expected)



Source: Morgan Stanley Research

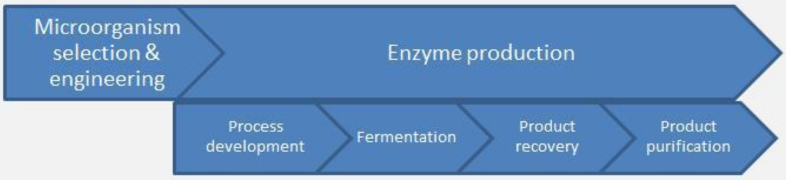
4.3. VALUE CHAIN ANALYSIS OF LIPASE ENZYMES

4.3.1. Value chain decomposition

Figure 4.6 shows the value chain of lipase enzymes, which consists of two phases. First there is the selection and genetic engineering of an appropriate microorganism, capable of producing the enzyme of interest. Second there is the actual production of the enzyme. The latter phase can be subdivided in four major steps. The first step is the development of the production process which entails finding the right conditions for fermentation (the following step) and the up-scaling of production from laboratory scale to commercial scale. Once the production process is optimised the large scale fermentation can occur. During fermentation the microorganisms grow on a substrate and produce the enzyme of interest. Once the fermentation is done, the following step is to separate the produced enzymes from the fermentation mass (product recovery). In the final step, the enzyme product is purified. The necessity of this final step depends on the application.

The value chain shown in Figure 4.6 applies not only to lipase enzymes but to enzymes in general, and even to a large extent to industrial biotechnology in general. Indeed, whether it concerns production of an enzyme, a platform molecule, a vitamin or an amino acid, the main steps include finding and engineering a suitable microorganism, letting it grow on a substrate such that it starts producing the product of interest (fermentation), followed by downstream processing of the product. In the next paragraphs, each step of the value chain will be described in more detail, while devoting particular attention to the lipase context.

Figure 4.6: Value chain decomposition for lipase enzymes



Source: IDEA Consult

Step 1: selection and engineering of microorganism

Since lipases are a broad class of enzymes, the first step is to select (and modify) the microorganism best suited for production of the specific enzyme of interest. Although lipases are also produced by plants (and animals), microbial lipases are preferred due to their stability, selectivity and broad substrate specificity. Within the class of microorganisms, mostly bacteria and fungi are exploited for lipase production and to some extent also yeast. The most important commercially available strains are from the *Pseudomonas* (bacteria), *Mucor* (bacteria), *Rhizopus* (fungal), *Geotrichum sp.* (fungal) and *Candida* (yeast) genera (Salihu, 2012). Microorganisms are selected on their ability to produce the enzyme in large quantities, whether they secrete this enzyme naturally (which eases the recovery afterwards) and whether they are capable of growing in conventional fermentation environments. A chosen microorganism will often be genetically modified to enhance its performance (production yield) or to improve the properties of the enzyme itself.

Step 2: process development

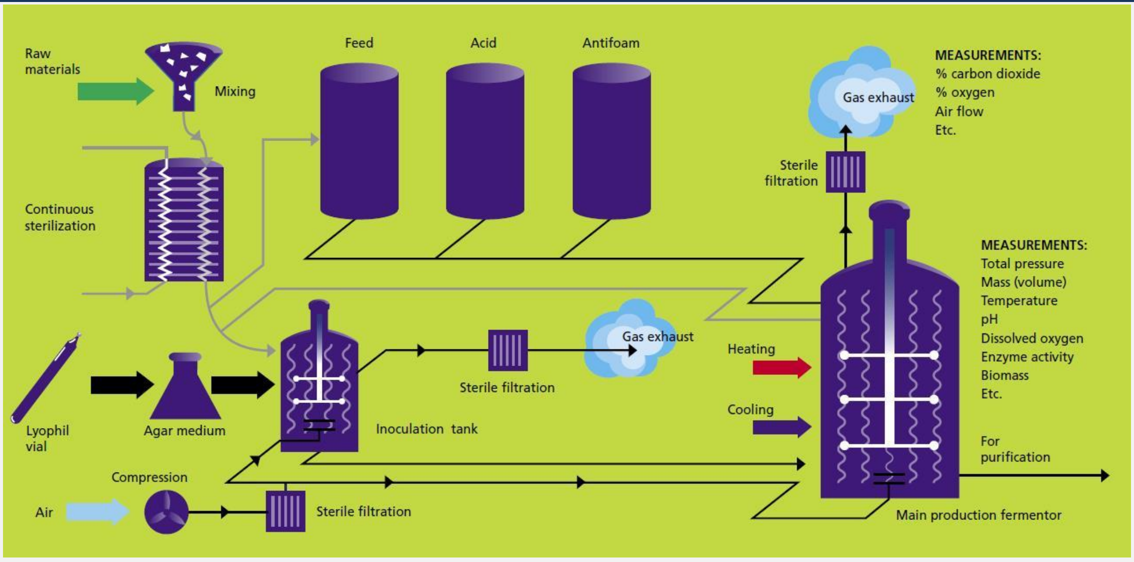
When a microorganism capable of producing an enzyme of interest is identified and engineered, the next step is to up-scale the production from laboratory scale to a scale that is commercially viable (up-scaling process). Often this involves pilot and demonstration production runs, in which production is gradually increased towards commercial scale. This is especially relevant to industrial biotechnology, where the up-scaling of production is less straightforward than in classical chemistry. During this process, the optimal production conditions (e.g. pH, concentrations of nutrients, etc.) are investigated. This step should certainly not be seen as independent from the first step; indeed there may be feedback loops between the production stage and the R&D stage. The development of a commercially viable production procedure is important in bridging the so-called 'valley of death': often promising results in the R&D stage do not make it to commercial products because the step in between is difficult to overcome. Also, even when the point is reached where large scale production can be done (see step 3), process optimization efforts will continue.

Step 3: fermentation

Once the production procedure has reached commercial viability, the actual large-scale production of the enzyme can start. This fermentation process is drawn in Figure 4.7. The centre of this process is the main production fermentor. Here the microorganisms can grow on the nutrients that are supplied, resulting in the production of the enzyme of interest. Before microorganisms are transferred to the (large) fermentor tank, they are grown first in a smaller volume called the inoculation tank. As demonstrated in Figure 4.7 , the fermentation process receives several inputs such as feed for the microorganisms, air (important for bacterial fermentation), acid (to control the pH) as well as antifoam. For lipases it is important to supply a lipid carbon source, which induces the production of lipase enzymes as in absence of this inducer, the microorganism would not produce lipase enzymes since there is no substrate for it. These inputs also need to be sterile (not containing traces of other microorganisms in order to avoid contamination). Process parameters such as pressure, pH ... are often monitored during the process. This allows for automatic intervention when one of these parameters deviates from the prescribed optimum, which can avoid the waste of a valuable batch of products.

There exist several modes for the fermentation process. The two most common are fed-batch and continuous process. In the first mode a certain amount of microorganism is brought into the reactor with all inputs, after which some important nutrients remain to be supplied to the fermentor tank. After some time period the whole production is then harvested. In the continuous process mode there is a constant supply of all inputs as well as a constant drain of fermentor broth of equal volume. Therefore the process can run continuous instead of in several batches, reducing the time cost of starting and stopping a batch. Also the downstream processing of the enzymes can happen in a continuous way rather than discontinuous. This is the ideal situation for large scale production; however it is not possible in all cases. The key to success for many companies is the extent to which they can increase the yield of the fermentation process (often expressed as enzyme units per milliliter). In this respect both the genetic engineering of the organism as well the optimization of fermentation process characteristics (temperature, pH, type of nutrients, fermentation mode ...) can contribute to a higher yield, and are central in the company's efforts to augment performance.

Figure 4.7: Overview of fermentation process



Source: Novozymes

Step 4: product recovery

After fermentation, the fermentation mass contains both microorganisms and enzymes. In most applications, the presence of microorganisms in the enzyme product is not wanted. The goal of the recovery step is therefore to separate both. This is often done using microfiltration, which separates microorganisms and enzymes on the basis of size. Another commonly used method is centrifugation, which separates by exploiting the difference in mass between enzymes and microorganisms.

Step 5: product purification

Depending on the application, the recovery step may not deliver the wanted degree of purity of the enzyme. Indeed, microorganisms will produce a number of other enzymes (and other non-enzyme proteins) as part of their natural metabolism, and some of these may be disturbing for the application of interest (e.g. lipase are among others used in food applications). In this case a purification step is needed, in which the enzyme of interest is purified from other molecules through more sophisticated methods, such as ultrafiltration or ion-exchange.

To illustrate how enzymes can add value for the customers, an example of the pharmaceutical company Pfizer is provided. Pfizer has been engaged in efforts to turn their production process more eco-friendly for years. For the production of Pregabalin, a drug for the treatment of neuropathic pain, on average 10 subsequent chemical reactions was needed using classical chemistry. This resulted in a low overall product yield which led to a high product cost. However, using a lipase already in the first step resulted in the production for the right enantionmeric form of the molecule of interest, resulting in a reduction of the number of steps needed from 10 to 4, and a great improvement in overall efficiency. This high performance could be achieved with lipase enzymes from the companies Novozymes and Amano Enzymes, which will both be discussed in the next paragraphs. Table 4.1 shows the comparison of both production routes. The number of inputs needed for the process was greatly reduced when using enzymatic catalysis, providing cost reductions to the company far greater than the extra cost of the enzyme. In addition the environmental footprint of the process was strongly reduced[78].

[78] http://www.dbu.de/media/130508051211a525.pdf

Table 4.1 - Comparison of classical and enzymatic route for Pregabalin production

Table 1. Inputs for 1000 kg Pregabalin via 1st Generation and New Routes

Inputs	1st Generation Route (Kilograms)	New Route (Kilograms)
CNDE	6212	4798
Enzyme	0	574
(S)-Mandelic acid	1135	0
Raney nickel	531	79.5
Solvents	50042	6230
Total	57920	11681.5

Source: Pfizer

4.3.2. EU activity along the value chain

In the next paragraphs, the key players in the lipase enzymes value chain will be identified and discussed. First, the lipase enzyme producers will be described, these are the companies selling lipase enzymes. Next, companies that do not sell lipases directly but contribute to the added value of this product by executing a specific step in the value chain will be discussed. The focus will first lie on companies providing services for the selection and engineering of microorganism, followed by companies that are active in the second part of the value chain, namely enzyme production.

Lipase producers

Table 4.2 provides an overview of the majority of companies active in the production of lipase enzymes. Industry experts were asked to list the companies with the highest market shares for each of the three major application fields of lipase enzymes, which provides insight into which regions are leading in the lipase segment. For companies not selling lipases but focusing on specific parts of the value chain, information on the relevance of lipase enzyme in their activities is typically more difficult to find since these activities are 'further away' from the end product.

Fifteen companies have been identified, of which almost half are located in Europe. With the Denmark-based Novozymes, Europe host worlds' largest player in the overall enzyme industry. This company, which spun off from Novo-Nordisk (Danish firm) in 2000, presented in 2011 about 47% of global enzyme sales (Figure 4.8). Over the past decade it has been able to maintain and even increase its market share through large investments in innovation, and nowadays it is a key player in all subfields of enzymes. With regard to lipase enzymes, the company offers a broad portfolio of enzymes for various applications, including traditional ones such as detergents and food processing, but also more recent applications such as biocatalysis for the pharmaceutical, cosmetics and chemicals industry.

Netherlands-based DSM is larger in revenue compared to Novozymes, but its share of enzyme-related activities is not as high[79]. Figure 4.8 show that DSM's total revenues from enzymes are only a fraction of Novozymes' revenues. DSM is active in lipases particularly in food applications, and has recently underlined its interest in this field by acquiring lipase technology from US-based Verenium[80], primarily to extend its activities in food applications. However, its lipase portfolio is not as broad as Novozymes' portfolio[81]. The other European

[79] Novozymes revenues stem for about 93% from enzymes, http://www.novozymes.com/en/investor/events-presentations/Documents/Novozymes_NasdaqOMX_071210_BDLO.pdf

[80] http://ir.verenium.com/releasedetail.cfm?ReleaseID=659239

[81] http://www.novozymes.com/en/about-us/brochures/documents/enzymes_at_work.pdf

companies active in the lipase segment are generally an order of magnitude smaller than DSM and Novozymes. Many of these companies focus on a number of specific applications. For example, AB enzymes (owned by the UK-based ABF) produce lipases predominantly for food (baking) purposes, while Biocatalyst Ltd. focuses on dairy applications. Eucodis Bioscience is a relatively young company with a high share of lipases in its product portfolio, targeting mainly pharmaceutical applications. Germany-based C-lecta is also a relatively young company, offering enzymes for a limited number of applications. However it does represent a rather large number of lipases and is a recognized player in this segment. With its lipase products, it focuses among others on the production of specialty chemicals [82].

Table 4.2 - Overview of lipase producers

Region	Country	Company name	Total Revenue 2011 (million dollar)	Main Production Sites
EU	Netherlands	DSM	9 048	CH, DE, NL, UK, US
	Denmark	Novozymes	1 891	CN, DK, US
	UK	ABF (AB Enzymes)[a]	16 650 (127)	DE, FI
	Germany	C-lecta	n.a.	DE
	UK	Biocatalysts Ltd	n.a.	UK
	Austria	Eucodis Bioscience	n.a.	AT, DE
Non-EU	US	Dupont (Genencor)[a]	38 000 (835[b])	BE, CN, FI, US
	US	Codexis	124	US, IN
	US	Verenium	61	Outsourced
	US	Dyadic	10	US
	Japan	Amano	1 074[c]	CN, JP
	Japan	Meito-Sangyo	176	JP
	India	Advanced Enzymes	34	IN
	India	Aumgene Bioscience	n.a.	IN
	China	Syncozymes	n.a.	CN

Source: IDEA Consult. Company turnover and main production sites are based on corporate annual reports and company website information.

Notes: a= in case the relevant activities are performed by a specific subsidiary, this subsidiary is listed in parentheses behind the parent company. The main production sites mentioned apply to this subsidiary; b= total revenue 2010; c= total revenue 2012

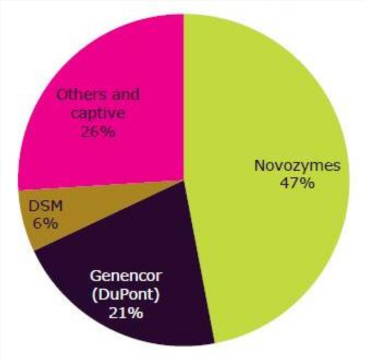
Outside the EU, the main country emerging from Table 4.2 is the US with three companies. In the US, the largest player is Dupont, which is due to the recent acquisition of Denmark-based Danisco and its US-based subsidiary Genencor. Genencor is the second major global enzyme producer in the world; representing about half of Novozymes sales (see Figure 4.8). Before the acquisition, Dupont and Genencor were already collaborating in the form of a joint venture that aimed to develop second generation cellulase enzyme technology needed for sustainable biofuel production. One of the goals of the acquisition by Dupont is to profit from the emerging bioenergy market[83]. Besides this, Genencor is also strong in the food enzyme market (its former parent company Danisco is a food producer), however in the lipase segment of the food market it has not been able to grow to a leading player (see also below). In addition, it is much less present in some of the emerging markets for lipases, such as pharmaceutical and chemical market applications, unlike Novozymes.

The three other US companies are significantly smaller than Genencor. Codexis produces enzymes used to improve production processes in the pharmaceutical industry, and is currently developing its lipase activities. Verenium has achieved certain successes in the commercial development of lipases as illustrated by the recent

[82] http://www.c-lecta.com/?lang=en&category=products&page=lipasen
http://www.bio-catalyst.com/enzyme-sources/c-lecta-gmbh/
[83] http://www.biofuelsdigest.com/bdigest/2012/02/24/the-enzyme-wars/

acquisition of enzyme technology including lipases, by DSM for about $37 million[84]. Currently it does not commercially sell lipases according to their website information; however the company does report to have several proprietary lipases and phospholipases candidates for future products. Dyadic is also a rather small company, that owns a revolutionary technology platform for the discovery and production of enzymes, but it does not have a specific focus on lipases.

Figure 4.8: Market shares of key players in global enzyme market, 2011



Source: Novozymes

Japan records two companies in Table 4.2. Amano Enzymes is a large and recognized player in the enzyme market. It has a long history as specialty enzyme developer, and its key strengths lie in the class of hydrolases (enzymes that cleave chemical bonds, thereby consuming water in the cleaving process) (Bio-catalyst, 2013). One of its most successful products is lipases, which has been widely produced over the past years. These lipases are useful for various chemical conversions, with applications notably in the pharmaceutical and chemical industry. In the example of Pfizer provided in the previous paragraph, the lipases from Amano Enzymes were, together with lipases from Novozymes, considered to be the best for improving the production process. However, Amano does not serve the wide range of applications Novozymes does. The other Japanese company, Meito-Sangyo, is smaller than Amano but also a recognized player in the field of lipases, especially in applications involving chiral transformations[85]. Also two companies from India appear in the list, both offering a rather broad portfolio of lipases. This reflects the emergence of India in the enzyme industry, as it appears to be one of the Asian countries with the highest commitment to the development of industrial biotech[86].

Broadly speaking, lipase enzymes have three application areas: detergent (removing fats in laundering, dishwashing, and industrial cleaning), food (fats and oil processing in applications such as dairy, baking, ...) and biocatalysis (the production of chemicals, cosmetics and pharmaceuticals), see also section 4.2.1. It can be seen in Table 4.3 that European companies are well represented in each segment. In the detergent segment, Genencor (US) and Novozymes are the two companies with the highest market shares. The food segment is dominated by Novozymes and DSM, while the in the biocatalysis segment Novozymes is the clear market leader.

[84] http://ir.verenium.com/releasedetail.cfm?ReleaseID=659239

[85] These are reactions in which the end-product is composed of the exact same atoms as the initial molecule, however the sterochemical (spatial) arrangement of the molecules has been changed, which can give it whole new properties.

[86] Source: interviewee

Table 4.3: Dominant companies per lipase application field

Application field	Detergent	Food	Biocatalysis
Companies with highest market shares	Novozymes, Genencor	Novozymes, DSM	Novozymes

Source: Interviewees[87]

Companies active in microorganism selection & engineering

Lipase producers do not necessarily execute all parts of the value chain themselves. Other companies can be active in specific parts of the chain. The first part of the value chain, the selection and engineering of microorganisms (see Figure 4.9) can sometimes be problematic for a company to pass on its own, and therefore, particular companies hire expertise from outside to overcome this. Only three companies have been identified as providers of such services (see Table 4.4). This can be explained by the fact that the first step of the value chain can be considered as a core competence of most lipase producers.

Figure 4.9: First part of the lipase value chain

Source: IDEA Consult

Regarding the companies that could be identified, DSM is a large company with many activities as mentioned in the previous paragraph. One activity is the guidance of other companies in the development of their technologies. For example when a lipase producer is working on the commercialization of its products, DSM can propose other microorganisms for the expression for the gene of interest as to facilitate the up-scaling of enzyme production. Similarly, Lonza possesses so-called expression platforms, in-house engineered microorganisms enabling high enzyme production levels. Augmene Bioscience on the other hand offers various types of contract research to third parties, such as genetic engineering for the development of suitable microorganism strains.

Table 4.4 - Overview of companies active in microorganism selection and engineering services

Region	Country	Company name	Total Revenue 2011 (million dollar)
EU	Netherlands	DSM	9 048
Non-EU	Switzerland	Lonza	2 019
	India	Augmene Bioscience	n.a.

Source: IDEA Consult, based on company annual reports.

Companies active in enzyme production

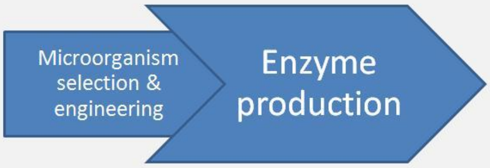
The large-scale production of enzymes requires considerable investment in infrastructure, which often forms a hurdle especially for smaller (start-up) companies. Similar to the concept of foundries in the semiconductor industry, there exist a number of companies that do the enzyme production (fermentation and downstream

[87] This table was composed by asking the interviewees about the most important players in each application field

processing) for other parties. In this section, companies active in this segment, the second part of the value chain (see Figure 4.10), will be discussed.

Outsourcing of enzyme production can deliver specific benefits to enzyme companies not only by reducing the financial risk, but also by providing access to fermentation know-how contained by the fermentation service provider. In this respect it is important to note that in industrial biotechnology the scaling-up of the production of a given product (enzyme, vitamin, ...) from laboratory to commercial scale is everything but straightforward, and more difficult compared to classical chemical production processes (Wydra, 2012). Therefore the fermentation service providers often guide enzyme producers through the gradual up-scaling of production of the novel enzyme (the process development step in Figure 4.6). These services are mostly used by smaller companies, whereas the large industrial players typically organize the whole production in-house (similar to the IDMs in the semiconductor market). One example of a company relying on outsourcing of its production is US-based Verenium. It performs its R&D and scale-up of its production in the US, but the commercial production is outsourced to a facility in Mexico.

Figure 4.10: Second part of the lipase value chain



Source: IDEA Consult.

The companies identified to be active in the second part of the value chain are shown in Table 4.5. These companies are known to be engaged in contract production of enzymes for industrial purposes. However, it should be noted that the importance of lipase production in their production services can be time varying and is not disclosed by these companies. This list therefore applies to industrial enzyme production in general.

Four companies are located in Europe. Netherlands-based DSM, by far the largest company involved, was already present in the list of lipase producers. Indeed, apart from producing enzymes under its own brand name, it also offers a broad range of fermentation services to other companies. Also two other companies, Eucodis Bioscience and Biocatalyst Ltd., have been identified as lipase producers[88]. Finland-based Galilaeus is a small company focusing on fermentation services for various fields.

Outside the EU, Switzerland records two companies. However, the presence of the large pharmaceutical company Novartis is due to its ownership of Sandoz, a German-based company which offers a broad range of fermentation services to its facilities in Germany, Austria and Italy. Lonza is also a large company with a broad range of activities. One of the pillars of its activities is its manufacturing service, which includes microbial fermentation of enzymes. Given that the main fermentation site of this company is located in Czech Republic, it can be concluded that many relevant activities of both Swiss companies are taking place in Europe, and in particular the fermentation services are accessible to European firms[89]. The company Fermic, based in Mexico, has an agreement with US-based Verenium for the manufacturing of all Vereniums' enzymes. Apart from this, it engages mostly in the production of pharmaceutical compounds through fermentation. Israel-based Biodalia is

[88] This may of course hinder other (lipase) producers to use facilities from these companies, given potential technology spillovers. However, this problem may vary from case to case (lipases are a broad class of enzymes). In any case it appears that DSM, despite having itself a broad portfolio, is able to run a solid enzyme manufacturing service for other companies.

[89] http://www.sandoz.com/assets/media/shared/documents/Sandoz_Global_Contract_Manufacturing_Flyer_Fermentation.pdf ; http://bio.lonza.com/uploads/tx_mwaxmarketingmaterial/Lonza_Brochures_Microbial_Fermentation_Services.pdf

a company focusing on microbial technologies for agricultural, chemical and food applications. Its manufacturing services include the production of enzymes for food processing and cosmetics.

Interestingly, outside the EU there is also one company found to be active in both proprietary enzyme production as well as manufacturing services for enzyme production, namely India-based Augmene Bioscience[90]. This company offers extensive manufacturing services for a variety of enzymes. It is noteworthy to mention that in the search for companies active in this segment, no US-based firms have been identified. During the process of identifying relevant companies it was noted that the offer for fermentation services for pharmaceutical purposes (e.g. the production of an antibody or a pharmaceutical compound) are available on a much larger scale, both in the EU and in particular also in the US. This corresponds to the general observation that the field of medical ('red') biotechnology is currently better developed, despite the fact that industrial biotechnology has higher long-term market potential (OECD, 2009).

Table 4.5 - Overview of companies active in enzyme production services

Region	Country	Company name	Total Revenue 2011 (million dollar)
EU	Netherlands	DSM	9 048
	Finland	Galilaeus Oy	1,9[b]
	Austria	Eucodis Bioscience	n.a.
	UK	Biocatalyst Ltd	n.a.
Non-EU	Switzerland	Novartis (Sandoz)[a]	58 566 (10 700)
	Switzerland	Lonza	2 019
	Israel	Biodalia	n.a.
	Mexico	Fermic	n.a.
	India	Augmene Bioscience	n.a.

Source: IDEA Consult, based on company annual reports.
Notes: a= when the relevant activities are executed by a given subsidiary, this subsidiary is listed in parentheses behind the mother company; b= total revenue 2012

As can be seen in Figure 4.8, the world enzyme market is dominated by a select number of companies (Novozymes, Genencor, DSM). In a market where product innovation is very important, their extensive R&D capabilities allow these companies to stay at the forefront. However, a second import element in the enzyme industry is the capability to produce enzymes at a large scale (and hence, at a moderate cost). This is because, as already touched upon above, the up-scaling of manufacturing processes in industrial biotech is far less straightforward than in classical chemistry. Currently Novozymes, Genencor and DSM (and to a lesser extent also AB Enzymes) distinguish themselves in large scale effective production of enzymes[91]. While many (smaller) firms are good in the discovery of new enzymes with interesting properties, the step towards large scale manufacturing is not easy to overcome. As a consequence, often the technology of those smaller companies is acquired by larger companies who then set right the large scale production of the enzyme. Europe is well placed in this regard and should foster its capabilities in large scale enzyme production, since it gives an important competitive advantage.

4.3.3. The EU position in the value chain of lipase enzymes

With Novozymes (worlds' leading enzyme supplier) and DSM, Europe has leading companies in all lipase application fields. In addition, Europe hosts a group of smaller companies who tend to specialize in certain applications. There is considerable competition from US companies, coming primarily from Genencor. However, this company has only a leading market position in detergent lipase enzymes. Japan, on the other hand, hosts

[90] http://www.aumgene.com/cram.htm
[91] Source: interviewees

two recognized players that are strong in emerging applications such as pharmaceutical and chemical applications; however, the lipase activities of these companies do not have the scale of the large EU players.

Looking at more specific parts of the value chain, it was noted that a significant share of fermentation services are provided within Europe, especially taking into account several EU-based activities of Swiss headquartered companies. No other major region emerges in this segment. With regard to the first step of the value chain, micro-organisms selection and engineering, only a few companies were identified among which one EU-based company. This represents however a smaller segment.

The analysis, which is largely expert-driven, confirms that Europe is a key player in the global enzyme market, and that it holds a strong position in the subfield of lipase enzymes.

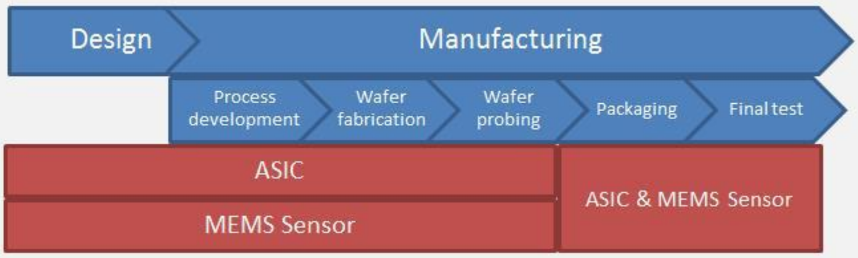
4.4. VALUE CHAIN ANALYSIS OF THE ACCELEROMETER

4.4.1. Value chain decomposition

The accelerometer consists of two major functional units: a mechanical component that senses the acceleration (hereafter referred to as sensor), and an electric unit that receives and translates the signals coming from the mechanical component. A common example of the operation of the accelerometer is the automatic screen rotation of a smartphone. As the smartphone is being moved by the user, a flexible mechanical component in the sensor will move due to the acceleration force imposed on it. As it moves, it position vis-à-vis fixed mechanical structures changes, which causes the capacitance[92] between the flexible and fixed plates to change. This will result in an electrical signal that will go to the electric unit of the accelerometer. This electric unit is often referred to as an application specific integrated circuit (ASIC), as it is designed to only receive and translate signals from the mechanical component, and not to perform a broad range of tasks. This particular ASIC will then send the appropriate signals to the central microprocessor of the smartphone. The central processor receives the signals from the ASIC, and sends out the signals to rotate the screen when appropriate.

In Figure 4.11 the value chain of the accelerometer is shown schematically. The value chain covers two phases, namely the design and manufacturing of the ASIC and the sensor. The manufacturing process can be divided in four steps. The first step is the fabrication of the ASIC and sensor on a large silicon substrate, called wafer. The next step is to inspect for malfunctioning ASIC and sensors on this wafer, called wafer probing. The next step is the integration of both components into one package, followed by a final test of the created accelerometer. Each step will be discussed in more detail in the following paragraphs.

Figure 4.11: Value chain decomposition for the accelerometer



Source: IDEA Consult

Step 1: Design

The first step is the design of the mechanical sensor and the ASIC. This step is elementary as it will determine the properties of the accelerometer. In the design phase a complete plan of the ASIC and sensor is drawn, detailing all functional structures and how they will be interconnected. For the ASIC, these plans will be translated to 'masks' for the photolithography manufacturing step. These masks are a kind of pictures of all the structures that are required on the chip, allowing these structures to be imprinted on the silicon substrate in the manufacturing phase. For the mechanical sensor, the design phase also results in pictures detailing all the mechanical structures for the manufacturing phase. At this stage the choice of the sensing mechanism (capacitive, piezoresistive, ...) needs to be made. Integrated circuits have become increasingly complex over the years and are subject to a large number of rules, which is why automated design software is extensively used in the design process.

Step 2: Process development

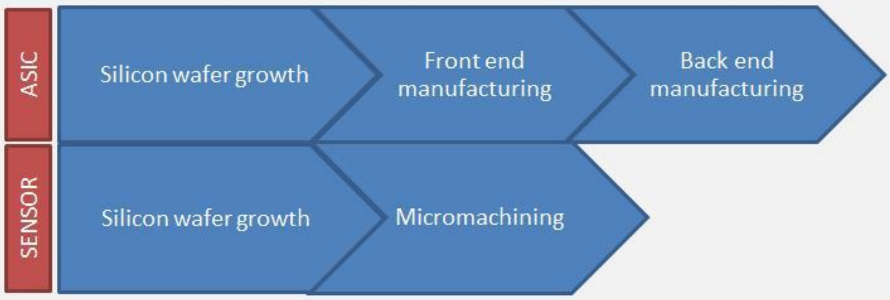
[92] Capacitance refers to the extent to which an object (e.g. two parallel plates) can store electrical charge. It is one of the common sensing mechanisms of accelerometer; other common mechanisms are based on piezoresistive and piezoelectric effects.

Following the design phase, the first initial production runs of the sensor can be executed. Predicted facile manufacturing is an important criterion in the development of the design, in order to smooth the manufacturing procedure afterwards. However again there may be feedbacks with the design phase, since the success of the manufacturing stage is not fully predictable and some changes to the design may be needed. Also, in case there are important novel features to the product or to the manufacturing process, pilot and demonstration runs will be done before the transition to large scale manufacturing can be done.

Step 3: Wafer fabrication

Subsequently the large-scale manufacturing phase takes place. The manufacturing process is often referred to as wafer fabrication, and is displayed in Figure 4.12. The term 'wafer' refers to a thin slice of the semiconductor material silicon, which serves as the substrate for chip manufacturing. The first step is the crystallization of silicon and the slicing of the pure silicon material into wafers. Once the silicon substrate is ready, the actual manufacturing can start. For the ASIC (and chips in general) this is called front end manufacturing. This part encompasses the patterning of the main structures (transistors, capacitors, resistors,) in the semiconductor material. The key concept of the manufacturing process is photolithography (see section 2.7.2 for more details). A light beam will be sent over a mask that contains the desired pattern to the chip, changing the properties of the material that has been lighted. Afterwards the material can be etched away chemically, and the desired structures have been imprinted in the material. A new layer of material can then be deposited on the surface, and the process can be repeated many times. The desired, complex structures are built up layer by layer. Once these structures are created, they will be interconnected with metal wires in the back end manufacturing step, which is often referred to as metallization (since the electric wires are made of metals such as copper). This is done in a process of alternately depositing metal and insulating layers, and interconnecting metal layers where needed.

Figure 4.12: Overview of the wafer fabrication step



Source: IDEA Consult

The fabrication of the mechanical sensor is often also done with silicon, since this is a stable material that has been well characterized due to its extensive use for electronic chips. It allows using the well-developed manufacturing techniques (such as photolithography) from electronics, which gives a cost benefit. Therefore the first step of the fabrication of the sensor is also the growth of a silicon substrate. The processing of silicon in the context of mechanical sensors is referred to as micromachining. Here the goal is to create very fine mechanical structures, rather than an integrated electronic circuit, and a metallization step is absent.

Step 4: wafer probing

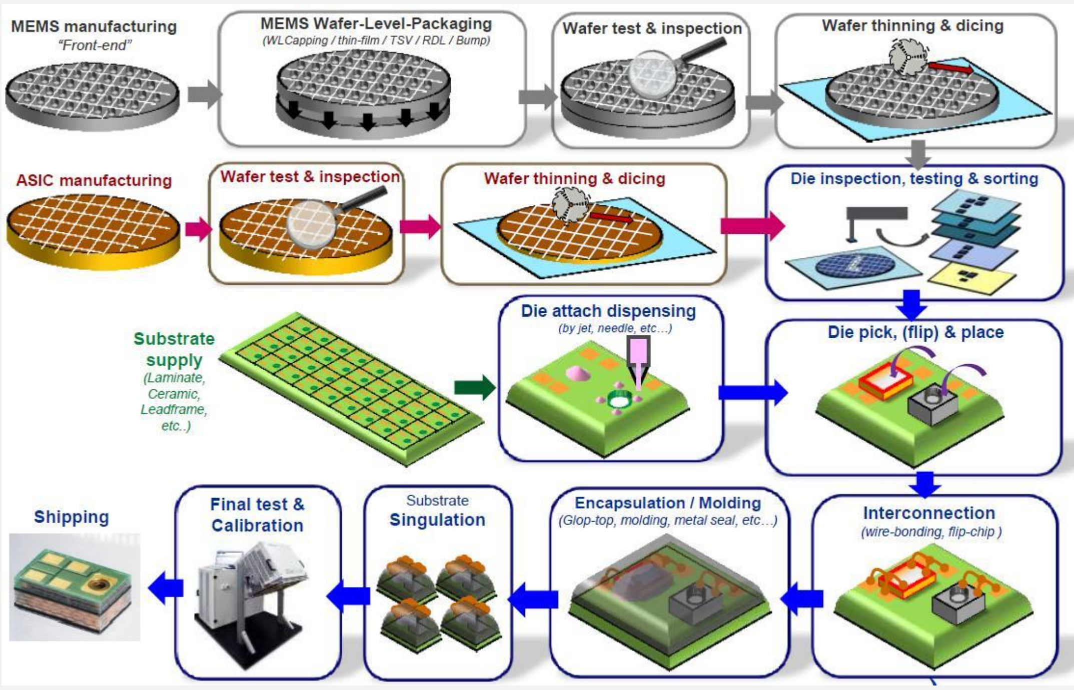
As discussed in section 2.7, the wafer forms a large area (diameter up to 0.3 meter) on which many individual chips are processed. Once the fabrication step is completed, all these individual elements (often called 'dies') are inspected for quality (see Figure 4.13). This is needed because the fabrication step typically produces a small percentage of non-functional dies, and from a cost point of view it is best to detect them at an early stage (before they are treated further). The inspection system will retain the position of all functional dies in its memory.

Step 5: packaging of ASIC and sensor

The next step is the packaging of the sensor and the ASIC. The packaging serves to protect the components and to pass the signal from the accelerometer to the central processor. The current industry standard is to integrate the sensor and ASIC in one package, as schematically shown in Figure 4.11. This is a so called System-in-Package (SiP). As was discussed in section 2.4, there has been an ongoing trend to integrate the sensing and the electronic parts ('More than Moore'). The main drivers are better signal transduction between the two parts, and lower space and power requirements (the latter are particularly relevant for mobile applications). Figure 4.13 shows the integration of both components in one package. After the ASIC and sensor have been produced and inspected on the wafer, they are brought together on a common substrate. Next, they are interconnected with wires, and encapsulated into a common package.

While currently the System-in-Package shown in Figure 4.13 is the industry norm, developments towards further integration of the two components are ongoing, evolving to a true System on a Chip (SoC). This integration can happen by putting a MEMS wafer on top of an ASIC wafer (e.g. as done by the company Invensense) or by building the mechanical sensor on top of the ASIC, which results in small, closely integrated accelerometers.

Figure 4.13: Detailed overview of MEMS modules packaging



Source: Yole Développement (2012b).

Step 6: final test

Once the ASIC and sensor are successfully combined in a package, the accelerometer is ready. However, the functionality of both elements and hence of the accelerometer needs to be verified, which is done in a final test step (see Figure 4.13).

4.4.2. EU activity along the value chain

As the analysis above illustrates, the value chain of the accelerometer consists of many steps. A company can opt to cover the whole value chain itself, or to focus on a specific number of steps. A company belonging to the first class is called an integrated device manufacturer (IDM), as it is responsible for the design, manufacturing and selling of its own products. However, other business models are possible as well.

A company can decide to focus on design, while leaving the actual manufacturing to another firm. Such a company is called a 'fabless' company. A company focusing exclusively on the manufacturing of chips commissioned by fables companies is referred to as a foundry[93]. Also intermediate forms can exist, e.g. a company can manufacture part of its products and outsource the rest to a foundry, in which it is called a semi-IDM or semi-fabless company. In addition, a company can be active only in the design phase by providing design services to other companies.

This illustrates that the value added from creating an accelerometer is divided among several companies, each executing particular steps of the value chain. Therefore it is important to not only look at end-producers of this product, but to look at all parts of the value chain when assessing the competiveness of Europe for this KETs-based product. In the following paragraphs the key players will be identified for each step in the value chain. We will start with the end-producers of accelerometers (companies selling accelerometers). Subsequently companies that are active in the first part of the value chain (design) will be discussed, followed by companies active in the second part of the value chain (manufacturing) and companies active in equipment supply for manufacturing.

Accelerometer producers

An overview of accelerometers producers is given in Table 4.6. This table contains the most important players in this area. In case of multinational companies, the country assigned to a company is the location of the mother company. It can be seen that Germany, the US and Japan are the three major countries covering the majority of the market.

A first observation is that in Europe a small group of large companies is active, while in the US a larger group of somewhat smaller companies are active. Japan counts three major players on the market, but two companies are the result of recent acquisitions e.g. by Rohm Semiconductor has acquired US-based Kionix, while Murata Electronics acquired Finland-based VTI. As discussed in section 4.2, the widespread use of accelerometers originated in the automotive industry, which remains an important market today. All large companies mentioned in Table 4.6 are strongly present in the automotive industry, and in this respect it has been advantageous for the European companies to have a strong domestic automotive market (e.g. Robert Bosch is the world's largest supplier of automotive components).

Gradually the interest of consumer electronics manufacturers in accelerometers (and other MEMS) has grown, in their drive to give electronics 'intelligent' attributes. This posed a number of technical challenges, such as smaller chips, higher production volumes and extreme cost consciousness. STMicroelectronics was one of the first sensor producers to recognize the large potential of the consumer electronics market and to develop large scale production facilities for this market. This has brought the company a solid growth and a strong position in this segment. Also Robert Bosch has become a key player in the consumer electronics market[94]. The strength in both automotive and consumer segments gives also the opportunity to operate at a large scale (the technology for both segments is fairly similar, although the requirements are different), allowing them to reduce costs. The main competition in the accelerometer market comes from US-based companies. Analog Devices and Freescale are two well established competitors, while Memsic and Invense are two young but promising, innovative

[93] Strictly speaking, the correct term is 'pure play foundry', since IDMs also have foundry activities. However, here the term foundry will be used to denote companies exclusively active in the manufacturing of sensors.

[94] http://www.electroiq.com/articles/stm/2012/03/top-mems-suppliers-near-1-billion-in-annual-sales.html

companies which recorded strong growth rates over the past years. The large conglomerate Honeywell is an exception in the sense that it produces its own accelerometers for integration in its inertial navigation systems.

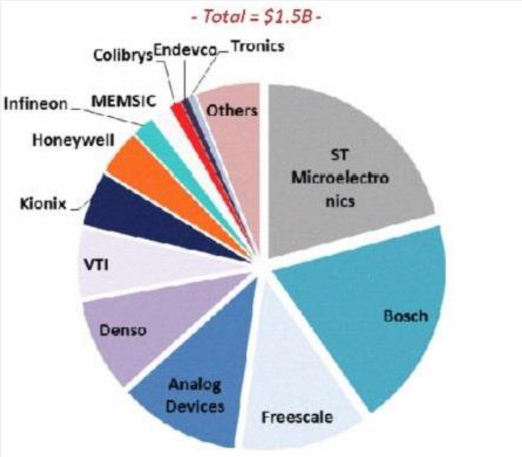
Figure 4.14 shows the accelerometer market share per company in 2011. The success of STMicroelectronics and Robert Bosch in both the automotive and the consumer electronics market makes them the two largest players in the accelerometer market. Adding up the market shares of Colibrys and Infineon, European companies represent almost half of the market in this segment, making Europe the leading player. Two US-companies Freescale semiconductor and Analog Devices also capture a significant share of the market, albeit less than the STMicroelectronics or Robert Bosch. Together with companies representing smaller market shares, the US come second in terms of market shares. The third player, Japan, has been able to capture a considerable share of the market with Denso and the acquisition of VTI and Kionix.

Table 4.6 - Overview of accelerometer end-producers

Region	Country	Company name	Total Revenue 2011 (million dollar)	Main Production Sites
EU	Germany	Robert Bosch	70 539	CH, CN, DE, ES,IN, IT, UK, US
	Netherlands	STMicroelectronics[b]	9 735	CN, FR, IT
	Germany	Infineon	5 479	DE, JP, SG, US
	France	Sagem (Colibrys)[a]	16 438 (16)	CH
Non-EU	US	Freescale Semiconductor	4 572	FR, JP, MA, US
	US	Analog Devices	2 993	IE, US
	US	Invensense	96	Outsourced
	US	Honeywell	36 529	CN, DE, ES, IN, IT, SG, US
	US	MEMSIC	68	US
	US	Endevco	n.a.	US
	Japan	Denso	37 660	CZ, DE, IN, IT, JP, UK, US
	Japan	Murata Electronics (VTI)[a]	7 130[c] (76[d])	FI
	Japan	Rohm Semiconductor (Kionix)[a]	3 187 (n.a.)	US

Source: IDEA Consult. Company turnover and main production sites are based on corporate annual reports and company website information. Notes: a= in case the relevant activities are performed by a specific subsidiary, this subsidiary is listed in parentheses behind the parent company. The main production sites mentioned apply to this subsidiary; b= Main activities of this company are located in France and Italy (the holding is located in the Netherlands); c= total revenue 2012; d= total revenue 2010

Figure 4.14: MEMS accelerometer market share, 2011



Source: Yole Développement (2012a).
Note: This graph excludes accelerometers sold in combo's with other sensors such as gyroscopes. This is why Invensense (US) is not depicted, as it sells only accelerometer in combo's.

Companies active in design

Companies specializing in design support to MEMS producers in the design phase, are often referred to as design houses (Figure 4.15). Their task involves helping other companies with the design and prototyping of a new product, after which the design resulting from the joint efforts of the two parties can be commercialized by the customer. These design houses can also help in identifying the right foundry for a given product.

Figure 4.15: First part of the accelerometer value chain

Source: IDEA Consult

Table 4.7 provide a list of companies active as design house in MEMS. It should be noted that the importance of accelerometer design in the activities of these companies varies in time and this information is not disclosed by these companies. Therefore the list applies to MEMS more generally. From the four identified actors, three are US-based. France-based Movea is a young, innovative company specialized in motion sensing, advising companies in product development and prototyping, supported by novel software platforms. The segment of design houses is a relatively small segment (much smaller than the foundry segment) since design is a core competence of most accelerometer end-producers and therefore often done to a large extent by these companies themselves. Design houses however can contribute to deliver a faster time to market (which tend to be quite long for MEMS in general), and by ensuring a good match of the design in early stage with conventional manufacturing techniques. An example is the recent cooperation between AM Fitzgerald and Silex Microsystems.

Table 4.7 - Companies active in MEMS design

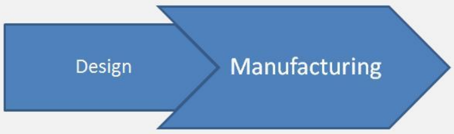
Region	Country	Company name	Total Revenue (2011)
EU	France	Movea	n.a.
Non-EU	US	A.M. Fitzgerald	n.a.
	US	Nanoshift	n.a.
	US	SVTC Technologies	n.a.

Source: IDEA Consult, based on company annual reports.

Companies active in accelerometer manufacturing

Companies active in accelerometer manufacturing are companies that execute manufacturing of accelerometer products on behalf of a second party (Figure 4.16). Most of the large companies listed in Table 4.6 (Robert Bosch, STMicroelectronics, Freescale, Analog Devices) are IDM's, covering the whole value chain. However, this is not true for all accelerometer producers. The US-based company Invensense for example operates a fabless model (all the manufacturing is outsourced) by operating a simplified and innovative manufacturing process. However, outsourcing is not unique to small companies such as Invensense, but also companies like Analog Devices opt to outsource part of its MEMS manufacturing[95],[96]. The main rationale behind the outsourcing is cost reduction. The manufacturing equipment for integrated circuits is capital intensive and cost-competitive production can only happen if done on a large scale. A high volume and quick turnaround consumer segment can often be better served by dedicated large-scale foundries. An exception is the automotive market, where strict compliance requirements are in place and hence production is best kept internally[97]. Another reason to use foundry services is the expertise these companies have gathered in the successful upscaling of production to large volumes (step 2 of the value chain, see Figure 4.11), which is particularly useful for younger and smaller companies.

Figure 4.16: Second part of the accelerometer value chain



Source: IDEA Consult

Table 4.8 lists the most important foundries active in accelerometer manufacturing. This list consists of companies who execute manufacturing of accelerometer products on behalf of a second party. It should be noted that, while the companies listed in Table 4.8 are known to have accelerometer production capabilities, the importance of accelerometer production in their total activities can be time-varying and is not disclosed by these companies. The last column indicates whether the foundry produces only MEMS products, or whether it is also active in the regular electronics markets (memory, microprocessors). The latter category of firms is referred to as silicon foundries. Typically MEMS-exclusive companies are able to process both the mechanical sensor and the ASIC (and hence the complete accelerometer), while silicon foundries sometimes only have the capabilities to process the ASIC (the electronic part). Often these foundries (MEMS-exclusive but also non-MEMS exclusive) develop their own technological (manufacturing) competences and hold a number of patents on in-house

[95] http://www.memsindustrygroup.org/i4a/headlines/headlinedetails.cfm?id=551

[96] In fact, almost all IDM's outsource at least part of their production, but this varies from company to company. The term IDM should therefore be interpreted as companies having a substantial part but not necessarily all of the production done in house.

[97] http://www.memsindustrygroup.org/i4a/headlines/headlinedetails.cfm?id=551

developed manufacturing technology. MEMS foundries also tend to offer a number of services aimed at facilitating the translation of design in a successful product, going from co-design to custom specific process development and packaging and testing.

In Europe there is considerable foundry activity, distributed over four countries. Silex Microsystems has recorded a strong growth in the field of MEMS and has become a strong player thanks to its in-house developed manufacturing technology which allows close integration of the ASIC and sensor. It is an example of a company demonstrating that technological competencies can be a differentiator in the foundry business. However, the EU foundry companies are relatively small and given that only a part of their revenues stem from accelerometer production[98], their economic weight compared to large accelerometer producers such as STMicroelectronics and Robert Bosch is rather small.

Outside the EU, it can be observed that US companies are somewhat less present in the foundry segment compared to the end-product market. Global Foundries is a leading silicon foundry, but in MEMS it is currently a small player as it has only recently started its activities in this field (including accelerometers), attracted by the good market prospects. The company Teledyne is in the list thanks to its Canada-based subsidiary Dalsa Semiconductor, which has recorded positive growth figures over the past years. IMT is a relatively small company, which is focused on MEMS foundry services, and is an established player in this field. It is also observed that Taiwanese companies emerge strongly in the foundry list compared to the list of accelerometer producers. The less prominent presence of US companies and the strong emergence of Taiwanese companies might be interrelated, as a number of US companies employ Taiwanese foundries for their manufacturing. For example, Invensense operates as a full fabless company, with all the manufacturing done by TSMC. In addition, Analog Devices also outsources the manufacturing of the electronic component (ASIC) of its accelerometer to TSMC.

The Taiwanese foundry giants TSMC and UMC are two examples of the successful development of the semiconductor industry in Taiwan, and in particular of the foundry segment. These firms are silicon foundries that gain the large majority of their sales in the regular semiconductor segments, but are increasingly used by other companies to produce the ASICs component of MEMS, as these large foundries are able to produce very cheaply and in large volume. In addition, the positive growth prospects of the MEMS segment have triggered the attention of these companies, and both have been active in developing skills needed for mechanical sensor production in recent years. Also other silicon foundries are now entering or planning to enter the MEMS segment. The Germany-based company Xfab has invested strongly in MEMS production capacities in recent years and has recorded positive growth figures in this segment. As can be seen in Table 4.8 there are quite some companies that are not exclusively focused on MEMS, and the competition from these companies is expected to grow over the coming years[99].

[98] For example, the MEMS business revenue of Xfab realized a revenue of about 12 million euro in 2010, which is to be divided among accelerometers, gyroscopes, pressure sensors, ... Source : http://www.fabtech.org/news/_a/x-fab_targeting_increased_revenue_from_mems_foundry_services/ and http://www.xfab.com/en/mems0/mems-applications/

[99] Article available at http://www.eetimes.com/electronics-news/4372141/MEMS-foundry-ranking
Article available at http://www.eetimes.com/electronics-news/4397325/X-Fab-pledges-more-money-for-making-MEMS

Table 4.8 - List of foundries active in accelerometer production

Region	Country	Company name	Total Revenue 2011 (million dollar)	MEMS only
EU	Sweden	Silex Microsystems	47	Yes
	France	Tronics	15.2	Yes
	Germany	Xfab	n.a.	No
	UK	Semefab	n.a.	No
Non-EU	Norway	Sensonor	7.5	Yes
	Israel	TowerJazz	611	No
	US	Global Foundries	3 480	No
	US	Teledyne (Dalsa Semiconductor)[a]	1 941 (212[b])	No
	US	IMT	24	Yes
	Canada	Micralyne	15	Yes
	Taiwan	Asia Pacific Microsystems	n.a.	Yes
	Taiwan	TSMC	12 914	No
	Taiwan	UMC	3 855	No
	Malaysia	MEMSTech	n.a.	Yes
	US/Japan	UT - SPP (Silicon Sensing Systems)[c]	n.a.	Yes

Source: IDEA Consult, based on company annual reports

Note: a= when the relevant activities are executed by a given subsidiary, this subsidiary is listed in parentheses behind the mother company; b= total revenue 2012; c= jointly owned by United Technologies (US) and Sumitomo Precision Products (JP)

As mentioned previously, the main driver behind the use of foundry services is to reduce the cost of production. The production infrastructure costs are also quite high, which require production on a large scale. This implies that in the traditional electronics segment as well as the MEMS segments, a significant share of the revenue generated by foundries and IDM's flows to equipment producers. Table 4.9 provides an overview of the fifteen largest equipment suppliers to the semiconductor industry as a whole in 2011. With ASML, the leading supplier of lithography equipment, Europe houses the world's largest semiconductor equipment supplier. However, apart from ASML only one other European company is present in the list, ASM International, also based in the Netherlands[100]. Companies in the US and Japan are well presented in the top 15.

[100] It should be emphasized here that although The Netherlands is known to be attractive for corporate headquarters, the two companies involved effectively also have much of their activities in The Netherlands.

Table 4.9 - Top 15 semiconductor industry equipment suppliers, 2011

Rank 2011	Country	Company name	Total Revenue 2011 (million dollar)
1	Netherlands	ASML	7,877.1
2	US	Applied Materials	7,437.8
3	Japan	Tokyo Electron	6,203.3
4	US	KLA Tencor	3,106.6
5	US	Lam Research	2,804.1
6	Japan	Dainippon Screen	2,104.9
7	Japan	Nikon	1,645.5
8	Japan	Advantest	1,446.7
9	Netherlands	ASM International	1,443.0
10	US	Novellus Systems	1,318.7
11	Japan	Hitachi High-Tech	1,138.7
12	US	Teradyne	1,106.2
13	US	Varian Semiconductor	1096.3
14	Japan	Hitachi Kobusai Electronic	838.4
15	US	Kulicke & Soffa	780.9

Source: VLSI Research (2012)

With regard to the future, an important competitive threat lies in the low investments that have been done over the past decade in Europe in semiconductor production capacity. European companies have followed a strategy of prolonging the life of 150mm and 200mm fabs (see section 2.7.2 for more details on the evolution of wafer sizes in the semiconductor industry) by using them for MEMS production[101]. Investments in 300mm fabs have been low compared to the US and Asia. Europe today has only a very limited market share in the mainstream semiconductor segments (microcontrollers, memory, etc.) where production in most cases is done on 300 mm wafers and with advanced technology. On the other hand, MEMS production can be competitively done without the latest technology (in terms of miniaturization of the structures on a chip) and on 150mm or 200mm wafer fabs, of which there is sufficient installed capacity in Europe. However, with the ongoing depreciation of this older 150mm and 200mm fabs[102] and the expected move of the mainstream semiconductor industry to 450 mm technology, it is expected that within 5-10 years MEMS production will take place on 300mm wafer fabs. Given that there is currently few of such production technology installed in Europe, there is a risk that manufacturing of MEMS (and the associated value added and employment) will move more and more out of Europe. Also, the increasing dependence on foreign countries for an enabling technology such as micro- and nanoelectronics may at some point also give rise to strategic concerns[103].

The problem of low investment in production capacity in Europe has led to a study commissioned by the European commission published in 2012[104]. This study suggests that Europe needs to take advantage of the shift to 450mm production technology, most likely the last major shift in the semiconductor industry in terms of wafer size, to catch up again with investments in production capacity. Indeed, it should be taken into account that once the new 450mm technology is installed (which should be expected within about 5 years), significant spare 300mm capacity will become available in other regions of the world, and it will not make economic sense for the

[101] Source: interviewee

[102] In 2011 about 50 fabs have been closed in the EU, mostly of the 150mm type. Source: http://www.newelectronics.co.uk/electronics-technology/could-450mm-manufacturing-give-the-european-semiconductor-industry-a-new-lease-of-life/40899/

[103] Source: interviewee

[104] SMART 2010/062: Benefits and Measures to Set Up 450mm Semiconductor Prototyping and to Keep Semiconductor Manufacturing in Europe - The role of Public Authorities and Programmes.

EU to invest massively in 300mm capacity[105]. In the study one of the proposed scenario's is to install 450mm capacity initially to safeguard the current strong position in More than Moore (including MEMS and the accelerometer), to expand the scope later on to more advanced technology for More Moore (mainstream semiconductor) production. The investment costs will be so large that they need to be spread out over several years, which calls for a rapid engagement[106].

4.4.3. The EU position in the value chain of the accelerometer

The analysis indicates that EU companies have a solid position in the end-producers segment of the accelerometer market. The EU is represented by a relatively small group of large companies that have a strong base in the automotive market. These companies have also been able to grasp significant shares of the fast growing consumer market. The strongest competition in the end-producers segment comes from US-based companies that consist of a mixture of well established companies and some young, fast growing innovative companies. In the smaller design segment, only a few companies have been identified, all of them located in the EU and US.

In the foundry segment the EU is also well represented, with four companies active in four different countries. Here the main competition is stemming from US, Canada and Taiwan, where regular silicon foundries as well as MEMS foundries are increasingly used by (US) end-producers.

In summary, EU companies are showing a solid performance in the value chain of the accelerometer. European companies dominate the accelerometer end-segment, representing almost half of the total market. Apart from the two large IDMs STMicroelectronics and Robert Bosch, also companies with smaller accelerometer revenues in both the end producer and foundry segment are present. In the foundry segment the EU is well represented with four companies active in four different countries. Here the main competition is stemming from US, Canada and Taiwan, where regular silicon foundries as well as MEMS foundries are increasingly used by (US) end-producers. In the multibillion semiconductor equipment supplier segment, the EU houses the number one company ASML, but overall speaking this segment is dominated by US and Japanese companies. However, it should be noted that this segment is not specific to the accelerometer or even MEMS.

The EU companies show a good performance thanks to a strong background in the automotive industry, good R&D competences and particularly in the case of the two large IDMs also a rapid understanding of the possibilities of new markets and the advantage of large scale production. However, with regard to the future an important competitive threat exists, as investments in new (300mm wafer) production capacity have been low in Europe over the past years compared to the US and Asia. Currently this is not problematic for MEMS (accelerometer) production, since the production wafer scale and technology for MEMS typically lies behind those used in the mainstream semiconductor industry. Yet, with the depreciation of 150mm and 200mm wafer capacity and the transition of mainstream semiconductor industry to 450mm wafer types, manufacturing of MEMS (accelerometers) will occur on 300mm in the not so far future (5-10 years). Therefore there is a risk that manufacturing of these products will move to other regions, primarily Asia, where a lot of spare 300mm capacity will become free once the transition to 450mm wafer technology is done and where the major foundries have shown intentions in recent years to develop their activities in MEMS. Foundries in Asia are already substantially used by the US companies in the accelerometer segment. For Europe it seems that the transition to 450mm should be taken as an opportunity to restore the balance in production capacity and to safeguard its leading position in accelerometers but also MEMS as a whole.

Also in the case of the accelerometer, it has not been possible to calculate the value added captured by European firms in the value chain of the accelerometer. For the accelerometer producers however, a market reports provides information available on the market share of each company, which provides insight in how the different

[105] SMART 2010/062 study, and endorsed by an interviewee
[106] Source: interviewee

regions are performing in the accelerometer market. For companies focusing on specific parts of the value chain, information on the relevance of the accelerometer in their activities is typically more difficult to find since these activities are ‘further away’ from the end product, and is therefore not present in this chapter.

4.5. CONCLUSION

On the basis of the analysis of the value chains of two selected KETs-based products, namely lipase enzymes and the accelerometer, a qualitative assessment has been made of the strength of Europe in these two selected value chains and in particular segments of these value chains. The value chain decomposition allows identifying relevant players in the different phases of the value chain. Hence, based upon the location of these players, an assessment can be made on the importance of European companies in these KETs areas by looking at their activities and financial performance.

At the same time it is fair to say that the results need to be interpreted with care, as a lot of essential information is treated confidentially (because of competition reasons) and is thus not publicly available. As a result, precise figures on the value added captured by EU firms could not be derived as the importance of the investigated KETs products in the overall portfolio of the companies considered, is simply not known.

In general, Europe holds a strong position in two very promising KET-based products. It is a key player in the area of lipase enzymes and the global enzyme market. Europe also has a solid position in the end-producers segment of the accelerometer as some European companies grasp a significant share of the automotive and consumer market, two markets where accelerometers are applied. Competition is nevertheless strong, especially in the foundry segment. Future developments in the semiconductor production capacity may influence (and even threaten) this success on the longer run.

CHAPTER 5. THE POSITION OF EUROPE IN THE PRODUCTION AND TRADE OF KETS-RELATED PRODUCTS

5.1. INTRODUCTION

Objective

This chapter focuses on the analysis of the position of Europe in the production and trade of products that are directly related to one of the six KETs. The main purpose is to identify the position that Europe holds in global value chains within each KET as compared to the main competitor regions, North America and East Asia. The analysis investigates whether Europe focuses on products that are more technologically advanced and on products that are characterised by quality competition (rather than price competition). In contrast to the previous chapter, this analysis is not based on case studies but rather attempts to draw a representative picture by employing country-level data for Europe, North America and East Asia. Furthermore, profiles for selected European countries[107] are provided.

Europe's position in the production and trade of KETs is evaluated by three approaches,

(1) the technology content of the manufactured goods (chapter 5.3);

(2) the type of competition Europe's exports in KET-related products face (chapter 5.4);

(3) the link between the creation of new technological knowledge and the technology content of manufactured goods (chapter 5.5).

For this purpose, export and import unit values are calculated to identify KETs-based products for which the EU-28 shows improving or deteriorating competitiveness over time (see box 5-1 below).Before that, the EU28's position in international trade is explored in the identified subfields of KETs-based products (chapter 5.2).

It is important to note that the analysis in this chapter is based on data for individual KET products, i.e. products that represent certain technological artefacts that are directly related to a KET (e.g. a certain new material, a photonics element, a semiconductor, a biochemical entity or a machine tool), but not for KETs-based products that use KETs as an input for more complex goods (such as batteries, measuring instruments, medical devices, information and communication devices). The notion of 'value chain' as used in this chapter therefore entirely refers to the division of labour within the production of KET products.

Trade Indicators

International trade is a useful performance indicator as it shows whether technology produced in one country can be commercialised in other countries as well. Export success of technology is often regarded as a higher level of performance compared to domestic sales since exporters have to overcome certain liabilities of foreignness, such as a lack of reputation, higher transaction costs and costs to adjust technology to specific local requirements. New technology that is successfully commercialised on international markets may thus contain a particular innovative superiority or a price advantage which both can contribute to overcoming the barriers of entering foreign markets. However, international trade is also affected by factors other than price and quality of products, such as exchange rates, tariff and non-tariff barriers to trade (e.g. regulations that discriminate against foreign products relative to domestic products), transport costs and the macroeconomic environment.

---

[107] Germany, France, United Kingdom, Italy, Belgium, Netherlands, Austria, Denmark, Sweden, Poland, Czech Republic, Hungary.

Three trade indicators are applied here**:**

- **Significance** only relates to export activities and measures the share of a country's exports in a certain KET over the country's total exports and depicts how important that KET is for a country's export activity.

- Two further trade indicators - **trade balance** and **specialisation** - relate exports to imports. The **trade balance** identifies whether a country is a net exporter or importer of a certain KET. It links the difference between exports and imports to the total trade volume (exports plus imports). A positive value shows that the country exports more than it imports within a certain KET area which indicates some form of competitive advantage.

- **Specialisation** is measured by a standard indicator in trade analysis, the so-called revealed comparative advantage. This indicator relates the ratio of exports to imports in a certain country to the same ratio for all countries considered. If this rate is higher than average in a certain country, it shows that the country is capable of yielding higher exports than imports compared to other countries for the respective KET (even in case imports exceed exports). If a country is able to export more than it imports -compared to a peer group of countries- then this country is likely to have a comparative advantage and is specialised in the export of this KET.

Unit value approach to identify EU-28's position in global value chains

A standard way to analyse a country's position in global value chains would be to look at input-output data and evaluate the composition of a country's products with respect to their position in a value chain from row products to end products. This approach is not feasible for KETs, however, since not enough detailed input-output data are available.[108] An alternative way is to employ trade data:[109] first, they offer a very detailed breakdown of individual products which can be directly linked to KETs. Secondly, the problem of missing data due to confidentiality is much less severe than for production data. Thirdly, trade data contain information on both prices and quantities which enables the construction of indicators on product competition and technology content. Fourthly, trade data can be used as proxies for the structure of production in a country in the absence of reliable actual production data. For open economies, export data are typically quite representative for the total production of products that are subject to intra-industrial trade. Since each country within an industry specialises in certain products and tries to exploit economies of scale, a large share of manufacturing output is exported. This is particularly true for KET-related products which are traded globally. Many KET-related products are inputs for other products manufactured in other countries, resulting in a high share of internationally traded KET-related products.

In this report, two trade indicators are used: unit values and trade balance. **Unit values** denote the value of one unit of a product, expressed in currency units per weight. While unit values generally depend on demand and prices, a higher unit value typically indicates that a product contains a higher amount of value added. For very similar products, higher unit values can thus be associated with a higher 'technology content', e.g. higher knowledge input or the use of more advanced manufacturing methods resulting in a higher product quality (in terms of innovativeness, technological sophistication, design, advertising or added value services).[110] Changes in unit values over time may reflect changes in quality as well as shifts to higher product segments or other value enhancing features. Differences in unit values across countries and over time can be interpreted as differences in 'technology content' and can represent different positions of countries along the value chain. However, unit

[108] In a feasibility study for a KETs Observatory (van de Velde et al., 2013), 8-digit codes of product classifications were used to define KETs-related products while input-output data typically provide information only at the 2-digit level.

[109] Initially, it was also planned to use production data from the Prodcom database of Eurostat and similar databases for non-EU countries. It turned out, however, that production data are by far too incomplete to allow any meaningful analysis at a detailed (8-digit) level of product codes.

[110] See, for instance, Aiginger (2000).

values for homogenous products may differ if one producer is able to enforce a higher price than other producers, e.g. due to market power. In an international comparison, exchange rates may also alter unit values for homogenous products. This is particularly true if exchange rates are not resulting from market transactions but are determined by governments. For example, if a currency is undervalued vis-à-vis the US-$ or the Euro, unit values expressed in US-$ or Euro will be underestimated, too.

The **trade balance** gives the difference between exports and imports and can be expressed either in values (currency units) or quantities (weights). For homogenous products, trade balance in quantities tends to represent the competitive advantage or a country's producers by either being able to export more or less to competitor countries than producers from these countries can sell on their home market.

Based on unit values and trade balance, two sets of indicators are produced (see Figure 5.1 for an illustration of the approach):

a) **Export unit values as indicators of technology content**: Export unit values are used to determine the technology content of KET-related products. Based on the assumption that a country's exports of a certain product represent a country's total production of this product, export unit values represent the average value of a product manufactured in this country. The assumption is somewhat unrealistic, though, since many studies have shown that exports tend to contain more innovative products than the average output of a certain product since it is the more innovative firms that engage in exports (see Wakelin, 1998; Bleaney and Wakelin, 2002; Beise and Rammer, 2006; Wagner, 1996; Ebling and Janz, 1999; Roper and Love, 2002; Lefebvre et al., 1998). For this study, the bias of exports towards innovative products can be seen as an advantage because this means to focus the analysis on the more innovative products within each KET.

   A country's (or region's) export unit value of a certain product is compared to the export unit value of this product in global trade. A value greater than 1 indicates that the country (region) manufactures (and exports) products of a higher value per unit, i.e. products with a higher technology content. Comparing export unit values over time informs about the dynamics in technology content, i.e. whether a country (region) moves away from the average unit value or converges to it. Combining both dimensions -level and dynamics of unit values- stretches a four field matrix. For each KET-related product, a country (region) can be positioned in the following way:

   (1) high and increasing technology content

   (2) high but decreasing technology content

   (3) low but increasing technology content

   (4) low and decreasing technology content

b) **Export/import unit values and trade balance as indicators of the type of competition**: Aiginger (1997, 2000) proposed a method to classify products according to quality and price competition based on the relation of a country's (region's) export unit values to import unit values on the one hand, and on a country's (region's) trade balance on the other hand. Products for which higher (lower) prices -i.e. export unit values are higher (lower) than import unit values- are associated with a negative (positive) trade balance are price elastic, i.e. price competition dominates. Products for which higher (lower) prices result in a positive (negative) trade balance are price inelastic, i.e. quality competition dominates. Combining the relation of export to import unit values with the trade balance stretches a four field matrix in which a country (region) can be positioned for each KET-related product:

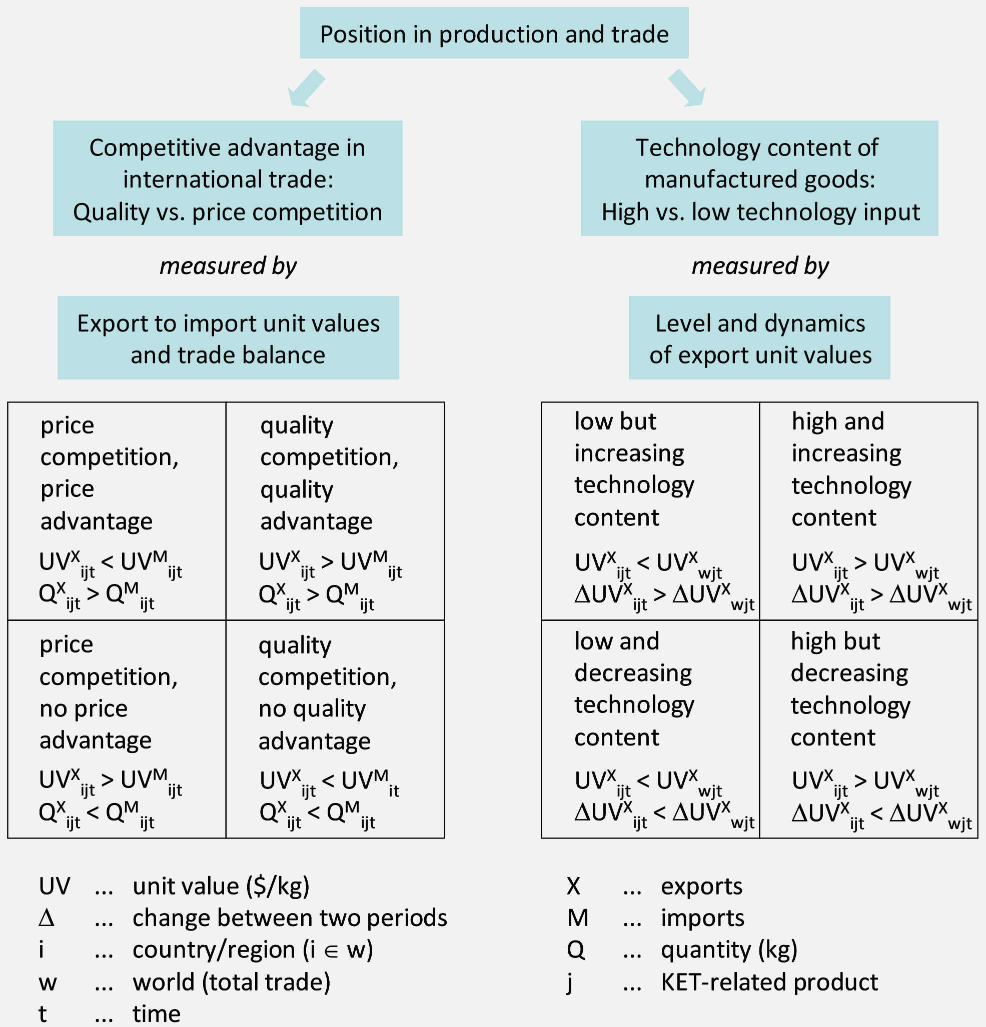
   (1) Quality competition with a quality advantage is the case when export unit values exceed import unit values and the trade balance is positive (i.e. a country can export more of a certain product than it imports despite higher prices)

(2) Quality competition without quality advantage exists in case export unit values are lower than import values, but the trade balance is negative (i.e. a country imports more than it exports despite lower prices, indicating that quality is the main driver for trade)

(3) Price competition with a price advantage occurs if a country shows lower export than import unit values and can translate lower prices into a positive trade balance

(4) Price competition without a price advantage emerges in case of higher export than import unit values along with a negative trade balance.

Figure 5.1: Methodology to analyse Europe's position in production and trade of KETs-related products



Source: NIW/ZEW, partially based on Aiginger (1997)

When analysing unit values, it is essential to use a highly disaggregated product level which represents products as homogenous as possible. Unit values for a group of different products (e.g. for an entire KET) represent aggregate prices of very different individual products. For aggregated unit values country differences, differences between export and import unit values, and changes over time most likely signify alterations in the product composition of the aggregate rather than changes in the technology content and prices. A similar issue arises if the product level considered includes products at different stages of the value chain. In such a case, more basic products that rest on only a few inputs will show lower unit values than more complex products that combine different intermediaries.

The technology content TC and competitive advantage CA of a country (region) i in a certain KET k is examined by determining the position p in the quadrants shown in Figure 5.1 (p ∈ {1,2,3,4}) of each individual product j belonging to KET area k weighted by the product's share in total exports X of products related to KET area k of country (region) i:

$$TC_{p,i,k} = \Sigma_j X_{i,j(k),p} / \Sigma_{i,p} X_{i,j(k),p}$$

$$CA_{p,i,k} = \Sigma_j X_{i,j(k),p} / \Sigma_{j,p} X_{i,j(k),p}$$

TC_p and CA_p hence indicate the share of products within a certain KET area that fall into one of the four positions p.

The link between technology production and the technology content of products is investigated using regression analyses. The level of export unit values for each product j belonging to a KET k in country i in period t are explained by the country's patent intensity in the respective KET area k (distinguishing subfields s within each KET k) in a preceding period t-n. Country-specific variables such as size (gross domestic product - GDP) and labour productivity (GDP per capita) control for effects of market size and the sophistication of the production system while time dummies are used to capture changes in prices over time:

$$\ln(UV^X)_{i,j(k),t)} = \alpha + \beta_1 \ln(PINT)_{i,s(k),t-n} + \beta_2 \ln(GDP)_{i,t} + \beta_3 \ln(PROD)_{i,t} + \Sigma_t \chi_t d_t + \varepsilon_i \quad \text{with } s,j \in k$$

Patent intensity (PINT) is measured by the number of patent applications per population and indicates to what extent a country produces new technological knowledge in a certain subfield of KETs when controlling for country size. In order to better capture non-linear relations, all variables are measured in logarithms.

Data

The analysis is performed for individual KET-related products defined as 6-digit classes of the product classification system used in trade statistics, the HS (harmonised system). In order to identify KET-related products, a conversion table produced in the context of a feasibility study for a 'KETs Observatory' (Van de Velde et al., 2013) is used. This table links Prodcom 8-digit codes to KETs. The feasibility study proposed a long list of Prodcom codes, including a number of products that are only partially related to KETs. In this report, a more narrow definition is applied that only uses products for which a proper link between an HS code and the respective KET activity can be established. This 'short list' of codes is presented in the Annex both for the Prodcom codes and the HS codes. The short list was established using information from the feasibility study, including results from expert workshops.

Export and import data needed to calculate unit values and trade balance are taken from the UN Comtrade database. All export and import values are expressed in US-$. The analysis covers the period from 2002 to 2011. Data for 2007 to 2011 rest on the HS 2007 classification while data for 2002 to 2006 are based on HS 2002. A conversion table is used to link the two classifications. To balance unit value fluctuations between single years the analysis focuses on the development between two sub-periods, 2002 to 2006 and 2007 to 2011. Box 5-1 provides some additional information on measurement issues related to unit values.

To classify products by technology content, changes in unit values between 2002-2006 and 2007-2011 are calculated. It is important to note that exchange rates between Euro and US-$ significantly changed between the two periods. While the average Euro to US-$ exchange rate was 0.87 during 2002-2006, it fell to 0.72 during 2007-2011. As a consequence, unit values expressed in US-$ per kg tend to increase stronger for products traded in Euro than for products traded in US-$. There might be an overestimation of changes in unit values for countries predominantly trading in Euro compared to countries mostly trading in US-$.

Box 5-1: Unit values: measurement issues[111]
The unit value is defined as the nominal value of a traded product divided by the physical volume that has been traded. In this study, Comtrade data are used to calculate unit values. Unit values are measured in US-$ per kg. US-$ data in Comtrade are derived by converting other currencies to US-$ based on the exchange rate at the time the trade was carried out. The unit value in general depends on demand and prices but specifically reflects changes in quality as well as shifts to higher product segments and to other value enhancing features (level of technology or innovation, design, service etc.). Therefore, unit values are often applied as indicators to measure quality or vertical product differentiation. Unit value analysis is predominantly meaningful at the most disaggregated product level (here: HS 2007 8-digit) since unit values for a group of products (e.g. for an entire KET) represent aggregate prices and quantities of very different individual products. For some products, however, value or (more often) net weight information is missing or implausible for some countries. After carefully testing basic data, imputation methods were used for missing or implausible data to correct the latter.

Unit values may also depend on the capital intensity of production. Industries that intensively use physical capital in large-scale production (e.g. basic chemicals) often exhibit rather low unit values. Thus, unit values for industrial biotechnology, nanotechnology and advanced materials rank much lower than those for micro- and nanoelectronics, photonics and AMT for other KETs, where the use of research and/or skilled labour is more decisive.

To clarify the influence of exchange rates changes on unit values, the latter were additionally calculated, weighted by purchasing power parity (PPP-$). The results show partly differing levels (particularly higher for East Asia), but identical trends, developments and relations between the three regions (c.f. appendix tables 8.3 and 8.4). Thus, it can be expected that changes in exchange rates will not significantly influence the classification of KETs-based products by technology content.

The main analysis is conducted for the following three regions:

- EU-28 (EU member states including Croatia)
- North America (USA and Canada)
- East Asia (Japan, South Korea and China)[112]

These three regions form the triad and constitute 'total trade' for calculating technology content indicators Furthermore, country profiles are presented for 12 EU member states: Germany, France, United Kingdom, Italy, Belgium, Netherlands, Austria, Sweden, Denmark, Poland, Czech Republic and Hungary.

39 countries enter the analysis concerning the link between the creation of new technological knowledge and the technology content of manufactured goods, including all EU-28 countries, Iceland, Norway, Switzerland, Macedonia, the USA, Canada, Japan, South Korea, China, Russia and Israel. Data on patents are taken from the Patstat database provided by the European Patent Office. For more details on data source and definitions, see Chapter 2.1.

5.2. TRADE PERFORMANCE AT A GLANCE

In 2011 the export volume of KET-related products accounted for approximately 700 bn. US-Dollar (about 500 bn. EUR) in total for the triad. With respect to the export volume of manufactured industrial goods this makes up a total share of 7 percent. Advanced materials constitute by far the highest export volume (280 bn. US-Dollar or 200 bn. EUR) accounting for 40 percent of total triad exports of KET-related products. Micro- and nanoelectronics rank second with 170 bn. US-Dollar (125 bn. EUR) and a share of 25 percent, followed by photonics with 150 bn. US-Dollar (105 bn. EUR) and a stake of 20 percent. 'AMT for other KETs' accounts for 8 percent of all KET-related exports (55 bn. US-$ or 40 bn. EUR). Industrial biotechnology constitutes less than 17 bn. US-Dollar (12 bn. EUR) with a stake of 2.5 percent. The triad export of nanotechnology products achieve

[111] For a detailed discussion, see Aiginger (1997, 2000).

[112] In contrast to the patent analysis in Chapter 2.2, Taiwan had to be excluded from the trade data analysis since no trade data for have been published for Taiwan in Comtrade.

13 bn. US-Dollar (less than 10 bn. EUR), thus, accounting for less than 2 percent of total KET-related products exports.

Table 5.1 – Share of exports in KET-related products in total exports of manufacturing products 2002-2011, by main regions

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
					EU-28					
Industrial Biotechnology	0.18	0.18	0.18	0.17	0.14	0.15	0.15	0.19	0.19	0.18
Nanotechnology	0.13	0.13	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14
Micro- and Nanoelectronics	1.53	1.32	1.39	1.26	1.08	0.92	0.76	0.65	0.71	0.64
Photonics	0.23	0.24	0.24	0.27	0.30	0.34	0.43	0.46	0.59	0.52
Advanced Materials	2.28	2.33	2.38	2.48	2.47	2.54	2.50	2.47	2.67	2.70
AMT for other KETs	0.42	0.42	0.42	0.43	0.45	0.51	0.51	0.55	0.50	0.52
All KETs	*4.76*	*4.63*	*4.73*	*4.73*	*4.56*	*4.59*	*4.47*	*4.46*	*4.79*	*4.68*
					North America					
Industrial Biotechnology	0.13	0.15	0.14	0.13	0.14	0.12	0.13	0.16	0.15	0.14
Nanotechnology	0.11	0.11	0.10	0.10	0.10	0.11	0.11	0.13	0.17	0.18
Micro- and Nanoelectronics	4.54	4.85	4.37	3.93	3.76	3.08	2.89	2.85	2.83	2.37
Photonics	0.53	0.51	0.58	0.58	0.55	0.55	0.61	0.78	0.77	0.68
Advanced Materials	2.54	2.62	2.69	2.79	2.85	2.97	2.97	3.07	3.29	3.26
AMT for other KETs	0.47	0.45	0.49	0.47	0.46	0.45	0.52	0.58	0.60	0.54
All KETs	*8.32*	*8.69*	*8.37*	*8.00*	*7.86*	*7.27*	*7.23*	*7.57*	*7.81*	*7.16*
					East Asia					
Industrial Biotechnology	0.13	0.12	0.12	0.12	0.12	0.11	0.11	0.13	0.13	0.14
Nanotechnology	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.09
Micro- and Nanoelectronics	4.28	4.32	4.33	4.12	3.97	3.76	3.10	3.49	3.62	3.20
Photonics	0.86	1.20	1.57	2.03	2.25	2.57	2.83	3.22	3.81	3.49
Advanced Materials	2.29	2.24	2.30	2.35	2.37	2.49	2.62	2.34	2.56	2.72
AMT for other KETs	0.35	0.36	0.37	0.36	0.35	0.51	0.63	0.60	0.68	0.67
All KETs	*7.98*	*8.31*	*8.75*	*9.04*	*9.12*	*9.51*	*9.36*	*9.85*	*10.88*	*10.29*

Source: COMTRADE Database. NIW calculations.

In East Asia, the significance of KETs is especially high for total manufacturing exports. KETs hold a stake of 1.3 percent, mostly attributable to photonics (3.5 percent) and micro-/nanoelectronics (3.2 percent). Concerning North America, KETs account for more than 7 percent of total manufacturing in this region; regarding the EU-28, this is less than 5 percent (Table 5-1). The lower significance of KET-related trade in North America's and in the EU-28 compared to East Asia is mainly attributed to the small amount of exports in the fields of micro-/nanoelectronics and photonics. In contrast, the export shares in industrial biotechnology, nanotechnology, advanced materials and AMT for other KETs are not very different between the three regions. Advanced materials and nanotechnology are comparably relevant for North America, industrial biotechnology for the EU-28.

Regarding East Asia, KETs have gained significant shares in the export portfolio over the time period from 2002 to 2011 due to comparably small losses in micro-/nanoelectronics but large growth in photonics, Advanced Materials and AMT for other KETs. In the EU-28 the contribution of all KETS to total manufacturing exports hardly changed over time (2002-2011) Diminishing shares of micro-/nanoelectronics have been compensated by rising shares of photonics, advanced materials and AMT for other KETs. Although North America's exports of KETs generally show the same structural development as those in the EU-28 and in East Asia, the relative export gains in other KETs were not sufficient to equalize the losses in micro-/nanoelectronics.

Compared to the EU-28 average, KETs play a specific role in manufacturing exports in Belgium (with particular strengths in advanced materials and industrial biotechnology), Germany (photonics and – less distinctive - AMT for other KETs, advanced materials, and micro-/nanoelectronics), the Netherlands (mainly advanced materials, moreover nanotechnology and micro-/nanoelectronics), and France (micro-/nanoelectronics). Referring to all

KETs, all other selected EU-countries stay behind the EU 28 average. However, each of them exhibits relatively high export shares in at least one KET (Table 5-2).

- United Kingdom and Denmark: industrial biotechnology
- Italy: advanced materials and AMT for other KETs
- Austria: AMT for other KETs
- Sweden: micro- and nanoelectronics
- Poland: nanotechnology
- Czech Republic: micro-/nanoelectronics
- Hungary: nanotechnology, photonics.

KETs have gained increases within the export portfolio of nearly every considered EU-country with the exception of the Netherlands (stagnating shares in total manufacturing exports) and the United Kingdom (decreasing shares due to large losses in micro-/nanoelectronics).

Table 5.2 – Share of exports in KET-related products in total exports of manufacturing products 2002-2011, by selected EU-countries

	2002	*2005*	*2008*	*2011*	*2002*	*2005*	*2008*	*2011*	*2002*	*2005*	*2008*	*2011*
	Germany				**Austria**				**France**			
Industrial Biotechnology	0.11	0.10	0.09	0.10	0.10	0.10	0.07	0.07	0.12	0.13	0.08	0.10
Nanotechnology	0.14	0.13	0.13	0.14	0.06	0.07	0.08	0.07	0.08	0.10	0.11	0.09
Micro- and Nanoelectronics	1.50	1.37	0.94	0.75	1.50	0.87	0.68	0.69	1.49	1.44	1.05	1.49
Photonics	0.43	0.51	0.85	0.98	0.20	0.24	0.44	0.36	0.14	0.16	0.20	0.21
Advanced Materials	2.58	2.61	2.44	2.86	1.02	1.55	1.87	1.86	2.08	2.40	2.41	2.58
AMT for other KETs	0.67	0.66	0.81	0.86	0.62	0.85	0.83	0.71	0.34	0.35	0.37	0.42
All KETs	*5.43*	*5.38*	*5.26*	*5.71*	*3.50*	*3.68*	*3.95*	*3.76*	*4.25*	*4.58*	*4.22*	*4.90*
	Sweden				**United Kingdom**				**Denmark**			
Industrial Biotechnology	0.10	0.08	0.07	0.08	0.27	0.16	0.21	0.23	0.97	0.95	1.00	1.19
Nanotechnology	0.12	0.11	0.12	0.12	0.15	0.14	0.16	0.14	0.06	0.09	0.09	0.12
Micro- and Nanoelectronics	0.31	0.33	0.30	0.75	3.29	1.75	0.68	0.53	0.35	0.27	0.15	0.14
Photonics	0.31	0.30	0.56	0.30	0.30	0.33	0.57	0.53	0.15	0.14	0.24	0.29
Advanced Materials	1.11	1.05	1.19	1.44	2.02	2.29	2.51	2.44	1.00	0.84	0.83	1.04
AMT for other KETs	0.81	0.72	0.66	0.62	0.37	0.36	0.47	0.48	0.47	0.49	0.54	0.53
All KETs	*2.75*	*2.59*	*2.90*	*3.32*	*6.40*	*5.04*	*4.59*	*4.34*	*3.00*	*2.78*	*2.86*	*3.29*
	Italy				**Poland**				**Belgium**			
Industrial Biotechnology	0.07	0.08	0.06	0.07	0.02	0.03	0.03	0.03	0.25	0.36	0.45	0.65
Nanotechnology	0.13	0.13	0.14	0.16	0.06	0.07	0.08	0.18	0.09	0.07	0.09	0.12
Micro- and Nanoelectronics	0.85	0.77	0.40	0.41	0.06	0.06	0.06	0.11	0.41	0.40	0.34	0.16
Photonics	0.11	0.12	0.15	0.17	0.01	0.01	0.03	0.07	0.12	0.19	0.31	0.44
Advanced Materials	1.87	1.90	1.99	2.18	1.83	1.90	2.22	2.60	4.30	5.13	5.00	5.19
AMT for other KETs	0.53	0.60	0.79	0.70	0.26	0.30	0.29	0.25	0.16	0.17	0.21	0.24
All KETs	*3.55*	*3.59*	*3.54*	*3.69*	*2.24*	*2.37*	*2.71*	*3.24*	*5.33*	*6.33*	*6.40*	*6.81*
	Czech Republic				**Netherlands**				**Hungary**			
Industrial Biotechnology	0.06	0.02	0.01	0.03	0.31	0.21	0.17	0.19	0.13	0.05	0.08	0.06
Nanotechnology	0.08	0.09	0.09	0.14	0.21	0.18	0.20	0.18	0.11	0.18	0.17	0.25
Micro- and Nanoelectronics	0.51	0.55	0.59	0.88	0.91	2.84	1.08	0.70	0.24	0.83	0.32	0.57
Photonics	0.11	0.16	0.58	0.74	0.13	0.22	0.25	0.54	0.09	0.16	0.50	0.58
Advanced Materials	1.54	1.93	1.85	1.94	3.45	3.60	3.42	3.39	0.86	1.19	1.98	1.90
AMT for other KETs	0.33	0.34	0.36	0.34	0.25	0.22	0.28	0.27	0.10	0.16	0.30	0.34
All KETs	*2.63*	*3.09*	*3.48*	*4.07*	*5.27*	*7.27*	*5.40*	*5.26*	*1.52*	*2.57*	*3.34*	*3.70*

Source: COMTRADE Database. NIW calculations.

Trade competitiveness does not only show on export markets. The development of imports has to be considered, too. A positive (negative) Revealed Comparative Advantage (RCA) means that the export to import ratio by KET is higher (lower) than the export to import ratio for total manufacturing, thus, indicating a positive (negative) trade specialization (Table 5.3).

Table 5.3 – Specialisation in trade with KET-related products by main regions. RCA: export to import ratio by KET over export to import ratio for total manufacturing (ln*100) 2002-2011

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
					EU-28					
Industrial Biotechnology	-16	-27	-29	-40	-37	-53	-37	-28	-35	-36
Nanotechnology	7	8	10	10	10	16	11	11	10	3
Micro- and Nanoelectronics	-10	-25	-22	-15	-17	-15	-14	-27	-35	-29
Photonics	-24	-25	-34	-39	-43	-39	-56	-61	-79	-72
Advanced Materials	-15	-16	-17	-16	-14	-13	-15	-3	-6	-10
AMT for other KETs	37	39	44	50	53	56	53	58	59	59
					North America					
Industrial Biotechnology	21	42	24	25	14	-1	-19	-12	-2	-20
Nanotechnology	72	67	68	64	55	74	79	85	108	109
Micro- and Nanoelectronics	81	100	95	96	99	90	92	83	77	51
Photonics	61	58	64	67	60	49	41	54	41	8
Advanced Materials	56	59	60	59	67	68	61	82	75	69
AMT for other KETs	50	49	63	58	54	47	61	60	80	60
					East Asia					
Industrial Biotechnology	-25	-24	-18	-11	-4	3	10	17	43	48
Nanotechnology	-58	-51	-48	-55	-47	-37	-38	-34	-31	-11
Micro- and Nanoelectronics	-71	-80	-86	-99	-110	-117	-127	-120	-114	-117
Photonics	-57	-75	-77	-65	-58	-49	-37	-19	-10	-9
Advanced Materials	-44	-48	-43	-44	-46	-50	-52	-58	-52	-46
AMT for other KETs	-60	-61	-59	-49	-45	-42	-35	-34	-39	-47

Notes: The table shows RCA values, i.e. export to import ratio for trade in KET over export to import ratio for total trade (ln*100)

Source: COMTRADE Database. NIW calculations.

Considering this relative export/import-ratio, the EU-28 has an increasingly high trade specialization in AMT and a small but decreasing advantage in nanotechnology (Table 5.3). Concerning the other four KETs, the EU-28's RCA values are negative and, apart from advanced materials, have worsened over the period of investigation. On the other hand, North America attains partly high advantages in trade specialization for nearly all KETs. Only in industrial biotechnology, former positive RCA values have turned negative (Table 5.3). However, North America's advantages of specialization in micro- and nanoelectronics and particularly in photonics show a shrinking trend over time whereas its relative trade position in advanced materials and AMT has further improved. Despite growing export shares in total manufacturing exports, KET-related products have not yet become a meaningful element in this region's foreign trade. Apart from industrial biotechnology RCA values are still significantly negative. Furthermore, the trend over time is not consistent: improvements in nanotechnology, photonics, and AMT stand in contrast to deteriorations in micro- and nanoelectronics and advanced materials.

Although the EU-28 as a whole only gains high positive trade specialization in AMT for other KETs as well as small, but decreasing advantages in nanotechnology, trade specialization patterns distinctly differ between single EU-countries (Table 5.4). Whereas Germany, Italy and Hungary reflect the EU-28 average, exhibiting positive RCA values in nanotechnology and AMT for other KETs, the United Kingdom and the Netherlands succeed in realizing trade advantages in micro-/nanoelectronics and advanced material. Besides AMT for other KETs, France's second relative strength lies in micro-/nanoelectronics. The same holds for Austria, disposing additional trade advantages in photonics. Within the selected EU-countries, only Denmark succeeds in gaining trade advantages in industrial biotechnology, as well as in AMT for other KETs and in photonics, just like Sweden. Belgium only attains comparative advantages with advanced materials. In contrast to Hungary, Poland and the Czech Republic have not been able to realize trade advantages with any KETs-related products.

It is quite remarkable that some countries have succeeded in resisting the general negative trend which can be observed for the EU-28 as a whole. This applies e.g. to France and Austria which both could increase their comparative trade performance in micro-/nanoelectronics. Denmark, Sweden and Austria were able to improve their performance in photonics.

Table 5.4 – Specialisation in trade with KET-related products by selected EU-countries, 2002-2011

	2002	*2005*	*2008*	*2011*	*2002*	*2005*	*2008*	*2011*	*2002*	*2005*	*2008*	*2011*
	Germany				**Austria**				**France**			
Industrial Biotechnology	-74	-91	-112	-114	10	21	-8	-29	-87	-118	-115	-99
Nanotechnology	44	31	23	24	-95	-73	-50	-48	-45	-8	-1	-23
Micro- and Nanoelectronics	-42	-38	-42	-52	15	22	33	46	1	14	34	58
Photonics	-12	-43	-39	-54	-28	-14	5	12	-32	-28	-48	-121
Advanced Materials	-11	-28	-38	-19	-84	-55	-39	-39	-26	-15	-10	0
AMT for other KETs	89	86	97	107	58	88	58	64	13	34	27	50
	Sweden				**United Kingdom**				**Denmark**			
Industrial Biotechnology	-40	-30	-23	-4	53	-88	-15	-26	139	148	171	138
Nanotechnology	-7	-5	-13	-3	66	63	59	42	-72	-45	-27	-13
Micro- and Nanoelectronics	-142	-112	-115	-94	74	35	23	24	-113	-87	-78	-85
Photonics	2	-4	10	19	16	30	44	-3	-23	-28	39	7
Advanced Materials	-86	-102	-92	-57	20	27	28	20	-88	-87	-78	-59
AMT for other KETs	62	66	56	45	41	51	76	77	44	42	56	61
	Italy				**Poland**				**Belgium**			
Industrial Biotechnology	-83	-54	-86	-83	-262	-198	-173	-180	-2	-24	-13	-15
Nanotechnology	9	35	55	62	-165	-129	-107	-59	-12	-21	-11	-16
Micro- and Nanoelectronics	-17	-13	-28	-20	-269	-277	-241	-236	-35	-23	4	-29
Photonics	-86	-77	-143	-269	-244	-283	-359	-297	-53	-3	-22	-66
Advanced Materials	-58	-67	-66	-55	-55	-64	-39	-47	24	37	34	40
AMT for other KETs	76	98	105	87	-70	-39	-49	-49	-43	-20	-20	-10
	Czech Republic				**Netherlands**				**Hungary**			
Industrial Biotechnology	-111	-153	-181	-107	11	4	-2	-9	10	-73	-16	-64
Nanotechnology	-79	-58	-63	-43	63	80	101	74	-13	4	-4	8
Micro- and Nanoelectronics	-168	-138	-97	-79	28	-4	66	13	-249	-184	-254	-186
Photonics	-66	-86	-55	-34	-67	-51	-25	-42	-221	-159	-28	-21
Advanced Materials	-65	-62	-58	-62	39	38	33	41	-87	-113	-35	-47
AMT for other KETs	-52	-3	-20	-28	23	30	24	19	-120	-43	-8	49

Notes: the table shows RCA values, i.e. the export to import ratio for trade in KET over the export to import ratio for total trade (ln*100)

Source: COMTRADE Database. NIW calculations.

The trade balance -which is exports minus imports as a percentage of the sum of exports and imports (see Table 5.5 and Table 5.6)- typically shows in the same direction as the RCA does. Signs sometimes differ, however, because the trade balance only refers to the export/import-ratio of each product group itself whereas RCA also considers its relative position compared to total manufacturing trade.

The EU-28 shows a positive and increasing trade balance for AMT for other KETs and a positive trade balance without a clear upwards or downwards trend for Nanotechnology. EU-28's trade balance for advanced materials is slightly negative in most years but turned positive in 2009 and 2010. In the three other KETs -industrial biotechnology, micro-/nanoelectronics and photonics- EU-28 imports exceed exports and the trade balance tend to get more negative over time, particularly in photonics. For total trade (i.e. trade in all manufactured products), EU-28 reports a positive trade balance of about 4 percent for the entire period.

North America reports a clearly negative trade balance for total trade, but shows positive trade balances for most KETs. The only exception is industrial biotechnology. In this KET, imports increasingly exceed exports, and North America's trade balance became strongly negative in recent years. In Nantechnology, advanced materials and AMT for other KETs, the positive trade balance tends to increase over time while it tends to fall in micro-and nanoelectronics and in photonics.

East Asia reports a highly positive trade balance for total trade as well as for three KETs, industrial biotechnology, nanotechnology and photonics, at least in recent years. Trade balances clearly improved in these three KETs over time, as they did for AMT for other KETs and -to a lesser extent- for advanced materials. The only KET that shows a strong negative trade balance which deteriorates over time is micro- and nanoelectronics.

Table 5.5 – Trade Balance by main regions, 2002-2011 (%)

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
					EU-28					
Industrial Biotechnology	-3.2	-9.2	-10.2	-15.7	-14.2	-23.1	-15.0	-9.8	-13.5	-13.0
Nanotechnology	8.5	8.1	9.1	9.2	9.2	10.9	9.1	9.4	8.9	6.3
Micro- and Nanoelectronics	-0.5	-8.4	-6.9	-3.6	-4.8	-4.5	-3.3	-9.5	-13.7	-9.7
Photonics	-7.5	-8.1	-12.7	-15.5	-17.2	-16.6	-24.0	-25.8	-34.1	-30.5
Advanced Materials	-2.6	-3.5	-4.3	-3.8	-3.1	-3.5	-4.1	2.7	1.1	-0.4
AMT for other KETs	23.1	23.6	25.5	28.4	29.7	30.1	29.6	32.6	32.4	33.1
Total manufacturing	*4.7*	*4.3*	*4.1*	*4.2*	*4.0*	*2.9*	*3.6*	*4.1*	*4.0*	*4.8*
					North America					
Industrial Biotechnology	-8.8	0.4	-9.1	-9.0	-13.0	-18.4	-24.3	-23.2	-18.7	-26.0
Nanotechnology	16.3	12.9	12.7	10.4	7.3	18.4	23.5	24.0	34.5	36.1
Micro- and Nanoelectronics	20.6	28.7	25.5	25.9	28.5	26.5	29.8	23.3	20.3	8.5
Photonics	11.1	8.4	10.5	11.9	9.6	6.4	5.2	9.2	2.9	-12.8
Advanced Materials	8.7	8.7	8.5	8.0	13.1	15.5	14.9	22.5	19.5	17.3
AMT for other KETs	5.7	4.1	10.1	7.2	6.8	5.3	14.8	12.2	22.0	13.0
Total manufacturing	*-19.1*	*-20.3*	*-21.0*	*-21.3*	*-20.0*	*-17.9*	*-15.3*	*-17.7*	*-17.6*	*-16.7*
					East Asia					
Industrial Biotechnology	4.3	3.7	7.8	13.1	18.0	23.2	27.8	28.2	40.3	42.1
Nanotechnology	-12.1	-9.7	-7.0	-8.8	-3.7	3.6	4.7	3.9	5.8	15.2
Micro- and Nanoelectronics	-18.6	-23.8	-25.6	-30.1	-33.7	-35.1	-38.2	-37.4	-34.4	-35.7
Photonics	-11.8	-21.7	-21.5	-13.8	-9.1	-2.4	4.8	10.9	15.9	16.3
Advanced Materials	-5.3	-8.4	-4.6	-3.3	-3.0	-3.2	-2.6	-8.2	-4.9	-2.1
AMT for other KETs	-13.4	-14.6	-12.8	-5.9	-2.6	1.0	5.8	3.7	1.4	-2.5
Total manufacturing	*16.5*	*15.5*	*16.6*	*18.2*	*19.8*	*21.6*	*23.1*	*20.4*	*20.8*	*20.7*

Source: COMTRADE Database. NIW calculations.

At the level of EU member states, trade balances vary substantially by KET (Table 5.6). For each KET, at least some EU countries show positive trade balances.

- In industrial biotechnology, Denmark reports a particularly strong trade performance for the entire period. In the Netherlands, exports of products related to industrials biotechnology also exceed imports, though trade surplus falls over time. Sweden was able to turn a negative trade balance in this KET into a slightly positive one in recent years.

- Strong positive balances in the trade with products related to nanotechnology can be found for the Netherlands, Italy and Germany. In addition, the UK and Sweden (with a declining trend) as well as Hungary (with an increasing trend) also report positive trade balances for this KET.

- Three EU member states (out of the group of 12 countries considered here) show a positive trade balance in micro- and nanoelectronics. Both Austria and France increased their trade surplus over time while the Netherlands report substantial fluctuations, though the trade balance is positive in all years.

- In Photonics, Austria and Denmark were able to turn a trade deficit into a surplus over the past decade while Sweden could maintain a positive trade balance throughout the entire period. In Germany and the UK, the trade balance was negative in the most recent year (2011) though it was positive in earlier years. Hungary reports an almost balanced trade in photonics in 2011 while the trade balance was strongly negative at the beginning of the last decade.

- Germany and Belgium are the only two EU member states among the 12 countries considered here that do export more products related to advanced materials than they import. While Belgium was able to increase the trade surplus over time, no clear trend can be observed for Germany.

- AMT for other KETs is clearly a strength of EU trade. 10 out of the 12 EU member states considered report a positive trade balance in 2011. Poland and the Czech Republic are the only two countries with a negative trade balance. In almost all countries, trade performance improved over the past decade or remained at a very high level.

Table 5.6 – Trade Balance by selected EU-countries, 2002-2011 (%)

	2002	*2005*	*2008*	*2011*	*2002*	*2005*	*2008*	*2011*	*2002*	*2005*	*2008*	*2011*
	Germany				**Austria**				**France**			
Industrial Biotechnology	-20.0	-27.0	-35.3	-39.3	7.7	13.1	-2.1	-15.4	-37.5	-52.7	-53.7	-50.0
Nanotechnology	37.1	32.4	29.6	26.6	-42.2	-32.4	-22.7	-24.7	-18.4	-3.4	-3.3	-16.6
Micro- and Nanoelectronics	-4.3	-0.9	-2.2	-10.5	9.8	13.7	18.3	21.5	4.6	7.7	14.3	23.4
Photonics	10.6	-3.4	-0.3	-11.7	-11.5	-4.1	4.6	5.0	-12.2	-13.4	-26.1	-57.8
Advanced Materials	11.5	3.9	0.2	5.9	-37.6	-24.2	-17.4	-20.3	-9.0	-7.0	-7.6	-5.2
AMT for other KETs	54.5	54.5	58.8	59.7	30.3	43.6	30.0	30.1	10.5	17.2	10.8	19.7
Total manufacturing	*16.6*	*17.8*	*18.8*	*15.2*	*2.5*	*2.9*	*1.9*	*-1.0*	*4.0*	*0.6*	*-2.6*	*-5.2*
	Sweden				**United Kingdom**				**Denmark**			
Industrial Biotechnology	-5.5	-1.5	-2.7	6.1	15.7	-50.5	-21.9	-25.7	62.1	63.4	68.7	61.3
Nanotechnology	10.8	11.2	2.1	6.7	21.9	19.7	14.4	7.9	-31.8	-21.0	-14.7	-4.3
Micro- and Nanoelectronics	-51.2	-39.9	-45.3	-37.1	25.9	5.7	-3.2	-1.0	-48.8	-40.0	-38.4	-38.2
Photonics	15.4	11.5	13.4	17.3	-2.7	3.4	6.8	-14.3	-8.4	-12.9	17.7	5.6
Advanced Materials	-27.7	-35.9	-35.7	-20.4	-0.9	1.9	-0.8	-3.2	-38.7	-40.3	-38.4	-26.8
AMT for other KETs	42.6	43.4	35.2	29.5	9.8	13.8	22.6	25.1	24.7	21.5	25.9	31.8
Total manufacturing	*14.3*	*13.4*	*8.6*	*8.0*	*-10.7*	*-11.7*	*-14.81*	*-13.0*	*3.1*	*0.9*	*-1.4*	*2.2*
	Italy				**Poland**				**Belgium**			
Industrial Biotechnology	-31.9	-19.5	-32.5	-32.6	-89.1	-76.8	-72.0	-70.7	6.2	-6.1	-1.8	-0.9
Nanotechnology	12.9	24.4	34.9	36.7	-73.7	-58.6	-51.9	-26.6	1.3	-4.7	-0.6	-1.4
Micro- and Nanoelectronics	0.0	0.8	-5.1	-2.1	-89.8	-88.8	-84.7	-82.0	-10.1	-5.4	6.9	-8.3
Photonics	-33.3	-30.1	-55.2	-85.3	-87.1	-89.4	-95.0	-89.9	-19.0	4.6	-6.2	-25.8
Advanced Materials	-20.2	-25.5	-23.5	-19.6	-37.7	-33.4	-23.3	-21.1	19.0	23.8	21.5	25.7
AMT for other KETs	43.2	50.8	55.0	47.1	-43.9	-21.7	-27.9	-22.1	-14.0	-4.1	-5.3	1.4
Total manufacturing	*8.3*	*7.2*	*9.1*	*7.7*	*-11.99*	*-2.6*	*-4.0*	*2.0*	*7.49*	*5.9*	*4.8*	*6.4*
	Czech Republic				**Netherlands**				**Hungary**			
Industrial Biotechnology	-50.1	-62.4	-69.3	-43.2	12.8	13.3	7.7	4.5	2.3	-33.5	-3.7	-21.4
Nanotechnology	-37.2	-25.2	-25.8	-14.1	36.8	47.2	53.1	42.9	-9.3	3.8	2.0	14.3
Micro- and Nanoelectronics	-68.4	-57.5	-40.8	-31.0	21.1	9.1	39.3	15.5	-85.5	-71.8	-84.3	-68.0
Photonics	-31.5	-37.5	-22.0	-9.5	-25.4	-14.1	-3.6	-11.7	-81.3	-65.0	-10.1	-0.5
Advanced Materials	-31.1	-26.9	-23.4	-23.2	26.2	29.4	24.9	28.8	-43.3	-49.9	-13.3	-13.2
AMT for other KETs	-25.0	1.8	-4.8	-6.5	18.6	25.8	20.5	18.3	-55.6	-19.5	0.3	33.4
Total manufacturing	*0.5*	*3.4*	*5.1*	*7.4*	*7.3*	*11.1*	*8.7*	*9.0*	*-2.8*	*1.69*	*4.0*	*10.1*

Source: COMTRADE Database. NIW calculations.

5.3. TECHNOLOGY CONTENT OF KET-RELATED PRODUCTS

Level and dynamics of export unit values

In 2011, the EU-28 only showed higher export unit values than the other two regions for industrial biotechnology. In four other KETs -nanotechnology, micro-/nanoelectronics, photonics and AMT for other KETs- average unit values were below those of North America and East Asia. In advanced materials, the EU-28 reported a lower unit value than East Asia but a slightly higher one than North America (Table 5.7). Between 2002 and 2011, unit values of the EU-28 were increasing in all KETs except for photonics; not all KETs show a steady increase, though. In AMT for other KETs, EU-28 unit values increased until 2008 but have been falling since. In micro-/nanoelectronics unit values fluctuate heavily from year to year without revealing a clear trend.

In North America, unit values clearly increased in nanotechnology, photonics, advanced materials and AMT for other KETs and stayed rather stable in industrial biotechnology and micro-/nanoelectronics. North America reports the highest export unit values in 2011 for nanotechnology, photonics and AMT for other KETs while unit values in industrial biotechnology were the lowest among the three triadic regions. For a couple of years North America's increasing unit values in photonics have been going hand in hand with decreasing unit values for the EU-28 and East Asia. This phenomenon is primarily attributable to differences in product composition. Trade in the field of photonics both in the EU-28 and in East Asia is highly dominated by products which have been experiencing high drops in prices over time (particularly *photosensitive semiconductor devices* which also include photovoltaic cells [113], but also *liquid crystal devices and other optical appliances and instruments)*. North America's product portfolio is more aligned to products with increasing unit values (c.f. *lasers* or *instruments and appliances for physical or chemical analysis*).

Table 5.7 - Average export unit values 2002 to 2011 in EU-28, North America and East Asia by KET

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
					EU-28					
Industrial Biotechnology	2.9	3.3	3.4	3.6	3.3	3.9	4.6	5.1	4.2	4.9
Nanotechnology	1.1	1.2	1.3	1.4	1.6	1.8	2.0	1.9	1.9	2.1
Micro- and Nanoelectronics	385	324	528	414	496	321	235	507	343	477
Photonics	85.5	97.2	99.8	87.7	79.7	80.3	70.1	55.8	38.0	31.4
Advanced Materials	1.3	1.5	1.7	1.9	2.0	2.1	2.4	2.2	2.2	2.5
AMT for other KETs	13.9	15.0	17.0	18.3	18.3	21.6	24.7	24.3	23.0	18.5
					North America					
Industrial Biotechnology	1.7	1.3	1.1	1.1	1.3	1.5	1.5	1.2	1.4	1.6
Nanotechnology	2.0	1.9	1.8	1.8	2.2	2.4	2.6	2.9	3.8	4.4
Micro- and Nanoelectronics	671	699	706	676	717	671	660	661	644	704
Photonics	137.2	159.7	140.3	87.1	150.1	154.5	158.2	165.8	172.3	173.3
Advanced Materials	1.4	1.4	1.5	1.8	1.9	2.0	2.1	1.9	2.2	2.4
AMT for other KETs	18.1	20.3	20.5	15.4	20.8	23.4	26.7	31.1	31.0	29.5
					East Asia					
Industrial Biotechnology	1.6	1.5	1.6	1.7	1.5	1.5	2.0	1.6	1.7	1.8
Nanotechnology	1.4	1.5	1.5	1.6	1.8	1.8	2.2	1.9	2.1	2.3
Micro- and Nanoelectronics	682	689	732	744	821	1058	992	1011	1136	1306
Photonics	87.7	105.7	124.8	108.4	104.5	67.9	59.3	49.0	50.0	45.9
Advanced Materials	1.4	1.5	1.6	1.8	2.0	2.1	2.4	2.0	2.4	2.9
AMT for other KETs	12.5	13.4	14.5	12.3	13.2	15.7	19.1	18.2	22.4	23.5

Source: COMTRADE Database. NIW calculations.

East Asia reports an upward trend of unit values in micro-/nanoelectronics, nanotechnology, advanced materials and AMT for other KETs. Unit values in industrial biotechnology peaked in 2008 while photonics showed a declining trend. East Asia's specific strength lies in micro- and nanoelectronics, a very homogenous group of only four products covering different forms of electronic integrated circuits. East Asia's export unit values have been steadily increasing over time and are now nearly twice as high as the respective values for North America and three times as high as compared to the EU-28. Furthermore, East Asia is slightly leading in terms of export unit values in advanced materials. In a regional comparison, however, only advanced materials show similar levels and variations in export unit values while for all other five KETs both the level and the dynamics of unit values differ significantly among the three regions. The uniform trends in advanced materials may be attributed to the size of this KET, which covers about 180 different products, implying that a peculiar development of a distinct product has less impact on the average unit value of this KET.

Advanced economies are supposed to realize higher export unit values than less developed countries. Hence, it is not surprising that large EU-countries like Germany, France, United Kingdom and Italy, but also smaller countries in northern and middle Europe (Belgium, Netherlands,, Austria, Sweden, Denmark) generally attain unit values that are distinctly higher than the EU-28 average and, in some cases, higher than those applying to North America or East Asia (Table 5.8). This is especially valid for micro-/nanoelectronics regarding France Sweden and Germany, for nanotechnology referring to United Kingdom, Belgium and Denmark, for photonics particularly in the Netherlands and Denmark, and - less distinctive - in France, United Kingdom, Austria and Sweden. In advanced materials, Denmark, United Kingdom, and Germany achieve the highest export unit values. Regarding AMT for other KETs, Germany, Sweden, Austria and France are holding the leading position, in which Germany, Austria and Sweden achieved the highest growth rates over time. Poland, the Czech Republic and

[113] See, for instance, REN21 (2012) or Jäger-Waldau (2011).

Hungary are catching-up, but, in most cases, still fall short of the selected EU-15 countries. Furthermore remarkable is that the considerably decreasing trend in photonics observed for the EU-28 does not apply to the Netherlands and Denmark.

Table 5.8 - Average export unit values 2002 to 2011 in selected EU member states by KET

	2002	2005	2008	2011	2002	2005	2008	2011
	Germany				**Austria**			
Industrial Biotechnology	2.8	3.6	3.9	4.4	5.8	3.9	3.3	3.7
Nanotechnology	1.4	1.7	2.3	2.3	1.1	1.2	1.4	1.3
Micro- and Nanoelectronics	799.1	1134.2	1238.6	753.3	693.7	705.0	721.4	637.9
Photonics	118.4	133.4	85.2	40.1	165.4	43.0	31.0	55.0
Advanced Materials	1.6	2.3	2.9	3.3	1.7	1.9	2.3	2.6
AMT for other KETs	17.8	24.3	34.2	39.2	13.5	19.9	26.4	31.5
	France				**Sweden**			
Industrial Biotechnology	5.1	7.2	9.9	10.4	4.5	5.8	4.3	8.9
Nanotechnology	1.1	1.6	2.2	2.4	1.2	1.8	2.3	2.6
Micro- and Nanoelectronics	170.7	209.5	1251.3	1023.2	122.4	103.1	305.1	876.0
Photonics	84.0	80.4	81.2	58.9	168.7	74.7	68.1	60.5
Advanced Materials	1.3	1.9	2.6	2.6	1.3	2.0	2.7	2.3
AMT for other KETs	20.9	24.6	31.4	30.7	16.6	22.8	37.4	37.3
	United Kingdom				**Denmark**			
Industrial Biotechnology	5.8	3.8	6.7	9.1	5.7	7.1	9.7	9.6
Nanotechnology	1.8	2.5	3.9	5.1	2.2	2.7	3.2	3.0
Micro- and Nanoelectronics	1294.8	614.1	290.2	306.0	298.2	159.4	136.1	209.4
Photonics	175.5	129.2	88.1	61.4	149.1	215.1	295.7	192.9
Advanced Materials	2.2	3.0	4.0	4.3	2.7	2.8	4.1	5.4
AMT for other KETs	14.4	17.6	25.4	25.7	16.6	19.1	23.4	26.3
	Italy				**Poland**			
Industrial Biotechnology	3.1	4.1	3.8	3.7	0.8	1.5	2.4	2.4
Nanotechnology	1.0	1.3	2.0	2.1	0.7	0.9	1.6	1.8
Micro- and Nanoelectronics	1025.3	811.3	596.0	659.7	42.5	36.5	116.7	201.4
Photonics	36.7	45.4	50.7	35.6	76.2	111.0	99.4	28.2
Advanced Materials	1.4	2.1	2.7	2.8	0.5	0.9	1.6	1.9
AMT for other KETs	9.4	12.7	17.9	17.3	4.6	8.0	9.8	11.5
	Belgium				**Czech Rep.**			
Industrial Biotechnology	1.1	2.1	3.7	3.4	1.2	2.8	4.3	8.6
Nanotechnology	1.8	2.6	2.9	3.1	0.7	0.9	1.5	1.5
Micro- and Nanoelectronics	180.1	143.3	104.8	307.5	154.6	143.0	116.2	142.4
Photonics	45.0	52.5	54.9	21.0	97.3	44.4	27.6	18.6
Advanced Materials	1.4	2.1	2.3	2.4	1.0	1.4	2.4	2.4
AMT for other KETs	11.2	15.3	17.9	20.1	4.9	5.6	8.9	10.9
	Netherlands				**Hungary**			
Industrial Biotechnology	2.0	1.6	2.8	3.1	3.8	3.1	4.1	3.0
Nanotechnology	1.0	1.2	2.4	2.7	0.6	0.8	1.3	1.5
Micro- and Nanoelectronics	370.3	734.1	249.0	418.8	85.1	70.8	111.7	208.5
Photonics	177.5	97.7	116.3	421.3	38.9	71.0	69.6	38.1
Advanced Materials	1.1	1.5	2.1	2.1	0.8	1.3	2.2	2.2
AMT for other KETs	19.3	24.8	35.4	24.2	6.0	16.2	21.3	20.7

Source: COMTRADE Database. NIW calculations.

While the pattern of export unit values at the level of KETs reveals some information on the three regions' respectively selected countries and on their general position in value chains within each of the six KETs, average unit values at the level of KETs are difficult to compare since the product composition differs across the three regions. Differences in average unit values may therefore simply reflect a different focus of each region on products with either higher or lower levels of unit values. Changes over time are also difficult to interpret since they may also reflect changes in product composition. In addition, changes in exchange rates between European and East Asian currencies on the one hand, and the US-$ on the other hand can affect trends in unit values, too. However, calculations on the basis of purchasing power parity (PPP) prove that changes in exchange rates do not significantly influence the performance and development of export unit values in comparison to calculations on the basis of nominal values (c.f. appendix Table 8.3 and Table 8.4).

Products by technology content

A classification of KETs-related products by their technology content[114] produces a significantly different result compared to average export unit values (Table 5.9). Despite low and decreasing average unit values in photonics and AMT for other KETs, the majority (69 to 74 percent) of the EU-28 trade in these two KETs is classified as having high and increasing technology content. This result reveals that the EU-28 is, in both KETs, specialised in the production of products with a rather low unit value compared to other products in these KETs. However, the EU-28 unit values of these KET-related products are higher than those of North America and East Asia and are increasing over time. In industrial biotechnology, the high average level of export unit values is confirmed by a very high share (90 percent) of trade with products having high and increasing technology content. In advanced materials, 57 percent of EU-28 trade concerns products in this category. Nanotechnology is the only KET within this group of the five investigated in Table 5.9 for which the majority of EU-28 trade is classified as low technology content.

Table 5.9 – Technology content of KET-related products by KET and triadic region (2007 to 2011 average)

KET1)	*high and increasing technology content*	*high but decreasing technology content*	*low but increasing technology content*	*low and decreasing technology content*
		EU-28		
Industrial Biotechnology	89.6	0.7	0.0	9.7
Nanotechnology	27.5	6.3	29.5	36.8
Photonics	*68.8*	*6.7*	*16.6*	*7.8*
Advanced Materials	57.2	12.6	9.0	21.1
AMT for other KETs	74.2	5.3	10.9	9.5
		North America		
Industrial Biotechnology	25.9	27.7	0.1	46.4
Nanotechnology	42.0	32.7	0.0	25.2
Photonics	*60.8*	*38.3*	*0.9*	*0.0*
Advanced Materials	25.2	17.7	12.3	44.8
AMT for other KETs	76.8	5.1	17.3	0.7
		East Asia		
Industrial Biotechnology	9.9	5.1	26.4	58.6
Nanotechnology	6.3	40.1	0.0	53.6
Photonics	0.5	0.2	4.2	95.1
Advanced Materials	17.2	25.5	19.1	38.2
AMT for other KETs	5.8	4.4	52.0	37.8

Note: 1) without micro-/nanoelectronics., since no exact change in unit values over time can be calculated for this KET due to the transition from HS 2002 to HS 2007.
Source: COMTRADE Database. NIW calculations.

In contrast to micro-/nanoelectronics below (Table 5.10), East Asia's share of trade with high technology content is below 50 percent in all other five KETs. North America has technology strengths in AMT for other KETs, photonics and nanotechnology.

In *industrial biotechnology*, the EU-28 shows high and increasing technology content for almost all products (see annex Figure 8.1 to Figure 8.3). Furthermore, the EU-28 has managed to either extent its technology advantage or to reduce a previous technological gap for industrial biotechnology based products over time, whereas North America and East Asia only show advance in some products. Particularly North America had experienced growing technological disadvantages, whereas East Asia considerably succeeded in reducing the technological gap.

[114] Note that for each KET only products with a minimum volume of trade are considered in order to avoid arbitrary results due to very small and strongly fluctuating trade figures.

In *nanotechnology,* North America has managed to maintain its leading position across nearly all products. The majority of nanotechnology products manufactured and exported by the EU-28 have increasing technology content. East Asia shows decreasing technology content for most of its trade in products related to nanotechnology, with the vast majority of trade in products with low technology content (see annex Figure 8.4 to Figure 8.6).

In *photonics*, North America is the leading technological region with broadly spread and further increasing technological advance. The EU-28's still high proportion of products with high and increasing technology content is contrasted by falling average export unit values which implies that the EU-28 is increasingly specialising in photonics products with a low unit value. The same applies to East Asia's increasing technological gap, apparently conflicting with its favourable trade performance. This is due to the fact that East Asia's export unit values have decreased more than those of the EU-28. Therefore, for several photonics-related products, the EU-28's export unit value (2007 to 2011) and its rate of change compared to the period 2002 to 2006 lies above the triad average, which is strongly determined by East Asia accounting for more than 70 percent of triad exports in this KET (annex tables Figure 8.7 to Figure 8.9).

Advanced materials constitute the biggest KET field with 180 different products. In this KET, each region manufactures and exports a significant share of products in each of the four product categories. This result indicates that there is a significant division of labour among advanced materials between the three triad regions. Although the EU-28 once again gains the highest export shares with products that feature extending technological advance in triad comparison, all three regions manage to achieve above average and increasing export unit values for certain products. Furthermore, there are a lot of products whose export unit values hardly differ between the triad regions (see annex Figure 8.10 to Figure 8.12).

Concerning *AMT for other KETs*, North America and the EU-28 exhibit high, broadly based, and growing technology content of exported products. At least 74 percent of their export value applies to products with high and increasing technological content. Most of their products achieve above average export unit values (see annex Figure 8.13 to Figure 8.15). East Asia has further fallen behind the other two regions during the past decade in this KET.

Within the EU-28, for some KETs the results considerably differ between single countries (Table 5-10). Whereas the EU-28's high and increasing technology content in *industrial biotechnology* applies to nine of the 12 selected EU-countries (with the exception of Sweden, Poland and Hungary), their comparatively favourable performance in *photonics* is mainly attributed to France and Sweden. On the other hand, Germany, the United Kingdom, the Netherlands, and Denmark report high but decreasing technology content referring to their exports of photonics-related products over time.

In *AMT for other KETs*, the share of exports with high technology content is higher than 50 percent for nearly all selected countries except Italy, Poland and the Czech Republic. Germany, France, the United Kingdom and the Netherlands are able to attain more than half of total exports with AMT for other KETs with products characterized by high and increasing technological content. However, remarkably high shares of exports with low but increasing technological content demonstrate that Austria, Belgium, Denmark and also Poland, the Czech Republic and Hungary are catching up.

Considering *advanced materials*, all selected EU-15 countries focus on products with high technological content. Denmark, Sweden, Germany and Belgium were especially successful in extending their technological advance over time.

Table 5.10 – Technology content of KET-related products by KET and selected EU-countries (2007 to 2011 average)

KET[1)]	*high and increasing technological content*	*high but decreasing technological content*	*low but increasing technological content*	*low and decreasing technological content*
		Germany		
Industrial Biotechnology	55.8	4.6	0.0	39.6
Nanotechnology	27.0	5.3	1.9	65.8
Photonics	10.3	55.4	6.6	27.8
Advanced Materials	55.4	17.4	5.4	21.8
AMT for other KETs	70.1	25.4	0.0	4.5
		France		
Industrial Biotechnology	79.9	0.4	0.0	19.7
Nanotechnology	17.7	14.1	58.2	10.0
Photonics	73.1	14.4	0.0	12.6
Advanced Materials	47.8	20.9	8.0	23.3
AMT for other KETs	53.4	42.8	0.0	3.8
		United Kingdom		
Industrial Biotechnology	59.5	11.4	5.4	23.7
Nanotechnology	54.6	10.0	1.9	33.5
Photonics	29.7	68.0	0.0	2.3
Advanced Materials	49.1	19.6	1.9	29.4
AMT for other KETs	59.1	10.0	1.5	29.4
		Italy		
Industrial Biotechnology	54.1	14.6	0.0	31.3
Nanotechnology	50.5	6.5	20.6	22.4
Photonics	46.4	0.0	33.3	20.3
Advanced Materials	46.4	14.3	23.9	15.4
AMT for other KETs	27.3	0.9	28.0	43.8
		Belgium		
Industrial Biotechnology	85.5	0.0	10.4	4.1
Nanotechnology	53.4	4.4	0.0	42.2
Photonics	18.2	2.9	73.2	5.7
Advanced Materials	52.5	21.6	4.8	21.1
AMT for other KETs	45.3	6.6	40.3	7.8
		Netherlands		
Industrial Biotechnology	70.5	3.8	0.0	25.7
Nanotechnology	54.4	17.7	27.9	0.0
Photonics	23.8	72.7	0.0	3.5
Advanced Materials	37.9	18.8	17.4	25.9
AMT for other KETs	73.6	22.3	0.0	4.1
		Denmark		
Industrial Biotechnology	98.1	0.8	0.0	1.1
Nanotechnology	2.8	95.7	1.5	0.0
Photonics	47.4	51.3	0.0	1.4
Advanced Materials	57.3	10.5	2.4	29.8
AMT for other KETs	40.3	13.2	37.3	9.3
		Austria		
Industrial Biotechnology	78.1	15.8	6.1	0.0
Nanotechnology	6.2	77.3	1.1	15.4
Photonics	22.9	12.7	64.1	0.3
Advanced Materials	39.5	16.7	6.8	37.1
AMT for other KETs	48.5	9.4	28.0	14.1
		Sweden		
Industrial Biotechnology	1.0	91.2	0.1	7.8
Nanotechnology	1.7	7.8	13.4	77.0
Photonics	91.0	0.2	0.0	8.8
Advanced Materials	68.1	8.6	7.8	15.5
AMT for other KETs	43.8	28.2	3.6	24.5

Note: 1) without micro-/nanoelectronics., since no exact change in unit values over time can be calculated for this KET due to the transition from HS 2002 to HS 2007.

Source: COMTRADE Database. NIW calculations.

Table 5-10 (continued)

KET	*high and increasing technological content*	*high but decreasing technological content*	*low but increasing technological content*	*low and decreasing technological content*
		Poland		
Industrial Biotechnology	20.1	9.9	25.4	44.5
Nanotechnology	1.5	0.9	63.5	34.1
Photonics	17.2	81.1	0.0	1.7
Advanced Materials	34.3	3.8	28.8	33.2
AMT for other KETs	18.4	2.5	64.5	14.6
		Czech Rep.		
Industrial Biotechnology	94.3	0.6	0.0	5.1
Nanotechnology	16.4	0.3	67.6	15.7
Photonics	1.8	0.1	95.1	3.0
Advanced Materials	31.9	4.7	29.5	33.9
AMT for other KETs	24.6	3.6	61.8	10.0
		Hungary		
Industrial Biotechnology	9.7	1.8	0.0	88.5
Nanotechnology	0.1	0.5	0.0	99.4
Photonics	3.8	96.0	0.3	0.0
Advanced Materials	14.7	7.0	4.6	73.8
AMT for other KETs	49.4	1.6	40.9	8.1

Note: 1) without micro-/nanoelectronics., since no exact change in unit values over time can be calculated for this KET due to the transition from HS 2002 to HS 2007.
Source: COMTRADE Database. NIW calculations.

Referring to the EU-28 as a whole, more than half of their *nanotechnology* exports apply to products classified as low technology. This result is valid for most of the selected countries, among them Germany and France, whose performance has a strong impact on overall results. However, the United Kingdom, Italy, Belgium and the Netherlands gain more than 50 percent of their nanotechnology exports with products featuring high and increasing technology content (Table 5.10).

Micro-and nanoelectronics are missing in Table 5.9 and Table 5-10, that are based on changes between the periods 2002 to 2006 and 2007 to 2011. Due to the methodical transition from HS 2002 to HS 2007 in trade statistics, there are no time series for *micro- and nanoelectronics* available at the product level.[115] Hence, it is neither possible to calculate growth rates between the two partial periods nor to compute export shares according to the four categories above. Furthermore, there are a lot of missings in trade volume data considering North America and East Asia in the period 2007 to 2011. Therefore, the technology content of micro- and nanoelectronics related products was calculated seperately, only referring to 2002 to 2006 and to changes between 2002/2003 and 2005/2006, alternatively (Table 5.11).

The results illustrate that not only production and trade but also technological advance in micro-/nanoelectronics have more and more shifted to East Asia, whose exports 2005/2006 were totally classified in category 1 and 2, standing for high – mostly increasing - technology content, whereas the EU-28 and North America focus on products with comparably low technological content. However, in contrast to the increasing gap between North America and East Asia during this short period – most American exports show low and decreasing technological content -, the EU-28 succeeded in catching up between 2002/2003 and 2005/2006 (category 3: low but increasing technological content). Although both regions' exports in micro- and nanotechnology 2005/2006 were dominated by monolithic integrated circuits, the EU-28 managed to achieve higher export unit values over time whereas North America had to deal with further declines (see also annex Figure 8.16 to Figure 8.18).

[115] There is no clear concordance of HS 2002 and HS 2007 product groups.

At the single country level, some considerably differing results arise which can also be attributed to the structural weight and unit value performance of particular product groups referring to one single country compared to the EU-28 at a whole. Although, most of the EU-countries predominantly export micro- and nanoelectronics-related products with comparably low (France, Belgium, Denmark, Sweden, the Czech Republic, Poland, Hungary) or still high but decreasing technology content (the United Kingdom, Italy, the Netherlands), Germany and Austria attain more than half ot their exports with products featuring high and increasing technological content.

Table 5.11 – Technology content of micro- and nanoelectronics related products by triadic region and selected EU-countries (2005/2006 average compared to 2002/2003 average)

country/region	*high and increasing technological content*	*high but decreasing technological content*	*low but increasing technological content*	*low and decreasing technological content*
EU-28	**0.0**	**0.0**	**98.1**	**1.9**
Germany	96.1	3.9	0.0	0.0
United Kingdom	9.8	74.2	2.6	13.5
France	0.0	2.7	96.4	0.9
Italy	0.0	96.7	2.8	0.5
Belgium	0.0	11.9	22.3	65.9
Netherlands	4.8	95.2	0.0	0.0
Denmark	0.0	0.5	0.0	99.5
Austria	50.7	4.6	0.0	44.7
Sweden	0.0	11.9	68.5	19.6
Czech. Rep.	0.0	0.0	16.9	83.1
Poland	0.0	0.0	81.6	18.4
Hungary	0.0	0.0	0.0	100.0
North America	**3.7**	**0.0**	**0.0**	**96.3**
East Asia	**83.0**	**17.0**	**0.0**	**0.0**

Source: COMTRADE Database. NIW calculations.

5.4. COMPETITIVE ADVANTAGE IN INTERNATIONAL TRADE

Exports in KETs-related products by the EU-28 face very different conditions on international markets (Table 5.12). In AMT for other KETs, most of the EU-28's exports (64 percent) concern products for which trade is characterised by quality competition. For almost all of these products, the EU-28 reports a quality advantage, i.e. the EU-28 is able to gain a positive trade balance based on superior product quality. In nanotechnology, industrial biotechnology and advanced materials, only 23 to 34 percent of EU-28 exports are based on quality competition. Although the majority of the EU-28 exports in these KETs face price competition, most of these exports benefit from price advantage. This means that the EU-28 specialises on those price-sensitive products for which a cost efficient production in the EU-28 is possible. In photonics and micro-/nanoelectronics, most of the products exported by the EU-28 are in price competition (89 and 94 percent, respectively), and for the majority of these products, the EU-28 has no price advantage.

There are no clear trends in the type of competition EU-28 KETs-related exports face in international trade. In AMT for other KETs, the share of EU-28 exports based on quality competition and quality advantage increased during the 2000s while the share of exports based on price competition and price advantage decreased.[116] In photonics, the share of EU-28 exports in markets with price competition that could profit from a price advantage in the EU-28 was substantially reduced over the past decade while the share of exports facing price competition without a price advantage increased. There is also an increase of the share of EU-28 exports in this category for nanotechnology.

[116] This result may partially be affected by changes in exchange rates which tend to raise unit values of EU-28 manufacturers, though the analysis in section 5.2 based on PPP conversion of currencies did not support this caveat.

Table 5.12 - Type of competition in trade with KETs-related products 2002 to 2011 in the EU-28

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	av.
Industrial Biotechnology											
Quality competition and quality advantage	50.5	40.0	11.5	0.0	45.6	11.3	11.7	8.9	39.3	37.3	**25.6**
Quality competition without quality advantage	0.0	0.0	1.8	0.0	0.0	13.5	16.1	0.3	16.7	1.3	**5.0**
Price competition and price advantage	38.8	48.9	75.1	88.9	21.7	59.1	57.7	62.2	29.6	26.0	**50.8**
Price competition without price advantage	10.6	11.1	11.5	11.1	32.8	16.1	14.5	28.7	14.4	35.4	**18.6**
Nanotechnology											
Quality competition and quality advantage	26.7	0.2	16.4	10.9	23.1	16.1	50.0	17.1	45.5	15.3	**22.1**
Quality competition without quality advantage	0.6	0.0	0.0	0.4	0.5	0.5	0.5	0.4	0.3	0.3	**0.4**
Price competition and price advantage	46.8	71.7	56.5	61.6	47.2	55.0	19.8	49.8	20.0	40.2	**46.9**
Price competition without price advantage	26.0	28.0	27.1	27.1	29.2	28.3	29.7	32.7	34.2	44.2	**30.6**
Micro- and Nanoelectronics											
Quality competition and quality advantage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
Quality competition without quality advantage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.2	0.0	**6.1**
Price competition and price advantage	24.0	3.4	4.3	3.7	6.4	19.3	46.8	0.0	0.0	0.0	**10.8**
Price competition without price advantage	76.0	96.6	95.7	96.3	93.6	80.7	53.2	100.0	38.8	100.0	**83.1**
Photonics											
Quality competition and quality advantage	1.2	20.2	2.8	8.8	2.1	9.5	0.0	6.8	6.1	10.9	**6.8**
Quality competition without quality advantage	20.8	1.3	1.2	0.8	0.7	0.7	10.3	0.6	0.4	0.0	**3.7**
Price competition and price advantage	38.0	14.9	31.7	21.7	26.1	10.8	7.3	7.0	5.7	6.4	**17.0**
Price competition without price advantage	40.1	63.6	64.4	68.7	71.1	79.0	82.4	85.7	87.8	82.7	**72.5**
Advanced Materials											
Quality competition and quality advantage	26.1	15.0	29.4	27.3	25.4	28.8	22.1	25.5	26.7	23.1	**24.9**
Quality competition without quality advantage	10.9	9.4	12.5	13.3	6.2	10.7	6.1	6.2	4.1	12.8	**9.2**
Price competition and price advantage	37.5	51.1	31.1	29.4	34.4	30.7	39.9	37.9	33.3	34.1	**35.9**
Price competition without price advantage	25.5	24.5	27.0	30.1	34.0	29.9	31.8	30.3	35.9	30.0	**29.9**
AMT for other KETs											
Quality competition and quality advantage	51.6	63.2	56.9	60.2	54.1	57.4	55.1	84.8	79.1	80.9	**64.3**
Quality competition without quality advantage	0.4	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.1**
Price competition and price advantage	41.8	30.6	37.7	33.4	25.7	32.8	14.6	10.5	16.0	8.4	**25.1**
Price competition without price advantage	6.2	6.2	4.5	6.4	20.2	9.8	30.3	4.7	4.9	10.7	**10.4**

Source: COMTRADE Database. NIW calculations.

North America shows significantly different positions for its exports in KET-related products (Table 5.13). In micro- and nanoelectronics, the majority of North American exports are based on quality advantages in markets with quality competition. This result is only observable until 2006, however, since no more recent data is available for this KET. In nanotechnology and photonics, about 55 percent of North American exports are in products facing quality competition, and most of these exports can exploit quality advantages. In the other three KETs -industrial biotechnology, advanced materials and AMT for other KETs-, North American exports are focused on products that are primarily in price competition on international markets; though, most of these products can build upon price advantages vis-à-vis their competitors.

North America was able to increase the share of exports based on quality competition and quality advantage in nanotechnology while the share of this category in total KET exports tended to decrease in industrial biotechnology and AMT for other KETs.

Most of East Asia's exports in KET-related products take place in markets characterised by price competition (Table 5.14). Exports of products facing quality competition account for only 10 percent (photonics) to 30 percent (micro-/nanoelectronics) of all exports in the respective KET. In most KETs, East Asia can build upon price advantages. These are particularly strong in industrial biotechnology, photonics and AMT for other KETs and substantial in nanotechnology and advanced materials. Interestingly, micro-/nanoelectronics exports of East Asia do not rely on price advantages since export unit values are higher than import unit values in most products in this KET area. This astonishing result may point to the fact that the product codes considered are not homogenous but include products at different stages of the production chain.

Table 5.13 - Type of competition in trade with KETs-related products 2002 to 2011 in North America

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*av.*
Industrial Biotechnology											
Quality competition and quality advantage	37,4	6,7	6,1	23,3	15,1	17,1	0,0	16,3	0,0	0,0	**12,2**
Quality competition without quality advantage	6,4	21,5	19,8	0,3	0,2	0,7	0,2	0,1	9,3	10,5	**6,9**
Price competition and price advantage	51,3	66,3	68,6	50,2	54,0	48,8	73,5	55,7	63,2	63,3	**59,5**
Price competition without price advantage	4,9	5,5	5,5	26,1	30,7	33,4	26,3	27,9	27,5	26,2	**21,4**
Nanotechnology											
Quality competition and quality advantage	45,1	37,3	39,1	72,9	59,3	55,2	26,4	48,8	77,6	79,1	**54,1**
Quality competition without quality advantage	0,1	0,0	2,5	0,0	0,0	0,0	0,0	0,0	0,0	1,4	**0,4**
Price competition and price advantage	10,5	15,8	13,8	10,6	12,9	17,7	59,4	33,7	8,5	6,8	**19,0**
Price competition without price advantage	44,3	46,9	44,6	16,5	27,8	27,1	14,2	17,5	13,9	12,7	**26,5**
Micro- and Nanoelectronics*											
Quality competition and quality advantage	21.1	80.0	96.1	96.2	96.3	n.a.	n.a.	n.a.	n.a.	n.a.	**77.9**
Quality competition without quality advantage	0.0	0.0	0.0	0.0	0.0	n.a.	n.a.	n.a.	n.a.	n.a.	**0.0**
Price competition and price advantage	2.1	1.7	3.9	3.8	3.7	n.a.	n.a.	n.a.	n.a.	n.a.	**2.6**
Price competition without price advantage	76.8	18.3	0.0	0.0	0.0	n.a.	n.a.	n.a.	n.a.	n.a.	**19.5**
Photonics											
Quality competition and quality advantage	36.8	40.3	49.7	48.6	51.7	47.5	34.6	36.6	61.7	0.0	**40.8**
Quality competition without quality advantage	1.1	1.7	8.3	5.0	40.3	19.7	19.1	19.4	17.7	18.0	**15.0**
Price competition and price advantage	26.0	23.0	39.2	34.5	5.3	17.9	39.4	37.2	16.0	77.8	**31.6**
Price competition without price advantage	36.2	35.0	2.8	12.0	2.7	15.0	7.0	6.8	4.7	4.2	**12.6**
Advanced Materials											
Quality competition and quality advantage	31.7	25.8	23.8	29.9	26.4	24.9	26.8	31.2	27.3	24.9	**27.3**
Quality competition without quality advantage	6.5	6.2	6.1	8.3	3.9	3.2	7.0	4.1	5.2	6.4	**5.7**
Price competition and price advantage	43.5	48.6	53.6	45.6	53.8	55.9	53.4	52.9	54.7	57.5	**52.0**
Price competition without price advantage	18.2	19.2	16.4	16.2	15.9	15.4	12.6	11.6	12.5	11.1	**14.9**
AMT for other KETs											
Quality competition and quality advantage	32.4	24.2	35.1	46.0	32.5	12.8	13.5	34.1	21.2	18.0	**27.0**
Quality competition without quality advantage	6.5	4.0	5.4	5.4	4.5	0.0	2.0	0.0	3.7	0.3	**3.2**
Price competition and price advantage	35.1	38.0	44.7	30.8	42.6	61.7	74.4	41.2	59.0	60.4	**48.8**
Price competition without price advantage	26.0	33.2	14.9	17.8	20.3	17.9	5.4	18.0	9.2	15.0	**17.8**

Note: * Missing basic data prohibit plausible calculations for 2007 to 2011.
Source: COMTRADE Database. NIW calculations.

East Asia was not able to expand exports of KET-related products that are based on quality competition and quality advantage. In contrast, the share of exports in this product category decreased in industrial biotechnology and in nanotechnology, and there is also a downward trend in advanced materials and AMT for other KETs.

The EU-28's favourable performance in quality competition in AMT for other KETs is mainly due to Germany and Austria, even though Sweden, France, the UK and – in recent years - also Hungary show substantial advantages in quality competition in this KET area (Table 5.13 and Table 5.14). On the other hand, the exports by Italy, Poland, the Czech Republic and Belgium successfully focus on products featuring price competition.

Concerning industrial biotechnology, only Denmark and Sweden predominantly compete in quality competition with most of their exports realizing both higher prices and higher export volumes. In contrast, all other selected European economies primarily export price-sensitive products; only Austria and Hungary predominantly exhibit advantages in this form of competition.

In the field of nanotechnology related products, only Belgium, Italy and the Netherlands as well as the Czech Republic and Hungary effectively compete in quality competition. The Netherlands, Germany and Sweden successfully gain focus on price-sensitive exports. However, it has to be considered that the corresponding trade values and volumes are rather small in this KET area.

In advanced materials only Belgium significantly departs from the EU-28 mean. Only there, the majority of exports are based on quality advantages. The other selected EU-countries assert their position on international markets in price competition, most of them (with the exception of Sweden, Denmark, Italy and UK) being able to predominantly realize price advantages.

Concerning photonics, it is Denmark that differs significantly from the mean, competing successfully in quality competition. Furthermore, a notably high share of German exports is based on quality advantages, even though the majority of German exports are focused on markets that are primarily in price competition which is also valid for all other EU-countries. Within this group, only Sweden, the Czech Republic and Hungary show comparably high shares of photonics exports featuring price advantages.

In micro- and nanoelectronics all EU-countries, among them particularly the large economies, compete mostly in price competition on international markets without being able to attain significant price advantages – except for the Czech Republic. This explains why most of the EU-countries have more and more backed out of the markets for those products. Remarkable is that although notably high shares of Denmark's, Sweden's and Poland's exports of micro- and nanoelectronic products are facing quality competition, they cannot realize quality advantages.

Table 5.14 - Type of competition in trade with KETs-related products 2002 to 2011 in East Asia

	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	***av.***
Industrial Biotechnology											
Quality competition and quality advantage	0.2	19.5	9.3	20.4	8.5	8.6	1.6	1.4	0.1	1.7	**7.1**
Quality competition without quality advantage	15.3	12.0	10.9	5.4	4.6	12.5	8.4	4.8	5.2	4.7	**8.4**
Price competition and price advantage	58.9	49.5	74.7	68.5	81.1	79.0	85.4	86.1	94.8	93.6	**77.2**
Price competition without price advantage	25.6	19.0	5.1	5.8	5.9	0.0	4.6	7.7	0.0	0.0	**7.4**
Nanotechnology											
Quality competition and quality advantage	0.0	6.5	15.2	7.8	7.1	0.0	0.0	0.5	0.3	9.8	**4.7**
Quality competition without quality advantage	0.1	29.7	31.5	21.9	22.5	11.7	9.9	9.8	10.3	8.1	**15.6**
Price competition and price advantage	25.8	20.5	42.3	47.8	47.9	82.5	84.1	83.6	83.0	82.1	**60.0**
Price competition without price advantage	74.1	43.2	11.0	22.5	22.6	5.7	6.1	6.2	6.4	0.0	**19.8**
Micro- and Nanoelectronics											
Quality competition and quality advantage	1.5	2.1	0.0	1.6	1.5	0.0	0.0	0.0	0.0	0.0	**0.7**
Quality competition without quality advantage	0.0	0.0	2.8	2.9	2.6	55.2	57.1	56.9	52.4	55.9	**28.6**
Price competition and price advantage	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	47.6	44.1	**9.3**
Price competition without price advantage	98.5	97.9	95.5	95.5	95.9	44.8	42.9	43.1	0.0	0.0	**61.4**
Photonics											
Quality competition and quality advantage	1.7	1.1	0.7	15.9	0.4	0.3	0.2	0.2	1.0	0.1	**2.2**
Quality competition without quality advantage	6.7	1.9	1.7	61.9	1.4	1.1	1.0	0.9	0.9	1.0	**7.9**
Price competition and price advantage	63.7	46.9	34.5	22.2	98.2	98.6	98.8	98.9	98.1	98.9	**75.9**
Price competition without price advantage	27.9	50.0	63.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**14.1**
Advanced Materials											
Quality competition and quality advantage	13.5	12.7	23.6	23.0	14.7	2.9	11.5	4.8	5.0	16.1	**12.8**
Quality competition without quality advantage	17.2	16.9	8.6	6.4	8.2	15.2	11.5	14.3	6.8	10.1	**11.5**
Price competition and price advantage	43.0	44.2	37.0	42.6	50.3	65.2	58.8	61.5	64.4	58.1	**52.5**
Price competition without price advantage	26.3	26.1	30.7	28.1	26.8	16.8	18.2	19.4	23.8	15.7	**23.2**
AMT for other KETs											
Quality competition and quality advantage	18.0	18.1	10.5	10.1	33.8	22.7	8.3	19.5	6.6	7.5	**15.5**
Quality competition without quality advantage	12.4	17.1	13.5	15.1	8.4	4.1	3.6	5.4	2.5	3.5	**8.6**
Price competition and price advantage	54.1	55.4	60.9	58.0	27.4	63.2	79.7	67.0	85.9	86.8	**63.8**
Price competition without price advantage	15.6	9.4	15.2	16.8	30.4	10.0	8.4	8.0	4.9	2.3	**12.1**

Source: COMTRADE Database. NIW calculations.

Table 5.15 - Type of competition in trade with KETs-related products in Germany, France, United Kingdom, Italy, the Netherlands, and Belgium (2002 to 2011 average)

	Germany	*France*	*United Kingdom*	*Italy*	*Nether-lands*	*Belgium*
Industrial Biotechnology						
Quality competition and quality advantage	20.5	0.0	0.8	20.1	19.0	10.3
Quality competition without quality advantage	0.4	17.3	28.1	7.9	1.2	2.9
Price competition and price advantage	19.5	21.8	35.6	20.6	25.9	13.8
Price competition without price advantage	59.6	60.8	35.5	51.4	50.7	73.0
Nanotechnology						
Quality competition and quality advantage	15.4	18.3	18.6	49.2	39.6	54.5
Quality competition without quality advantage	0.7	28.3	1.3	0.0	0.5	0.5
Price competition and price advantage	55.8	12.7	32.1	30.7	49.2	2.5
Price competition without price advantage	28.1	40.6	48.0	6.8	9.7	42.6
Micro- and Nanoelectronics						
Quality competition and quality advantage	0.5	0.0	0.0	0.0	29.4	3.5
Quality competition without quality advantage	13.4	0.0	8.7	4.4	0.0	2.2
Price competition and price advantage	5.2	41.8	15.3	1.3	33.6	8.6
Price competition without price advantage	80.9	58.2	76.0	94.3	27.0	85.7
Photonics						
Quality competition and quality advantage	38.0	5.4	25.7	5.1	6.2	3.7
Quality competition without quality advantage	0.0	26.6	4.9	20.3	8.3	22.0
Price competition and price advantage	11.9	13.3	31.4	33.0	18.0	20.2
Price competition without price advantage	50.0	49.4	38.0	41.5	57.1	53.7
Advanced Materials						
Quality competition and quality advantage	34.4	20.9	29.1	17.3	36.1	52.7
Quality competition without quality advantage	2.8	8.3	5.8	11.6	2.8	2.5
Price competition and price advantage	39.2	44.1	32.4	35.8	43.8	27.5
Price competition without price advantage	23.6	26.3	31.3	35.3	15.9	17.3
AMT for other KETs						
Quality competition and quality advantage	74.8	43.9	45.4	29.8	29.6	10.5
Quality competition without quality advantage	0.0	0.8	1.0	2.9	3.1	8.3
Price competition and price advantage	22.3	20.7	18.5	66.5	36.0	25.6
Price competition without price advantage	2.9	34.1	35.1	0.8	30.4	55.5

Source: COMTRADE Database. NIW calculations.

Table 5.16 - Type of competition in trade with KETs-related products in Denmark, Austria, Sweden, Poland, Czech Republic, and Hungary (2002 to 2011 average)

	Denmark	*Austria*	*Sweden*	*Poland*	*Czech Republic*	*Hungary*
			Industrial Biotechnology			
Quality competition and quality advantage	95.4	6.9	55.7	0.2	0.0	16.4
Quality competition without quality advantage	0.7	6.0	5.9	43.4	38.3	7.8
Price competition and price advantage	0.1	68.8	0.0	0.1	6.6	48.5
Price competition without price advantage	3.9	18.2	37.6	56.3	54.9	23.8
			Nanotechnology			
Quality competition and quality advantage	19.6	0.0	15.8	0.0	42.6	90.6
Quality competition without quality advantage	8.6	5.0	10.0	39.1	21.2	6.7
Price competition and price advantage	0.3	14.4	64.0	0.0	31.6	0.5
Price competition without price advantage	71.5	80.6	9.7	60.9	4.1	1.0
			Micro- and Nanoelectronics			
Quality competition and quality advantage	1.2	4.9	2.1	0.0	0.0	0.0
Quality competition without quality advantage	40.7	5.9	40.0	55.7	26.8	27.0
Price competition and price advantage	20.3	2.4	21.1	4.6	61.9	13.9
Price competition without price advantage	37.9	86.8	36.8	39.7	9.7	59.0
			Photonics			
Quality competition and quality advantage	61.4	21.6	19.8	0.0	0.0	0.0
Quality competition without quality advantage	5.0	6.6	0.7	24.5	29.4	21.3
Price competition and price advantage	4.4	38.3	50.5	23.6	49.7	60.5
Price competition without price advantage	29.3	33.4	28.9	48.2	15.6	18.1
			Advanced Materials			
Quality competition and quality advantage	13.3	12.2	17.5	13.0	20.2	22.5
Quality competition without quality advantage	11.3	9.6	12.9	18.9	13.5	8.5
Price competition and price advantage	36.7	53.5	26.1	54.0	50.5	52.1
Price competition without price advantage	38.7	24.6	43.4	13.9	15.7	16.7
			AMT for other KETs			
Quality competition and quality advantage	29.1	50.5	46.1	9.4	15.5	34.9
Quality competition without quality advantage	3.3	2.4	1.9	17.2	5.2	14.0
Price competition and price advantage	56.3	33.0	39.2	64.3	69.4	47.5
Price competition without price advantage	11.3	14.2	12.5	9.0	9.9	3.4

Source: COMTRADE Database. NIW calculations.

5.5. LINK BETWEEN PATENTING AND THE TECHNOLOGY CONTENT OF EXPORTS

For analysing the link between patenting in a certain KET and the technology content of exports, patent intensity (the number of patent applications per population) is regressed on a country's level of export unit values (see section 5.1) while controlling for country size, a country's productivity level and time trends. Note that there is only one data point per time, country and KET for patent intensity while there are several data points for unit values, depending on the number of different KET-related products considered for each KET (see Table 8.1). Since unit values of exports vary considerable between the individual KET-related products within each KET, reflecting different stages in the value chain and different technical features of production, it is difficult to explain the variation in unit values by patent intensity and other country-specific variables. As a consequence, standard measures of model fit for regression models such as adjusted R^2 perform weak. This is no limitation for this analysis, however, since the purpose is not to explain the level of unit values of KET-related products, but rather to investigate whether the (lagged) patent activity has a statistically significant effect on the level of export unit values in a cross-country comparison. The hypotheses to test is hence whether countries that invested more in the production of KET patents can gain from a higher technology content of their exports.

The results of OLS regressions reveal that there is indeed a positive link between patent intensity and export unit values. Across all six KETs, patent intensity by KET has a statistically significant influence on the level of unit values of exports in KET-related products in the following year (Table 5.17). An increase in patent intensity by 10 percent is associated with an increase in unit values of 1.2 percent.[117] Country size has a negative impact on unit values while countries with a higher overall productivity level (which reflects the quality of infrastructure) show higher unit values. There is a clear time trend in unit values which was temporarily interrupted in 2009 and 2010 when the economic and financial crisis caused unit values to drop.

The main findings also hold when only the EU-28 countries are considered. For the EU, the link between patent intensity and unit values of exports is of similar magnitude as for the entire set of countries. A 10 percent increase of patent intensity would transfer into an increase of export unit values by 1.0 percent. Negative country size and positive productivity effects also hold for the EU-28. Unit values of EU-28 countries did increase at a somewhat higher pace than in the entire group of countries, which partially reflects the revaluation of the Euro against the US Dollar in the period considered

Table 5.17 - Effect of patent intensity on export unit values, all KETs: results of panel OLS regressions

dependent variable: ln(UV^X)	*Total*			*EU-28*		
	Coefficient		*Std.dev.*	*Coefficient*		*Std.dev.*
ln($PINT_{t-1}$), all KET patents	0.116	***	0.004	0.101	***	0.005
ln(GDP)	-0.078	***	0.004	-0.092	***	0.006
ln(GDP/cap)	0.085	***	0.006	0.104	***	0.008
Year dummies (reference: 2002)						
2003	0.138	***	0.027	0.163	***	0.032
2004	0.239	***	0.027	0.284	***	0.032
2005	0.283	***	0.027	0.318	***	0.032
2006	0.359	***	0.027	0.395	***	0.033
2007	0.453	***	0.027	0.524	***	0.032
2008	0.584	***	0.027	0.629	***	0.032
2009	0.520	***	0.027	0.546	***	0.032
2010	0.516	***	0.207	0.542	***	0.032
2011	0.636	***	0.027	0.668	***	0.032
Constant	2.019	***	0.040	2.090	***	0.059
No. of observations	80,627			56,449		
R-squared adjusted	0.035			0.028		

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

The positive link between lagged patent intensity and unit values can be found for each KET. The impact of patenting on technology content of exports is greatest in 'AMT for other KETs' (a 10 percent increase in patenting results in a 2.4 percent increase in unit values, see Table 5.23) and micro-/nanoelectronics (2.3 percent increase, Table 5.20). In industrial biotechnology, the elasticity of unit values on patent intensity is 1.5 percent (Table 5.18), in nanotechnology 1.4 percent (Table 5.19), in advanced materials 1.0 percent (Table 5.22) and in photonics 0.8 percent (Table 5.21).

These results also hold if one only looks at EU-28 countries. For three KETs, the link between patenting and technology content of exports is stronger in the EU-28 as compared to all 39 countries considered in this analysis. In micro-/nanoelectronics, a 10 percent increase in patent intensity results in a 2.7 percent increase in export unit values in the EU-28. In photonics, the elasticity in the EU-28 is 1.0 percent and in industrial biotechnology 1.6 percent. In AMT for other KETs, the EU-28 countries report the same elasticity for patenting as the total group of countries. In nanotechnology and advanced materials, elasticity of patenting in the EU-28 is somewhat lower (0.9 and 0.8 percent increase of export unit values, respectively).

Some interesting results emerge when the effects of patenting by subfields on the technology content of exports are considered (see the lower parts of the tables). In industrial biotechnology, the impact of patenting on the

[117] Note that the number of patents has been added by one for each country to avoid missing values for countries without any patent activity in a certain KET after logarithmic transformation of data. In addition, the 2 percent largest values of export unit values were set to missing. Sensitivity analysis showed that smaller or larger cut-off points for extreme values (1 or 3 percent) produce almost identical results.

technology content of products comes entirely from the subfield of enzymes while patenting in the subfield of proteins has even a negative effect on export unit values. The latter does not hold for EU-28 countries, however. In nanotechnology, nano-analytics and nano-optics drive the impact of patenting on technology content. For Europe, no significant effects for any subfield can be found, owing to the small number of patent activity per subfield. In micro- and nanoelectronics, effects of patenting by subfields vary between the total group of countries and EU-countries. While for the total group, semiconductor patenting has the largest impact on products' technology content, the subfield of devices is most important in the EU-28. The technology content of photonics products is mainly positively affected by patenting in the subfields of laser and measuring, while there is a negative effect of patenting in lighting and opto-semiconductors. In advanced materials, only three subfields are relevant to explain the technology content of products (electronics, macrostructures and layers). In AMT, patenting in four of the six subfields exerts a positive impact on technology content of products while patenting in the subfields of controlling (incl. AMT for nanotechnology) and AMT for photonics contributes to lower export unit values.

The effects of country size and productivity levels are ambiguous. Larger countries tend to have higher technology contents of KET-related products in nanotechnology, mirco- and nanoelectronics, photonics and AMT for other KETs while country size has a negative effect on export unit values in advanced materials and an insignificant one in industrial biotechnology. For the EU-28, country size effects often behave in a different way, however. A positive impact of country size can only be found for industrial biotechnology and for nanotechnology while smaller countries tend to have higher technology content of exports in advanced materials. For all other KETs, no significant country size effects within the EU-28 emerge.

Overall productivity, measured by GDP per capita, is negatively related to the technology content of products in most KETs, namely nanotechnology, micro-/nanoelectronics, photonics and AMT for other KETs. This finding implies that less productive countries tend to specialise in more sophisticated or more complex products in these KETs. One could interpret this result as an attempt of countries with some lag in overall productivity to focus their catching up activities on the field of KETs. Industrial biotechnology and advanced materials report a positive impact of overall productivity levels on technology content.

Table 5.18 - Effect of patent intensity on export unit values in industrial biotechnology: results of panel OLS regressions

dependent variable: ln(UV^X)	*Total*			*EU-28*		
	Coefficient		*Std.dev.*	*Coefficient*		*Std.dev.*
ln(PINT$_{t-1}$), all industrial biotechnology patents	0.149	***	0.020	0.161	***	0.027
ln(GDP)	-0.018		0.018	0.061	**	0.027
ln(GDP/cap)	0.041	*	0.026	-0.039		0.039
Year dummies (reference: 2002)						
2003	0.227	*	0.119	0.209		0.147
2004	0.201	*	0.118	0.169		0.146
2005	0.169		0.118	0.169		0.146
2006	0.184		0.118	0.219		0.146
2007	0.319	***	0.118	0.317	**	0.144
2008	0.377	***	0.119	0.355	**	0.146
2009	0.381	***	0.118	0.379	***	0.145
2010	0.405	***	0.119	0.422	***	0.146
2011	0.478	***	0.118	0.580	***	0.145
Constant	1.526	***	0.175	0.844	***	0.258
No. of observations	3,914			2,709		
R-squared adjusted	0.027			0.021		
ln(PINT$_{t-1}$), subfield of enzymes	0.164	***	0.031	0.190	***	0.039
ln(PINT$_{t-1}$), subfield of proteins	-0.173	***	0.061	0.019		0.094
ln(PINT$_{t-1}$), subfield other	0.067		0.044	-0.063		0.056

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

Table 5.19 - Effect of patent intensity on export unit values in nanotechnology: results of panel OLS regressions

dependent variable: ln(UV^X)	*Total*			*EU-28*		
	Coefficient		*Std.dev.*	*Coefficient*		*Std.dev.*
ln($PINT_{t-1}$), all nanotechnology patents	0.136	***	0.019	0.090	***	0.022
ln(GDP)	0.112	***	0.024	0.168	***	0.029
ln(GDP/cap)	-0.054	***	0.016	-0.110	***	0.020
Year dummies (reference: 2002)						
2003	0.257	**	0.111	0.326	**	0.134
2004	0.414	***	0.110	0.497	***	0.132
2005	0.285	**	0.110	0.363	***	0.134
2006	0.356	***	0.110	0.453	***	0.133
2007	0.428	***	0.111	0.535	***	0.134
2008	0.558	***	0.111	0.647	***	0.134
2009	0.588	***	0.111	0.686	***	0.133
2010	0.626	***	0.111	0.707	***	0.133
2011	0.771	***	0.112	0.855	***	0.134
Constant	1.148	***	0.165	1.547	***	0.235
No. of observations	3,186			2,192		
R-squared adjusted	0.059			0.046		
ln($PINT_{t-1}$), subfield of nano-analytics	0.116	**	0.055	0.054		0.077
ln($PINT_{t-1}$), subfield of nano-biotechnology	-0.060		0.055	0.024		0.076
ln($PINT_{t-1}$), subfield of nano-electronics/magnetics	-0.009		0.055	-0.033		0.063
ln($PINT_{t-1}$), subfield of nano-materials	0.071		0.061	0.108		0.072
ln($PINT_{t-1}$), subfield of nano-optics	0.102	*	0.061	0.040		0.081
ln($PINT_{t-1}$), subfield of nano-structures	-0.067		0.043	-0.104		0.066

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

Table 5.20 - Effect of patent intensity on export unit values in micro-/nanoelectronics: results of panel OLS regressions

dependent variable: ln(UV^X)	*Total*			*EU-28*		
	Coefficient		*Std.dev.*	*Coefficient*		*Std.dev.*
ln($PINT_{t-1}$), all micro-/nanoelectronics patents	0.228	***	0.026	0.270	***	0.030
ln(GDP)	0.109	***	0.026	-0.012		0.036
ln(GDP/cap)	-0.104	***	0.037	-0.062		0.052
Year dummies (reference: 2002)						
2003	0.058		0.181	0.010		0.205
2004	0.163		0.181	0.222		0.205
2005	0.044		0.179	0.097		0.203
2006	0.106		0.199	0.117		0.203
2007	0.214		0.200	0.208		0.219
2008	0.425	**	0.197	0.435	**	0.222
2009	0.312		0.197	0.492	**	0.219
2010	0.555	***	0.191	0.536	**	0.216
2011	0.652	***	0.191	0.663	***	0.219
Constant	4.203	***	0.277	5.491	***	0.362
No. of observations	1,211			887		
R-squared adjusted	0.090			0.104		
ln($PINT_{t-1}$), subfield of devices	0.117		0.089	0.232	**	0.096
ln($PINT_{t-1}$), subfield of semiconductors	0.241	***	0.060	0.079		0.069
ln($PINT_{t-1}$), subfield testing/amplifiers/nano-electronics	-0.156	*	0.090	0.117		0.110

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

Table 5.21 - Effect of patent intensity on export unit values in photonics: results of panel OLS regressions

dependent variable: ln(UV^X)	*Total*			*EU-28*		
	Coefficient		*Std.dev.*	*Coefficient*		*Std.dev.*
ln($PINT_{t-1}$), all photonics patents	0.080	***	0.012	0.097	***	0.015

ln(GDP)	0.027	**	0.011	-0.017		0.016
ln(GDP/cap)	-0.027	*	0.016	-0.010		0.024
Year dummies (reference: 2002)						
2003	0.182	**	0.078	0.233	**	0.097
2004	0.146	*	0.078	0.194		0.097
2005	0.126		0.078	0.157		0.097
2006	0.268	***	0.079	0.269	**	0.098
2007	0.331	***	0.078	0.335	***	0.097
2008	0.340	***	0.078	0.393	***	0.097
2009	0.390	***	0.078	0.433	***	0.097
2010	0.292	***	0.078	0.333	***	0.097
2011	0.310	***	0.078	0.325	**	0.097
Constant	4.320	***	0.115	4.764	***	0.167
No. of observations	4,256			3,024		
R-squared adjusted	0.021			0.028		
$\ln(PINT_{t-1})$, subfield of devices	-0.009		0.039	0.027		0.051
$\ln(PINT_{t-1})$, subfield of electron-optics	-0.049		0.038	-0.024		0.050
$\ln(PINT_{t-1})$, subfield of laser	0.188	***	0.039	0.202	***	0.047
$\ln(PINT_{t-1})$, subfield of lighting	-0.076	**	0.031	0.012		0.039
$\ln(PINT_{t-1})$, subfield of measuring	0.113	***	0.038	-0.024		0.057
$\ln(PINT_{t-1})$, subfield of opto-semiconductors	-0.112	***	0.031	-0.100	**	0.044

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

Table 5.22 - Effect of patent intensity on export unit values in advanced materials: results of panel OLS regressions

dependent variable: $\ln(UV^X)$	*Total*			*EU-28*		
	Coefficient		*Std.dev.*	*Coefficient*		*Std.dev.*
$\ln(PINT_{t-1})$, all advanced materials patents	0.095	***	0.004	0.080	***	0.005
ln(GDP)	-0.071	***	0.004	-0.086	***	0.006
ln(GDP/cap)	0.087	***	0.006	0.108	***	0.008
Year dummies (reference: 2002)		***				
2003	0.124	***	0.029	0.140	***	0.035
2004	0.247	***	0.029	0.277	***	0.034
2005	0.312	***	0.029	0.329	***	0.034
2006	0.394	***	0.029	0.418	***	0.034
2007	0.506	***	0.029	0.552	***	0.035
2008	0.617	***	0.029	0.639	***	0.035
2009	0.553	***	0.029	0.570	***	0.034
2010	0.554	***	0.029	0.573	***	0.034
2011	0.690	***	0.029	0.713	***	0.034
Constant	1.456	***	0.043	1.547	***	0.062
No. of observations	49,943			34,833		
R-squared adjusted	0.045			0.039		
$\ln(PINT_{t-1})$, subfield of alloys	0.014		0.013	-0.006		0.016
$\ln(PINT_{t-1})$, subfield of coatings	0.013		0.017	-0.007		0.020
$\ln(PINT_{t-1})$, subfield of composites	-0.011		0.014	0.003		0.017
$\ln(PINT_{t-1})$, subfield of electronics	0.032	***	0.011	0.086	***	0.014
$\ln(PINT_{t-1})$, subfield of layers	0.029	*	0.015	0.021		0.020
$\ln(PINT_{t-1})$, subfield of macrostructure	0.039	***	0.013	0.057	***	0.016
$\ln(PINT_{t-1})$, subfield other/nano-materials	0.013		0.014	-0.020		0.017

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

Table 5.23 - Effect of patent intensity on export unit values in AMT for other KETs: results of panel OLS regressions

dependent variable: $\ln(UV^X)$	*Total*	*EU-28*

	Coefficient		Std.dev.	Coefficient		Std.dev.
ln($PINT_{t-1}$), all AMT for other KETs patents	0.236	***		0.239	***	0.010
ln(GDP)	0.031	***		-0.003		0.011
ln(GDP/cap)	-0.076	***		-0.000		0.016
Year dummies (reference: 2002)						
2003	0.142	***	0.050	0.163	***	0.060
2004	0.233	***	0.050	0.264	***	0.060
2005	0.282	***	0.050	0.341	***	0.060
2006	0.355	***	0.050	0.395	***	0.060
2007	0.559	***	0.050	0.670	***	0.060
2008	0.683	***	0.049	0.721	***	0.059
2009	0.636	***	0.049	0.645	***	0.059
2010	0.624	***	0.049	0.645	***	0.060
2011	0.654	***	0.049	0.710	***	0.060
Constant	2.175	***	0.074	2.291	***	0.106
No. of observations		11,037			7,704	
R-squared adjusted		0.124			0.130	
ln($PINT_{t-1}$), subfield of AMT for biotechnology	0.097	***	0.025	0.039		0.031
ln($PINT_{t-1}$), subfield of controlling/AMT for nanotechnology	-0.091	***	0.020	0.037		0.029
ln($PINT_{t-1}$), subfield of instruments	0.047	**	0.022	0.053	*	0.030
ln($PINT_{t-1}$), subfield of AMT for materials	0.152	***	0.021	0.107	***	0.030
ln($PINT_{t-1}$), subfield of AMT for photonics	-0.061	***	0.019	0.032		0.030
ln($PINT_{t-1}$), subfield of AMT for microelectronics	0.052	***	0.019	0.061	**	0.026

Note: ***, **, *: estimated coefficients significant at the 1%-, 5%-, 10%-level.
Source: COMTRADE and Patstat. ZEW and NIW calculations.

5.6. CONCLUSIONS

The analysis of the value chain position of the EU-28 in the production and trade of KET-related products showed different results for the 6 KETs (Table 5.24):

- In **industrial biotechnology**, Europe is specialised in products with high technology content, i.e. in products with higher quality or at later stages in the production chain. During the past decade, Europe was able to further strengthen its position. Despite Europe's technological advance, exports predominantly face price competition. However, Europe tends to have a price advantage in international trade in industrial biotechnology products which could point to a more efficient production. Patenting is a major driver for the technology content of industrial biotechnology products.
- Europe holds a rather unfavourable position in **nanotechnology**. Technology content of most products is lower than in the two main competitor regions and rather tends to decrease, indicating a specialisation in less complex products. Europe's exports in nanotechnology mainly compete in prices, though Europe tends to have price advantages for most of these exports. Patenting is important to achieve a high technology content of products; though, this effect is less pronounced in Europe compared to North America and East Asia.
- **Micro- and nanoelectronics** are a KET area where Europe's position in value chains is weakest. Technology content of products is low and decreasing which is accompanied by strong price competition of exports and no sign of a price advantage for Europe. To maintain the level of technology content, patenting is highly important with an even stronger impact in Europe than in the other two regions. Patent activities in Europe were not sufficient, however, to improve its trade position. In micro- and nanoelectronics it is important to note that only basic products (integrated circuits) are considered, but not micro- and nanoelectronics contained in more complex products.
- In **photonics**, Europe shows a high and increasing technology content of its exports which primarily face price competition. Most of Europe's exports do not show a price advantage relative to their competitors. The role of patenting is lower for the products' technology content than for most other KETs. One may conclude that Europe is specialised in rather high-end products in photonics while global markets are increasingly characterised by price erosion.
- **Advanced materials** show a similar state as industrial biotechnology products in Europe. Technology content is high and increasing for most of Europe's exports. International competition is driven by price competition and Europe can build upon price advantages for most of its export products. Patenting is of subordinate relevance for the technology content of products.
- **AMT for other KETs** is certainly the KET area for which Europe holds the most advanced position in production and trade. Technology content of export is high and increasing and strongly based on patenting. Most of Europe's exports compete in quality and Europe holds quality advantages for most of its export products. It is fair to conclude that Europe is the leading region in this KET which is also confirmed by a high positive specialisation and a high positive trade balance.

Table 5.24 - The position of the EU-28 in the production and trade of KET-related products: summary overview

	Industrial biotechnology	*Nano-technology*	*Micro-/nano-electronics*	*Photonics*	*Advanced Materials*	*AMT for other KETs*
Technology content of exports	high and increasing	low, mostly decreasing	low and decreasing	high and increasing	high and increasing	high and increasing
Type of competition	mostly price competition, price advantage	price competition, mostly with price advantage	price competition, no price advantage	price competition, no price advantage	price competition, mostly with price advantage	mostly quality competition, quality advantage
Impact of patenting	moderate	low	high	low	low	high

Source: ZEW and NIW.

CHAPTER 6. CONCLUSION AND POLICY IMPLICATIONS

Underlying study has the aim to analyse the competitiveness of Europe in the global production of KETs-based products by employing a value chain approach. Both qualitative and quantitative data are used to create insight in the position of Europe in global value chains. The study clearly shows that Europe holds a varying position in the different KETs, but in general the increasing importance of Asia that has become a main producer of new technological knowledge in KETs and that demonstrates a higher pace of market share gains, cannot be ignored.

1. A large commercialization potential lies ahead of us but there are challenges

Considering all Key Enabling Technologies (KETs), a certain number of developments and applications are already commercialized and make a real difference in terms of commercial and social value. However, the majority of the (scientific and) technological development, still needs considerable development and upscaling in order to reach the market. **For Europe, this poses enormous opportunities and at the same time major challenges with respect to future R&D and innovation policy support priorities**.

- For **industrial biotechnology**, several promising technological developments and applications have been identified such as bio-based polymers and enzymes. With regard to the market potential, most platform chemicals need further optimization in order to be produced at economically interesting rates. Bio-based polymers such as bio-based plastics have a major market potential, but few applications have reached large scale production yet. At the same time, enzymes, such as carbohydrases, proteases and lipases, are increasingly used to perform chemical reactions in various industries. The emphasis is currently put on improving the performance and stability in industrial conditions of enzymes, next to a reduction of the production costs. In addition, biorefinery concepts can play an important role in the utilization and conversion of biogenic raw materials and residues.
- **Photonics** is a key enabling technology that has technological developments and applications in many industries such as in the photovoltaics, communication, display and lighting industry. Photovoltaic solar panels have entered a third generation approach focused on lower costs and higher efficiency. In addition, research is being conducted in the area of concentrated solar power systems such as the parabolic through concentrator. In the transportation of information arena, a huge challenge lies in overcoming crosstalk between different data sources in multiple mode/core fibres, next to a reduction of energy consumption. Also the rise of organic light emitting diodes (OLEDs) is promising as displays can be made thinner and less power consuming, while LEDs have the potential to reduce energy consumption in the area of lighting. All these challenges could, and perhaps should, be reflected in future European R&D and innovation priorities.
- **Micro- and nanoelectronics** developments and applications have diffused into almost all industries. They play a crucial role in the development of the information age. The introduction of multicore processors offers potential in enhancing efficiency, as processing tasks can be well divided and delegated, but it poses major challenges on the software side. Also in the computer memory area, there are continuous developments to reduce either size or power consumption, and/or to enhance performance. In this regard, Resistive RAM and Spin Torque Ram are promising technologies for the future. The More than Moore trend entails promising applications in the area of continued integration of functionalities.
- **Advanced Materials** are at the basis of multiple value chains and strongly enable industrial innovation, as they are the building blocks of most physical products. The significance of lightweight materials is largely driven by their role in achieving greater energy efficiency as for example it takes less energy to accelerate a lighter object. Another promising area of research is focused on materials that are resistant to harsh conditions such as intermetallics. The availability and access to advanced material is crucial for the further development of the European industry.
- **Nanotechnology** is essential in many economic value chains, as it can be used to realize smaller, quicker, more powerful, or more “intelligent” intermediates and systems components for products with

significantly improved or even completely new functions (HLG Nano, 2010). Graphene and its rolled equivalent carbon nanotubes are both very promising materials that could serve for a variety of applications. Their thin carbon structure gives them light weight, high strength and excellent electrical properties. These properties have brought them at the forefront of scientific research across the globe. Quantum dots are also of interest because of their unique optical and electrical properties. However, as nanotechnology develops rapidly, caution is warranted regarding associated health risks. Here there is clearly also a societal challenges and responsibility that need to be addressed.

- **Advanced manufacturing technologies** enable technological innovations to be applied in various goods and services. It involves both pure manufacturing techniques and supporting techniques for modelling or simulation. Additive manufacturing entails promising applications such as 3D printing, as it allows straightforward manufacturing of complex geometries and uses only the material needed to produce a product, thereby reducing waste compared to the traditional subtractive process of removing material from solid blocks. In some applications it also reduces the need for large stocks. In addition, major progress has been realized in the use of lithography and wafer size transitions. The transition to 450 mm wafers will pose considerable challenges in the next years and seem to be essential for several future developments, especially in relation to the semiconductor and associated industries.

2. **Europe has a strong technological capacity, a substantial production base, is specialised in (mature) products with high technology content, but has to compete mainly on price. Moving to the higher end of the value chain is necessary.**

When looking at Europe's position in the production and trade of KETs (evaluated by 1) the technology content of the manufactured goods, 2) type of competition faced, 3) link between new technological knowledge and technology content of manufactured goods) we see that Europe has both a strong technological capacity and a substantial production base in all KETs. Europe is, in contrast to the emerging competitors from East Asia, specialised on KET-related products with high technology content. However, most of these products seem to be rather mature since they mostly compete on prices and less on quality. There are differences per KETs (see below).

2.1. Industrial biotechnology: high and increasing technology content of exports, and a price advantage

In industrial biotechnology, Europe is specialised in products with high technology content, i.e. in products with higher quality or at later stages in the production chain. During the past decade, Europe was able to further strengthen its position. Despite Europe's technological advance, exports predominantly face price competition. However, Europe tends to have a price advantage in international trade in industrial biotechnology products which could point to a more efficient production. Patenting is a major driver for the technology content of industrial biotechnology products.

2.2. Nanotechnology: low and decreasing technology content of exports but there is a price advantage

Europe holds a rather unfavourable position in nanotechnology. Technology content of most products is lower than in the two main competitor regions (North America and East Asia) and rather tends to decrease, indicating a specialisation in less complex products. Europe's exports in nanotechnology mainly compete in prices, though Europe tends to have price advantages for most of these exports. Patenting is important to achieve a high technology content of products; though, this effect is less pronounced in Europe compared to North America and East Asia.

2.3. **Micro- and nanoelectronics: low and decreasing technology content of exports and no price advantage**

Technology content of products is low and decreasing which is accompanied by strong price competition of exports and no sign of a price advantage for Europe. To maintain the level of technology content, patenting is highly important with an even stronger impact in Europe than in the other two regions. Patent activities in Europe were not sufficient, however, to improve its trade position. In micro- and nanoelectronics it is important to note that only basic products (integrated circuits) are considered, but not the micro- and nanoelectronics contained in more complex products.

2.4. Photonics: high and increasing technology content of exports and a price advantage

In photonics, Europe shows a high and increasing technology content of its exports which primarily face price competition. Most of Europe's exports do not show a price advantage relative to their competitors. The role of patenting is lower for the products' technology content than for most other KETs. One may conclude that Europe is specialised in rather high-end products in photonics while global markets are increasingly characterised by price erosion.

2.5. Advanced materials: high and increasing technology content of exports and a price advantage

Advanced materials show a similar state as industrial biotechnology products in Europe. Technology content is high and increasing for most of Europe's exports. International competition is driven by price competition and Europe can build upon price advantages for most of its export products. Patenting is of subordinate relevance for the technology content of products.

2.6. Advanced manufacturing for other KETs: Europe is leading, high technology content of exports and a clear quality advantage

Advanced manufacturing for other KETs is certainly the KET area for which Europe holds the most advanced position in production and trade. Technology content of export is high and increasing and strongly based on patenting. Most of Europe's exports compete in quality and Europe holds quality advantages for most of its export products. It is fair to conclude that Europe is the leading region in this KET which is also confirmed by a high positive specialisation and a high positive trade balance.

Europe's position in summarized in Table 5.24.

A key challenge for European competitiveness policy is to bring European industry onto a competitive path that stronger rests on more innovative and more complex products. In many KETs this would mean to focus on more integrated technologies, including technologies that link several KETs. Such a product portfolio would promise a shift of competitive pressure towards quality competition. In such an environment, EU industry could better exploit its competitive advantages and create real value on several levels.

In order to make this shift (or ***'upgrading'***) possible, various approaches may be followed:

- Improving the links between producers of basic technological elements with producers of components and final products;
- Strengthening cross-fertilisation of technology developments across KETs;
- Fostering and reinforcing the development of clusters along value chains in KETs, including both knowledge producers (such as universities and research institutes) and knowledge users.

A strategy of moving European industry to the higher end of value chains in KETs can, but need not rest on a strong base in each basic technological element within each KET. Policy should also consider the advantages of global cooperation in the development and deployment of new KETs and new applications of KETs. This could mean, on the one hand, to cooperate with specialised technology suppliers from other global regions. On the other hand, successful commercialisation of new applications often depends on cooperating with the right customers in those markets that set future trends (so-called Lead Markets), and this paying sufficient attention to the demand side. It can be more beneficial for European industry to commercialise new KETs abroad - even if parts of the production will move to dynamic markets abroad - than to focus on European markets with less promising long-term perspectives.

Moving up to the higher end of the value chain is at the same time enormously complex and challenging. While monitoring the developments in the entire value chains, it is equally important to focus on promising segments and the value chains of these segments. This is amply confirmed by the analysis of the two promising KETs products that have been analysed.

3. Zooming into promising KET product segments: a starting point for 'moving up' the value chain?

On the basis of the analysis of the value chains of two selected KETs-based products, namely lipase enzymes (industrial biotechnology) and the accelerometer (micro- and nanotechnology), a qualitative assessment has been made of the strength of Europe in these two selected value chains and in particular segments of these value chains. The value chain decomposition allows identifying relevant players in the different phases of the value chain. Based upon the location of these players, an assessment can be made on the importance of European companies in these KETs areas by looking at their activities and financial performance.

Although precise figures on the value added captured by European companies are lacking (due to confidentiality issues and the lack of insight into the share of valued added of a particular KET in the overall valued added of a company) the obtained results shows that Europe is a key player in the area of lipase enzymes and the global enzyme market. Europe also has a solid position in the end-producers segment of the accelerometer, as some European companies grasp a significant share of the automotive and consumer market, two markets where accelerometers are applied. Competition is nevertheless strong, especially in the foundry segment.

It is interesting to note that although the general position of Europe in the entire micro- and nanotechnology value chain is weak (cf. supra), the position of Europe with respect to the value chain of the accelerometer (segment inside micro- and nanotechnology) is good. This suggests that even if the overall position in a particular KET is not optimal, there may always be segments (existing or newly emerging) where Europe has a good position, and where active policy support can make a difference on the longer run. **It is important to observe and monitor these specific segments closely (through the future KETs Observatory), and act in time in order to stay ahead of the (increasing) competition. A focused and intensified policy in this respect may on the longer run lead to Europe climbing-up in the global KETs value chains.**

CHAPTER 7. REFERENCES

Ahn, J.-H., (2013), 'Implementation of an LED tile controller for high-quality image display', *Displays* **34**, pp. 17–26.

Aiginger, K. (1997), 'The use of unit values to discriminate between price and quality competition', *Cambridge Journal of Economics*, vol. 21, pp. 571-592.

Aiginger, K. (2000), '*Europe's Position in Quality Competition, Background Report for The European Competitiveness Report 2000'*, Working Paper, European Commission, DG Enterprise.

Alam M.E., Han S., Nguyen, Q.B., Hamouda, A.M.S., Gupta, M., (2011), 'Development of new magnesium based alloys and their nanocomposites', *Journal of Alloys and Compounds* **509,** pp. 8522– 8529.

Amendement2, (2012), Information taken from the company website: http://www.amendment2.com/the-company/

Arcam, (2013), Information taken from the company website http://www.arcam.com/.

Arora, A., Fosfuri, A., Gambardella, A. (2002), '*Markets for Technology: The Economics of Innovation and Corporate Strategy*', Cambridge: The MIT Press.

Aschhoff, B., Brandes, F., Crass, D. Diaz-Lopez, F., Cremers, K. Grimpe, C., Klein Woolthuis, R., Mayer, M., Montalvo, C., Rammer, C. (2010), '*European Competitiveness in Key Enabling Technologies. Background Report to the European Competitiveness Report 2010'*, Mannheim and Delft: ZEW and TNO.

ASML, (2012), Information available at http://www.asml.com/asml/show.do?ctx=5869&rid=46974

BCC Market Research, (2011a), In Report BIO030F - Enzymes in Industrial Applications: Global Markets.

BCC Market Research (2011b), Graphene: Technologies, Applications and Markets

BCC Market Research (2011c), Quantum Dots: Global Market Growth and Future Commercial Prospects

BCC Market Research (2011d), Robotics: Technologies and Global Markets.

BCC Market Research, (2012), Advanced Materials and Devices for Renewable Energy: Global Markets

Beise, M., Rammer, C. (2006), 'Local User-Producer Interaction in Innovation and Export Performance of Firms', *Small Business Economics*, vol. 27, pp. 207-222.

Bleaney, M., Wakelin, K. (2002), 'Efficiency, innovation and exports', *Oxford Bulletin of Economics and Statistics*, vol. 64, pp. 3–15.

Boivie, K., Dolinsek, S., and Homar, D., (2011), 'Hybrid manufacturing; integration of additive technologies for competitive production of complex tools and products', Paper presented on 15th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT, Prague, Czech Republic.

BP, (2012), Article available at http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7079431

CambridgeIP, (2013), *IP Insight Report*. Patenting flatland: *Graphene*

Cefic, (2012), The European chemical industry in worldwide perspective: Facts and Figures 2012

CENT, (2007), Article available at http://news.cnet.com/8301-13579_3-9758926-37.html

CENT, (2011), Article available at http://news.cnet.com/8301-17938_105-20077829-1/led-based-lcd-tvs-explained-compared/

Chaar, L., Lamont, L.A., Zein, N., (2011), 'Review of photovoltaic technologies', *Renewable and Sustainable Energy Reviews* **15**, pp. 2165–2175

Cheng, Jian, Liu C.S., Shang, S., Liu, D., Perrie, W., Dearden, G., and Watkins, K., (2013), 'A review of ultrafast laser materials micromachining'. *Optics & Laser Technology* **46**, pp. 88–102

Chundawat, Shishir, Beckham, G.T., Himmel, M.E., & Dale, B.E., (2011), 'Deconstruction of Lignocellulosic Biomass to Fuels and Chemicals'. *Annual Review of Chemical and Biomolecular Engineering* **2**, pp. 121–45

Cinca, N., Guilemany, J.M., (2012), 'Thermal spraying of transition metal aluminides: An overview', *Intermetallics* **24**, pp. 60-72

CNSE Albany, (2011), Information available at http://cnse.albany.edu/LeadingEdgeResearchandDevelopment2/Global450Consortium.aspx

Conibeer, Gavin (2012), 'Si and Other Group IV Quantum Dot Based Materials for Tandem Solar Cells', *Energy Procedia* **15,** pp. 200 – 205

De Volder, M., Tawfick, S., Baughman, R., Hart, J. (2013). Carbon Nanotubes: Present and Future Commercial Applications. *Science*, pp. 535-539

Demir Hilmi Volkan, Nizamoglub, S., Erdemb T., Mutluguna, E., Gaponik, N., Eychmüller, A., (2011), 'Quantum dot integrated LEDs using photonic and excitonic color conversion', *Nano Today* **6**, pp. 632—647

Deng, Y., Zhou, J., (2011), 'Architectures and optimization methods of flash memory based storage systems', *Journal of Systems Architecture* **57,** pp. 214–227

DOE, (2008), 'Basic research needs for materials under environments' US Department of Energy (DOE)

DOE, (2010), 'Materials Technologies: Goals, Strategies, and Top Accomplishments', United States Department of Energy (DOE).

DOE, (2012), 'Solid-State Lighting' Available at http://www1.eere.energy.gov/buildings/ssl/. US department of Energy (DOE)

Domeika, Max, (2008), 'Software Development for Embedded Multi-Core Systems: A Practical Guide Using Embedded Intel Architecture'

DSM, (2011), 'DSM and Roquette to open commercial scale bio-based succinic acid plant in 2012' http://www.dsm.com/en_US/cworld/public/media/pages/press-releases/36_11_dsm_and_roquette_to_open_commercial_scale_bio_based_succinic_acid_plant_2012.jsp.

Ebling, G., Janz, N. (1999), '*Export and Innovation Activities in the German Service Sector: Empirical Evidence at the Firm Level*', ZEW Discussion Paper No. 99-53, Mannheim.

EC (2012a), '*A European strategy for Key Enabling Technologies – A bridge to growth and jobs*', COM(2012) 341, Brussels, 26.6.2012.

EC (2012b), 'A Stronger European Industry for Growth and Economic Recovery', COM(2012) 582, Brussels, 10.10.2012.

EETimes, (2006), Article available at http://www.eetimes.com/electronics-news/4057964/AMD-licenses-Innovative-Silicon-s-SOI-memory

Environmental Entrepreneurs (2012). Advanced Biofuel Market Report 2012

ESMAP, (2011), Assessment of the Local Manufacturing Potential for Concentrated Solar Power (CSP) Projects. Energy Sector Management Assistance Program (ESMAP).

Essiambre, R.J., Foschini, G., Winzer, P., and Kramer, G., (2009), 'Capacity Limits of Fiber-Optic Communication Systems', Presentation at Optical Fiber Communication (OFC) Conference in San Diego, California, USA

EC (2012), '*A European strategy for Key Enabling Technologies – A bridge to growth and jobs*', COM(2012) 341, Brussels, 26.6.2012.

EuMAT, (2006), Roadmap of the European Technology Platform for Advanced Engineering Materials and Technologies.

Extremat, (2010), ExtreMat IP- New Materials for Extreme Environments.

Ferguson, A., Blackburn, J., Kopidakis, N. (2013). Fullerenes and carbon nanotubes as acceptor materials in organic photovoltaics. *Materials Letters* **9,** pp. 115–125

Festel, G. (2010), Industrial biotechnology: Market size, company types, business models, and growth strategies, *Industrial Biotechnology* **6**(2), pp. 88-94

FitzPatrick, M., Champagne P., Cunningham M.F., Whitney, R.A., (2010), 'A biorefinery processing perspective: Treatment of lignocellulosic materials for the production of value-added products', *Bioresource Technology* **101**, pp. 8915–8922

Foresight, (2010), 'Technology and Innovation Futures: UK Growth Opportunities for the 2020s', Foresight Horizon Scanning Centre, UK Government Office for Science

Freescale, (2009), 'Embedded Multicore: An Introduction', Freescale Semiconductor

Frietsch, R., Schmoch, U. (2010), 'Transnational patents and international markets', *Scientometrics*, 85, pp. 185-200.

Frommeyer, G., Rablbauer, R., (2008), 'High Temperature Materials Based on the Intermetallic Compound NiAl Reinforced by Refractory Metals for Advanced Energy Conversion Technologies', *Steel research international* **79**(7), pp. 507-513.

Gambardella, A., Giuri, P., Luzzi, A. (2007), 'The market for patents in Europe', *Research Policy,* 36, pp. 1163–1183.

Geim (2009). Graphene: Status and Prospects. *Science* **324**, pp. 1530-1534

Ghosh, S., Bayoumi, M., (2005), 'On Integrated CMOS-MEMS System-on-Chip', Paper presented at the 3rd International IEEE-NEWCAS Conference.

Glänzel, W., Moed, H., Schmoch, U. (eds.) (2004), '*Handbook of Quantitative Science and Technology Research. The Use of Publication and Patent Statistics in Studies on R&D Systems*', Dordrecht: Kluwer Academic Publishers.

Global Industry Analysts, (2012), Industrial enzymes – A global strategic business report

GlobalFoundries, (2011), Reaping the benefits of the 450mm transition. Presentation at Semicon West 2011. Presentation available at http://semiconwest.org/sites/semiconwest.org/files/Thomas%20Sonderman_GLOBALFOUNDRIES.pdf

Goh, G., Ismail A.F., Ng, B.C., (2013), Carbon nanotubes for desalination: Performance evaluation and current hurdles. *Desalination* **308**, pp. 2–14

Graphene Flagship, (2013), Press release available at http://www.graphene-flagship.eu/GFfiles/130124_PresseText_A4.pdf

Herrera-Herrera, A., González-Curbelo M.A., Hernández-Borges, J., Rodríguez-Delgado, M.A., (2012), 'Carbon nanotubes applications in separation science: A review.' *Analytica Chimica Acta* **734,** pp. 1– 30.

HLG AMT, (2010), Thematic Report by the Working Team on Advanced Manufacturing Systems.

HLG IB, (2011), KET – Industrial Biotechnology, High Level Group (HLG) on Key Enabling Technologies.

HLG MAT, (2010), Working document – working group on advanced material technologies, High Level Group (HLG) on Key Enabling Technologies.

HLG MNE, (2011), Interim Thematic Report by the Micro/Nanoelectronics Sherpa Team, High Level Group (HLG) on Key Enabling Technologies

HLG Nano, (2010), Nanotechnology: a sustainable basis for competitiveness and growth in Europe, High Level Group (HLG) on Key Enabling Technologies;

HLG Photonics, (2011), Photonics – a key enabling technology for Europe, High Level Group (HLG) on Key Enabling Technologies.

IC Knowledge, (2010), White paper – Forecasting the 450mm ramp up.

InformationWeek, (2008), Article available at http://www.informationweek.com/storage/systems/google-plans-to-use-intel-ssd-storage-in/207602745

ION, (2012), 'Making the most of carbon nanotubes – the miracle material of the 21st century? The Institute of Nanotechnology (ION)', Article available at http://www.nano.org.uk/nano/nanotubes.php

IRENA, (2012), 'Renewable energy technologies: cost analysis series, Concentrating Solar Power' Volume 1: Power Sector Issue 2/5. International Renewable Energy Agency (IRENA)

ITRS, (2010), "More-than-Moore" White Paper. International Technology Roadmap for semiconductors (ITRS).

Jäger-Waldau, A. (2011), '*Research, Solar Cell Production and Market Implementation of Photovoltaics, PV Status Report 2011*', European Commission, DG Joint Research Centre, Institute for Energy, Renewable Energy Unit.

Jang, Y.S., Byoungjin Kim, Jae Ho Shin,Yong Jun Choi, Sol Choi, Chan Woo Song,1 Joungmin Lee, Hye Gwon Park & Sang Yup Lee, (2012), 'Bio-Based Production of C2–C6 Platform Chemicals. *Biotechnology and Bioengineering* **109**(10), pp. 2437-2459

Jegannathana, Kenthorai Raman and Per Henning Nielsen, (2012), 'Environmental assessment of enzyme use in industrial production – a literature review', *Journal of cleaner production.* doi: 10.1016/j.jclepro.2012.11.005.

Joshi, Pooran C., Ryan R. Dehoff, Chad E. Duty, William H. Peter, Ronald D. Ott, Lonnie J. Love, and Craig A. Blue, (2012), Direct Digital Additive Manufacturing Technologies: Path Towards Hybrid Integration. Paper appeared for Future of Instrumentation International Workshop (FIIW), Gatlinburg, TN, USA.

Kaija, K., V. Pekkanen, M. Mantysalo, S. Koskinen, J. Niittynen, E. Halonen, and P. Mansikkamaki, (2010), 'Inkjetting dilectric layer for electronic applications', *Microelectronic Engineering* **87,** pp. 1984-1991

Kalyania, N. Thejo, S.J. Dhobleb, (2012), 'Organic light emitting diodes: Energy saving lighting technology—A review', *Renewable and Sustainable Energy Reviews* **16**, pp. 2696– 2723

Kawahara, T., K. Ito, R. Takemura, H. Ohno, (2012), 'Spin-transfer torque RAM technology: Review and prospect', *Microelectronics Reliability* **52**, pp. 613–627

Kircher, M. (2012), 'How to turn industrial biotechnology into reality', *New Biotechnology,* 29(2), pp. 243-247

Kohler, Andreas R. , Claudia Som , Aasgeir Helland , Fadri Gottschalk, (2008), Studying the potential release of carbon nanotubes throughout the application life cycle. *Journal of Cleaner Production* **16**, pp. 927-937

Kostopoulos, V., A. Baltopoulos, P. Karapappas, A. Vavouliotis, A. Paipetis, (2010), Impact and after-impact properties of carbon fibre reinforced composites enhanced with multi-wall carbon nanotubes. *Composites Science and Technology* **70**, pp. 553–563

Kuhad, Ramesh Chander, Rishi Gupta & Ajay Singh, (2011), 'Microbial Cellulases and Their Industrial Applications', *Enzyme research* 1-10

Lamoreaux, N., Sokoloff, K. (1999), '*Inventive Activity and the Market for Technology in the United States, 1840-1920*', NBER Working Paper 7107, Washington.

Lefebvre, E., Lefebvre, L.A., Bourgault, M. (1998), 'R&D-Related Capabilities as Determinants of Export Performance', *Small Business Economics*, vol. 10, pp. 365–377.

Li, Sikun, Xiangzhao Wang, Yang Bu, (2013), 'Robust pixel-based source and mask optimization for inverse lithography', *Optics & LaserTechnology* **45**, pp. 285–293

Lightman, K. (2013). Choosing a MEMS foundry. Article available at http://www.memsindustrygroup.org/i4a/headlines/headlinedetails.cfm?id=551

Lightman, K., (2013), Choosing a MEMS foundry', Information available at http://www.memsindustrygroup.org/i4a/headlines/headlinedetails.cfm?id=551

Makarov, A., V. Sverdlov, S. Selberherr, (2012), 'Emerging memory technologies: Trends, challenges, and modeling methods', *Microelectronics Reliability* **52,** pp. 628–634

McKinsey, (2009), Pathways to a low-carbon economy

NanoRoadSME (2006). Roadmap Report Concerning the Use of Nanomaterials in the Energy Sector.

Nobel Prize committe (2010). Press release available at http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/press.html

NRC, (2012), '*Optics and Photonics: Essential Technologies for Our Nation*', National Research Council (NRC)

OECD(2009). The Bioeconomy to 2030.

OECD, (2005), A framework for biotechnology statistics.

OECD, (2009), The Bioeconomy to 2030 - Designing a policy agenda.

OECD, (2010), 'Discussion Paper - Session Trends in Technology and Applications', OECD Workshop on "Outlook on Industrial Biotechnology".

Optech, (2007), '*Photonics in Europe, Economic Impact'*, Photonics21 & Optech Consulting

Palencia, J., Furubayashi, T., Nakata, T. (2012). Energy use and CO2 emissions reduction potential in passenger car fleet using zero emission vehicles and lightweight materials. *Energy* **48**, pp. 548-565

Pautrat J.L., (2011), 'Nanosciences: Evolution or revolution?', *Comptes Rendus Physique* **12**: 605–613

Perlmutter, M. & Robin, L. (2012). High-Performance, Low Cost Inertial MEMS: a Market in Motion. *Position Location and Navigation Symposium (PLANS), 2012 IEEE/ION,* pp. 225-229

Perlmutter, M. & Robin, L., (2012), 'High-Performance, Low Cost Inertial MEMS: a Market in Motion', *Position Location and Navigation Symposium (PLANS), 2012 IEEE/ION,* pp. 225-229

Photonics21, (2012), '*Photonics - A Key Enabling Technology on its way to Horizon 2020*', European Technology Platform Photonics21

Reilly, R., (2007), 'Carbon Nanotubes: Potential Benefits and Risks of Nanotechnology in Nuclear Medicine', *Journal of Nuclear Medecine.* **48** (7), pp. 1039-1042

REN21 (2008), '*Renewables 2012, Global Status Report'*, Paris.

Reuters, (2012), Article available at http://www.reuters.com/article/2012/06/12/us-tsmc-renesas-idUSBRE85B06J20120612

Roper, S., Love, J.H. (2002), 'Innovation and Export Performance: Evidence from UK and German Manufacturing Plants', *Research Policy*, vol. 32, pp. 1087–1102.

Ryhänen, T., (2010), Impact of Silicon MEMS—30 Years After. In: Handbook of Silicon Based MEMS Materials and Technologies, edited by Veikko Lindroos, Markku Tilli, Ari Lehto & Teruaki Motooka. Pages xv-xxxii

Saez, J.C., Shelepov, D., Fedorova, A., Prieto, M., (2011), 'Leveraging workload diversity through OS scheduling to maximize performance on single-ISA heterogeneous multicore systems. *Journal of Parallel and Distributed Computing* **71**, pp. 114–131

Salihu, A., Alam, Z., Karim, M., Salleh, H. (2012). Lipase production: An insight in the utilization of renewable agricultural residues. *Resources, Conservation and Recycling* **58**: 36– 44

Sanderson, K., (2009), 'Quantum dots go large', Nature **459**, pp. 760-761

Sangeetha, R., Arulpandi, I., and Geetha A., (2011), 'Bacterial Lipases as Potential Industrial Biocatalysts: An Overview', *Research Journal of Microbiology* **6**, pp. 1-24.

Sarrouh, B., Marcos Santos, T., Miyoshi, A., Dias, R. & V. Azevedo, (2012), 'Up-To-Date Insight on Industrial Enzymes Applications and Global Market', *Journal of Bioprocessing Techniques* S4:002 doi:10.4172/2155-9821.S4-002

Schmoch, U. (2009), 'Patent analyses in the changed legal regime of the US Patent Law since 2001', *World Patent Information*, 31, pp. 299-303.

Schörken, U., Kempers, P., (2009), 'Lipid biotechnology: Industrially relevant production processes', *European Journal of Lipid Science and Technology* **111**, pp. 627–645

Sengül H., Theis, T.L., (2011), 'An environmental impact assessment of quantum dot photovoltaics (QDPV) from raw material acquisition through use', *Journal of Cleaner Production* **19**, pp. 21-31

Serrano, C.J. (2005), '*The Market for Intellectual Property: Evidence from the Transfer of Patents*', mimeo, University of Minnesota and Federal Reserve Bank of Minneapolis.

Shen, L., Haufe, J. & Patel, L., (2009), Product overview and market projection of emerging bio-based plastics.

Shipp S., Gupta, N., Bhavya Lal, Scott J.A., Weber, C.L., Finnin, M.S., Blake M., Newsome, S., Thomas, S., (2012), 'Emerging Global Trends in Advanced Manufacturing', Institute for Defense Analyses

Sillard, P., (2011), 'New fibers for ultra-high capacity transport', *Optical Fiber Technology* **17**: 495–502

Singer, P., (2007), 'The big debate: 450 mm or not', *Semiconductor International* **30** (2): 61–63

Socol, Y., (2013), High-power free-electron lasers – technology and future applications', *Optics & LaserTechnology* **46**: 111–126

STPI, (2010). White Papers on Advanced Manufacturing Questions. Science and Technology Policy Institute (STPI).

Tan L.L., Wee-Jun Ong, Siang-Piao Chai, Abdul Rahman Mohamed, (2012), 'Growth of carbon nanotubes over non-metallic based catalysts: A review on the recent developments', *Catalysis Today* http://dx.doi.org/10.1016/j.cattod.2012.10.023

Technology Review, (2012), Article available at http://www.technologyreview.com/news/419426/flexible-touch-screen-made-with-printed-graphene/

TechRadar, (2013), Article available at http://www.techradar.com/news/phone-and-communications/mobile-phones/samsung-gives-glimpse-of-youm-its-flexible-oled-phone-future-112399

Temponi, C., Jimenez, J.A., and Mendez Mediavilla, F.A., (2012), 'Critical Variables in the Decision-Making Process for AMHS Technology Selection in Semiconductor Wafer Size Transitions: Exploratory Study', *IEEE transactions on semiconductor manufacturing* 25(3): 408-419

Tenent, Robert, Teresa M. Barnes, Jeremy D. Bergeson, Andrew J. Ferguson, Bobby To, Lynn M. Gedvilas, Michael J. Heben, & Jeffrey L. Blackburn, (2009), Ultrasmooth, Large-Area, High-Uniformity, Conductive Transparent Single-Walled-Carbon-Nanotube Films for Photovoltaics Produced by Ultrasonic Spraying. *Advanced Materials* **21** (31): 3210–3216

The Wall Street Journal, (2013), 'LG Beats Samsung in OLED TV Race', Article available at http://blogs.wsj.com/digits/2013/01/02/lg-beats-samsung-in-oled-tv-race/

Transparency Market Research, (2013), 'OLED Displays Market - Global Industry Analysis, Market Size, Share, Growth And Forecast, 2012 – 2018'

Upadhyayula, V., and Venkataramana Gadhamshetty, (2010), 'Appreciating the role of carbon nanotube composites in preventing biofouling and promoting biofilms on material surfaces in environmental engineering: A review', *Biotechnology Advances* **28**, pp. 802–816

Van de Velde, E., Rammer, C., de Heide, M., Pinaud, F., Verbeek, A., Gehrke, B., Mertens, K., Debergh, P., Schliessler, P., van der Zee, F., Butter, M. (2013), '*Feasibility study for an EU Monitoring Mechanism on Key Enabling Technologies'*, Brussels: European Commission.

van de Velde, E., Rammer, C., de Heide, M., Pinaud, F., Verbeek, A., Gehrke, B., Mertens, K., Debergh, P., Schliessler, P., van der Zee, F., Butter, M. (2013), '*Feasibility study for an EU Monitoring Mechanism on Key Enabling Technologies'*, Brussels: European Commission.

VLSI Research, (2012), '2011 Top Semiconductor Equipment Suppliers', Information available at https://www.vlsiresearch.com/public/cms_pdf_upload/706001v1.0.htm

Wagner, J. (1996), 'Export performance, human capital, and product innovation in Germany: a micro view', *Jahrbuch für Wirtschaftswissenschaften*, vol. 47, pp. 40–45

Wakelin, K. (1998): 'Innovation and export behaviour at the firm level', *Research Policy*, vol. 26, pp. 829–841.

Wilson, B., (2007), 'Photolithography. Connexions', Available at http://cnx.org/content/m1037/2.10/

Winzer, P.J., (2010), 'Beyond 100G Ethernet', *IEEE Communications Magazine* **48**(7), pp. 26-29.

Wydra, S. (2012). Overview of policy measures of biobased products. *Industrial biotechnology 8(1),* pp. 8-12

Ying ,L., Amran bin Mohd Salleh, M., Mohamed Yusoff, H., Suraya Binti Abdul Rashid & Abd. Razak, J., (2011), 'Continuous production of carbon nanotubes – A review', *Journal of Industrial and Engineering Chemistry* **17**, pp. 367–376

Yole Développement, (2012a), Status of the MEMS Industry 2012

Yole Développement, (2012b), MEMS Packaging Market & Technology Trends.

Yurish, S., (2007), 'MEMS Based System-on-Chip and System in Package: New Perspectives', *Sensors & Transducers Journal* **78**(4): I-IV

Zhao, D., Liu, T., Park J.G., Zhang M., Chen, J.M., and Wang B., (2012), 'Conductivity enhancement of aerosol-jet printed electronics by using silver nanoparticle ink with carbon nanotube', *Microelectronic Engineering* **96**: 71-75

CHAPTER 8. APPENDIX

8.1. LIST OF INTERVIEWEES

For the value chain analysis, following persons were interviewed:

- Andreas Wild (Executive Director, ENIAC Joint Undertaking)
- Alun Foster (Programme Manager, ARTEMIS Joint Undertaking)
- Volkert Claassen (Vice-President Strategy and Growth, DSM)
- David Rozzell (Director, Sustainable Chemistry Solutions, Inc.; Author, www.bio-catalyst.com)

The value chain decomposition was done with the help of experts from the Catholic University of Leuven and Bio Base Europe.

8.2. LIST OF PRODUCT CODES USED IN THE ANALYSIS

Table 8.1– Product Codes used for trade data analysis (Prodcom 8-digit)

Industrial Biotech-nology	Nano-technology	Micro-/ nano-electronics	Photonics	Advanced Materials			AMT for other KETs
20.14.32.71	20.11.12.90	26.11.30.03	26.11.22.20	13.96.11.00	20.16.54.50	23.12.12.70	26.51.52.39
20.14.34.73	20.12.21.60	26.11.30.06	26.11.22.40	13.96.12.00	20.16.54.90	23.14.11.10	26.51.52.71
20.14.42.90	20.12.23.30	26.11.30.23	26.11.40.70	20.12.21.10	20.16.55.50	23.14.11.30	26.51.53.81
20.14.64.70	20.13.21.30	26.11.30.27	26.51.53.30	20.12.21.20	20.16.55.70	23.14.11.50	26.51.62.10
20.30.22.73	20.13.52.90	26.11.30.34	26.51.53.50	20.12.21.50	20.16.56.30	23.19.25.00	26.51.62.55
20.59.59.57	20.14.13.25	26.11.30.54	26.60.11.30	20.12.21.60	20.16.56.50	23.44.12.10	26.51.65.00
21.10.20.10	20.14.61.50	26.11.30.65	26.60.13.00	20.12.24.15	20.16.56.70	23.44.12.30	27.90.31.18
21.10.20.20	20.14.64.30	26.11.30.67	26.70.22.30	20.12.24.19	20.16.57.00	23.65.12.20	27.90.31.45
	20.30.11.50	26.11.30.80	26.70.23.30	20.12.24.40	20.17.10.50	23.99.11.00	27.90.31.54
	20.30.12.90	26.11.30.91	26.70.23.90	20.13.21.30	20.17.10.90	23.99.14.00	27.90.31.90
	20.30.21.70		26.70.24.30	20.13.21.50	20.30.21.30	23.99.15.00	28.14.11.20
	20.30.22.73		26.70.25.00	20.13.22.35	20.30.21.50	24.10.12.15	28.14.11.40
	20.30.22.79		28.41.11.10	20.13.22.37	20.30.21.70	24.10.12.30	28.21.12.70
	20.59.54.00			20.13.22.60	20.51.11.30	24.10.12.45	28.21.13.51
				20.13.24.13	20.51.11.50	24.10.12.60	28.21.13.53
				20.13.24.15	20.52.10.60	24.10.12.75	28.21.13.55
				20.13.24.33	20.52.10.80	24.10.12.90	28.21.13.57
				20.13.24.53	20.59.41.55	24.10.12.90	28.25.11.50
				20.13.24.55	20.59.41.57	24.10.14.10	28.29.11.00
				20.13.24.60	20.59.41.75	24.10.14.20	28.29.12.70
				20.13.24.73	20.59.41.79	24.10.23.21	28.29.31.30
				20.13.24.75	20.59.53.00	24.10.23.22	28.29.39.10
				20.13.24.77	20.59.54.00	24.42.21.00	28.29.41.00
				20.13.31.10	20.59.55.50	24.44.21.00	28.29.60.30
				20.13.31.30	20.59.55.70	24.45.21.00	28.29.60.50
				20.13.31.50	20.59.55.80	25.50.20.20	28.29.60.90
				20.13.31.70	20.59.55.90	26.80.13.00	28.29.70.90
				20.13.43.10	20.59.56.20	27.20.11.00	28.29.82.20
				20.13.43.20	20.59.56.30	27.90.13.30	28.29.82.50
				20.13.43.40	20.59.56.40	27.90.13.50	28.29.86.00
				20.13.43.90	20.59.56.50	27.90.13.70	28.91.11.30
				20.13.65.00	20.59.56.60	27.90.13.90	28.91.11.53
				20.13.68.00	20.59.56.70	27.90.20.20	28.91.12.30
				20.16.40.13	20.59.57.40	27.90.20.50	28.94.11.00
				20.16.40.15	20.59.57.50		28.99.20.20
				20.16.40.20	20.60.12.20		28.99.20.40
				20.16.40.30	20.60.12.40		28.99.20.60
				20.16.40.40	20.60.12.60		28.99.39.45
				20.16.40.50	20.60.22.00		28.99.51.00
				20.16.40.62	22.19.20.13		33.13.11.20
				20.16.40.64	22.19.20.19		33.20.11.00
				20.16.51.30	23.12.12.10		33.20.33.00
				20.16.51.50	23.12.12.30		33.20.39.00
				20.16.53.90	23.12.12.50		33.20.60.00

Source: NIW/ZEW based on Van de Velde et al. (2013).

Table 8.2 – Product Codes used for trade data analysis (HS 6-digit)

Industrial Biotech-nology	Nanotech-nology	Micro-/ nano-electronics	Photonics	Advanced Materials				AMT for other KETs
291521	280300	854221	845610	280300	320490	390740	700719	840510
291814	290314	854229	854140	280461	320611	390750	700721	841780
291815	291250	854260	854190	280469	320619	390760	700729	841940
292221	294200	854890	900510	280610	320710	390810	701911	841960
292229	320210	(HS 2002)	901190	280620	320720	390890	701912	841989
292231	320420		901320	280910	320730	390910	710410	842129
292239	320730	854231	901380	280920	320740	390920	710420	842191
292241	320740	854232	901390	281000	340311	390930	720211	842199
292242	320910	854233	901820	281111	340319	390940	720221	842320
292243	380210	854239	902221	281119	340391	390950	720229	844400
292244	381400	(HS 2007)	902229	281122	340399	391000	720230	844511
292249			902730	281210	350520	400211	720241	844512
292250			902750	281290	350610	400219	720249	844513
350790				281310	350691	400220	720250	844519
381400				281390	350699	400231	720260	845410
				281810	360100	400239	720270	845420
				282612	360200	400241	720280	845430
				282619	380110	400249	720291	845490
				282630	380120	400251	720292	845510
				282690	380130	400259	720293	845521
				282720	380190	400260	720299	846820
				282731	380210	400270	720450	846880
				282732	380910	400280	720510	846890
				282735	380991	400291	720521	848110
				282739	380992	400299	720529	848610
				282741	380993	400510	722410	848630
				282749	381010	400520	722490	848640
				282751	381090	400591	740610	851420
				282759	381210	400599	740620	851430
				282760	381220	540211	760310	851440
				283620	381230	540219	760320	851519
				283630	381511	540220	760410	851521
				283640	381512	540310	850519	851529
				283650	381519	560500	850610	851531
				283660	381590	580900	850630	902410
				283691	381700	681140	850640	903281
				283692	381800	681280	850650	
				283699	382430	681291	850660	
				284610	382440	681292	850680	
				284690	390210	681293	853120	
				320411	390220	681299	854511	
				320412	390230	681320	854519	
				320415	390290	681381	854520	
				320416	390690	681389	854590	
				320417	390710	690912	854610	
				320419	390720	690919		
				320420	390730	700711		

Source: NIW.

Table 8.3 –Export unit values in nominal US-$ and in PPP US-$ by KET and triadic region 2002 to 2011

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
EU-28	**Export Unit Value in US $**										**Export Unit Value in PPP US $**									
KET 1 Industrial Biotechnology	2,9	3,3	3,4	3,6	3,3	3,9	4,6	5,1	4,2	4,9	3,2	3,2	3,1	3,3	3,1	3,4	3,9	4,5	3,9	4,4
KET 2 Nanotechnology	1,1	1,2	1,3	1,4	1,6	1,8	2,0	1,9	1,9	2,1	1,2	1,2	1,2	1,3	1,5	1,6	1,7	1,6	1,7	1,9
KET 3 Micro Nanotechnology	385	324	528	414	496	321	235	507	343	477	432	312	474	384	471	282	196	446	319	427
KET 4 Photonics	85	97	100	88	80	80	70	56	38	31	96	94	90	81	76	71	59	49	35	28
KET 5 Advanced Materials	1,3	1,5	1,7	1,9	2,0	2,1	2,4	2,2	2,2	2,5	1,5	1,5	1,6	1,7	1,9	1,9	2,0	1,9	2,1	2,2
KET 6 AMT	13,9	15,0	17,0	18,3	18,3	21,6	24,7	24,3	23,0	18,5	15,6	14,4	15,3	17,0	17,3	19,0	20,6	21,4	21,4	16,5
North America	**Export Unit Value in US $**										**Export Unit Value in PPP US $**									
KET 1 Industrial Biotechnology	1,7	1,3	1,1	1,1	1,3	1,5	1,5	1,2	1,4	1,6	1,7	1,3	1,1	1,1	1,3	1,5	1,5	1,2	1,4	1,6
KET 2 Nanotechnology	2,0	1,9	1,8	1,8	2,2	2,4	2,6	2,9	3,8	4,4	2,1	1,9	1,9	1,8	2,2	2,3	2,5	2,9	3,7	4,3
KET 3 Micro Nanotechnology	671	699	706	676	717	671	660	661	644	704	679	703	707	676	715	665	653	659	638	694
KET 4 Photonics	137	160	140	87	150	155	158	166	172	173	140	161	141	87	149	153	156	165	170	169
KET 5 Advanced Materials	1,4	1,4	1,5	1,8	1,9	2,0	2,1	1,9	2,2	2,4	1,5	1,4	1,5	1,8	1,9	1,9	2,1	1,9	2,1	2,3
KET 6 AMT	18,1	20,3	20,5	15,4	20,8	23,4	26,7	31,1	31,0	29,5	18,8	20,7	20,7	15,4	20,6	23,0	26,3	30,9	30,5	28,8
East Asia	**Export Unit Value in US $**										**Export Unit Value in PPP US $**									
KET 1 Industrial Biotechnology	1,6	1,5	1,6	1,7	1,5	1,5	2,0	1,6	1,7	1,8	2,7	2,6	2,8	3,0	2,7	2,6	3,1	2,6	2,6	2,5
KET 2 Nanotechnology	1,4	1,5	1,5	1,6	1,8	1,8	2,2	1,9	2,1	2,3	2,1	2,2	2,2	2,4	2,6	2,7	3,0	2,7	2,7	2,8
KET 3 Micro Nanotechnology	682	689	732	744	821	1.058	992	1.011	1.136	1.306	845	864	969	999	1.160	1.592	1.438	1.509	1.563	1.702
KET 4 Photonics	88	106	125	108	105	68	59	49	50	46	101	143	187	174	166	108	92	79	74	63
KET 5 Advanced Materials	1,4	1,5	1,6	1,8	2,0	2,1	2,4	2,0	2,4	2,9	2,1	2,2	2,4	2,7	2,9	3,0	3,4	2,7	3,1	3,6
KET 6 AMT	12,5	13,4	14,5	12,3	13,2	15,7	19,1	18,2	22,4	23,5	14,3	14,9	16,1	14,6	17,0	19,2	22,5	22,7	24,3	24,1

Source: COMTRADE Database, OECD Main Science and Technology Indicators. NIW calculations.

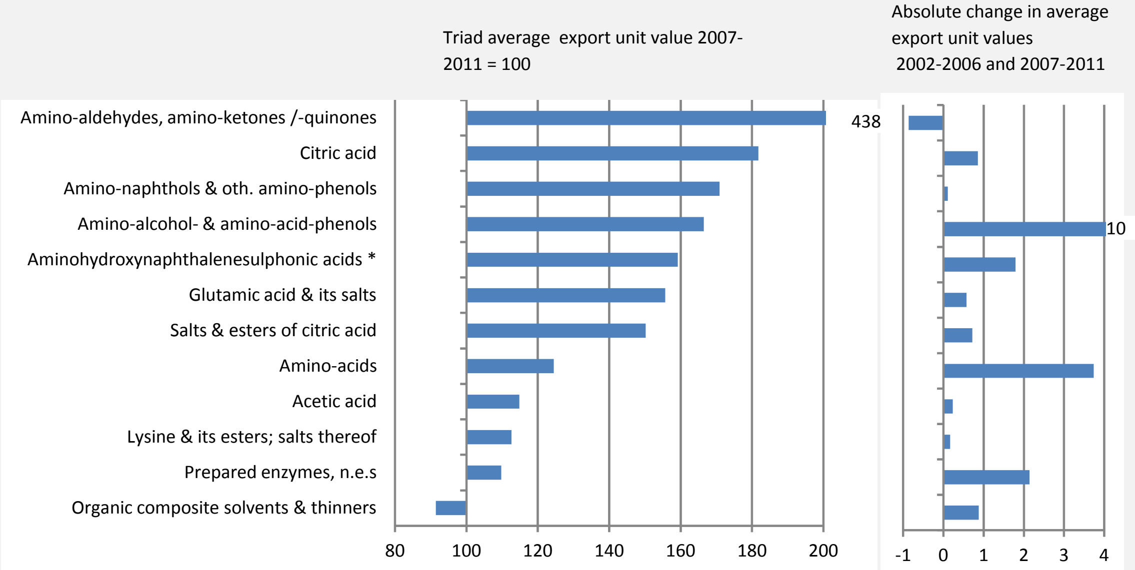
Table 8.4 –Import unit values in nominal US-$ and in PPP US-$ by KET and triadic region 2002 to 2011

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
EU-28	**Import Unit Value in US $**										**Import Unit Value in PPP US $**									
KET 1 Industrial Biotechnology	1,7	2,3	2,6	2,8	2,5	3,4	3,5	3,3	3,1	3,6	1,9	2,2	2,3	2,6	2,3	3,0	2,9	2,9	2,9	3,2
KET 2 Nanotechnology	1,1	1,2	1,3	1,4	1,5	1,8	2,0	2,0	1,9	2,1	1,2	1,2	1,2	1,3	1,5	1,6	1,7	1,7	1,7	1,9
KET 3 Micro Nanotechnology	448	273	329	399	389	247	198	230	288	248	503	263	295	371	369	217	166	203	268	222
KET 4 Photonics	82	88	77	63	62	64	49	36	28	14	92	85	69	59	59	56	41	31	27	12
KET 5 Advanced Materials	1,2	1,4	1,7	1,8	1,9	2,1	2,4	2,0	2,0	2,4	1,3	1,3	1,5	1,7	1,8	1,9	2,0	1,8	1,9	2,1
KET 6 AMT	13,2	14,8	16,4	16,6	13,0	18,1	19,3	20,0	19,4	9,7	14,8	14,2	14,7	15,4	12,3	15,9	16,2	17,6	18,0	8,7
North America	**Import Unit Value in US $**										**Import Unit Value in PPP US $**									
KET 1 Industrial Biotechnology	3,9	3,6	3,9	3,6	4,0	4,4	6,1	6,7	5,9	6,7	4,1	3,7	3,9	3,6	3,9	4,3	6,0	6,7	5,7	6,5
KET 2 Nanotechnology	1,1	1,2	1,4	1,5	1,8	1,7	2,2	2,2	2,2	2,4	1,2	1,3	1,4	1,5	1,7	1,6	2,1	2,1	2,1	2,2
KET 3 Micro Nanotechnology	429	522	579	560	579	702	656	580	742	894	441	529	583	560	574	693	645	577	733	878
KET 4 Photonics	117	129	131	73	127	122	127	128	133	139	122	131	132	73	126	120	125	127	130	135
KET 5 Advanced Materials	1,6	1,6	1,8	2,0	2,1	2,4	2,6	2,4	2,5	2,6	1,7	1,7	1,8	2,0	2,1	2,3	2,5	2,3	2,4	2,5
KET 6 AMT	16,9	19,1	19,9	14,6	20,2	24,5	28,0	29,4	31,6	30,4	17,9	19,7	20,2	14,6	19,9	23,7	27,1	29,2	30,6	28,9
East Asia	**Import Unit Value in US $**										**Import Unit Value in PPP US $**									
KET 1 Industrial Biotechnology	1,2	1,2	1,3	1,4	1,3	1,5	1,9	1,9	2,6	2,9	2,1	2,1	2,2	2,3	2,1	2,4	2,6	2,6	3,2	3,3
KET 2 Nanotechnology	1,3	1,5	1,6	1,7	1,9	2,0	2,4	2,4	2,7	2,8	2,4	2,5	2,5	2,7	2,9	3,0	3,1	3,4	3,5	3,3
KET 3 Micro Nanotechnology	548	573	618	607	657	1.813	1.557	1.506	2.071	2.391	989	1.064	1.178	1.185	1.277	3.519	2.682	2.639	3.383	3.595
KET 4 Photonics	123	143	153	153	154	138	144	149	152	151	247	311	333	329	318	270	248	260	249	225
KET 5 Advanced Materials	1,5	1,6	1,7	2,0	2,3	2,5	3,1	2,4	2,8	3,3	2,8	3,0	3,1	3,5	3,9	4,2	4,6	3,7	4,1	4,4
KET 6 AMT	14,6	15,4	18,0	18,6	18,2	25,3	32,6	24,5	35,6	45,2	30,6	32,0	36,8	36,1	34,2	38,1	51,6	39,9	54,8	65,3

Source: COMTRADE Database, OECD Main Science and Technology Indicators. NIW calculations.

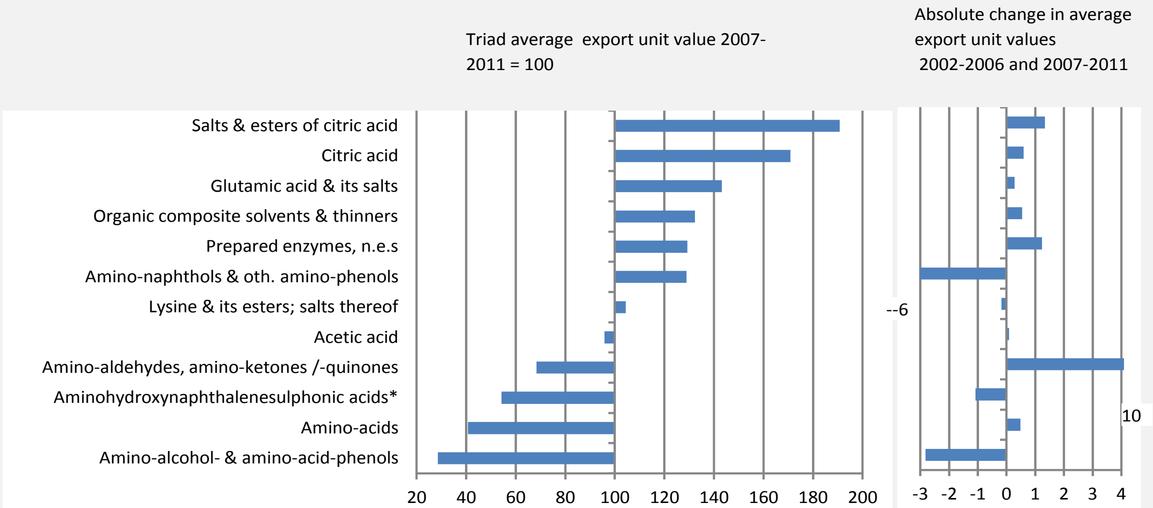
8.3. TECHNOLOGY CONTENT OF EXPORTS BY INDIVIDUAL KET-RELATED PRODUCTS

Figure 8.1: EU-28's performance and dynamics of export unit values in industrial biotechnology, product level



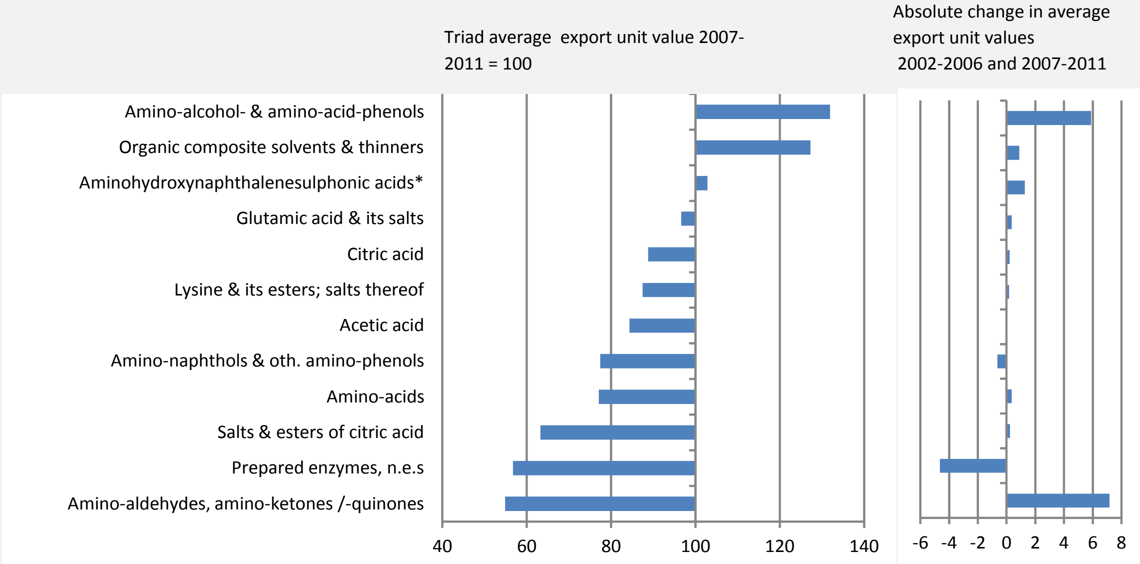
Note: * and their salts.
Source: COMTRADE Database. NIW calculations.

Figure 8.2 - North America's performance and dynamics of export unit values in industrial biotechnology, product level



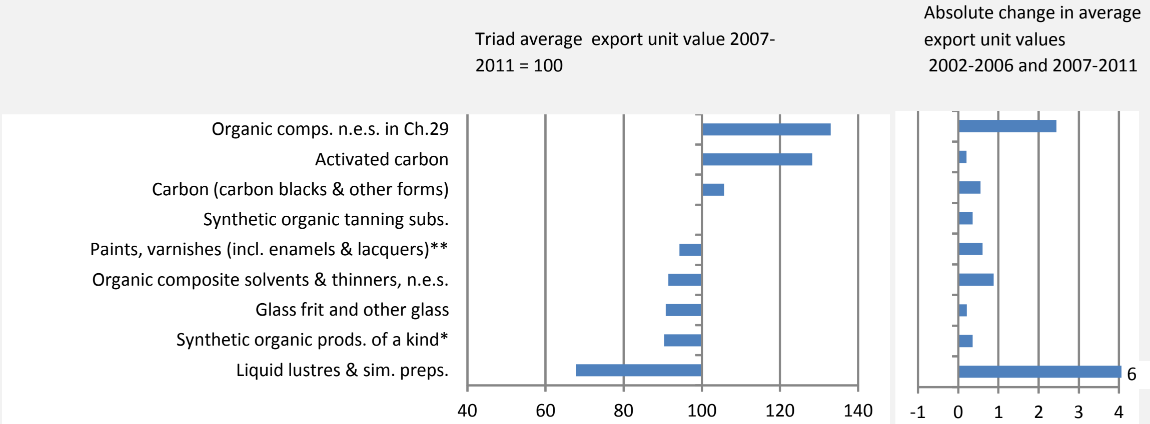
Note: * and their salts.
Source: COMTRADE Database. NIW calculations.

Figure 8.3: East Asia's performance and dynamics of export unit values in industrial biotechnology, product level



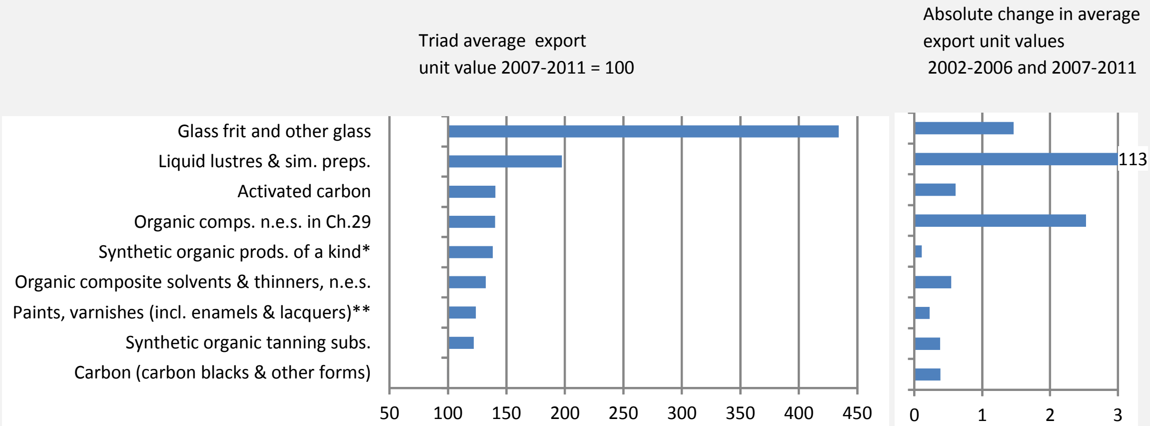
Note: * and their salts.
Source: COMTRADE database. NIW calculations.

Figure 8.4: EU-28's performance and dynamics of export unit values in nanotechnology, product level



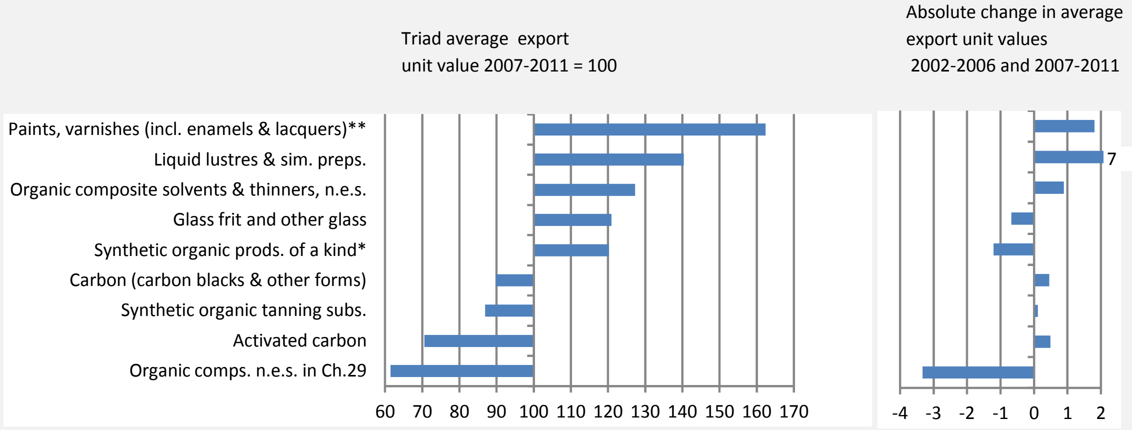
Note: * used as fluorescent brightening agents. ** based on acrylic/vinyl polymer.
Source: COMTRADE Database. NIW calculations.

Figure 8.5: North America's performance and dynamics of export unit values in nanotechnology, product level



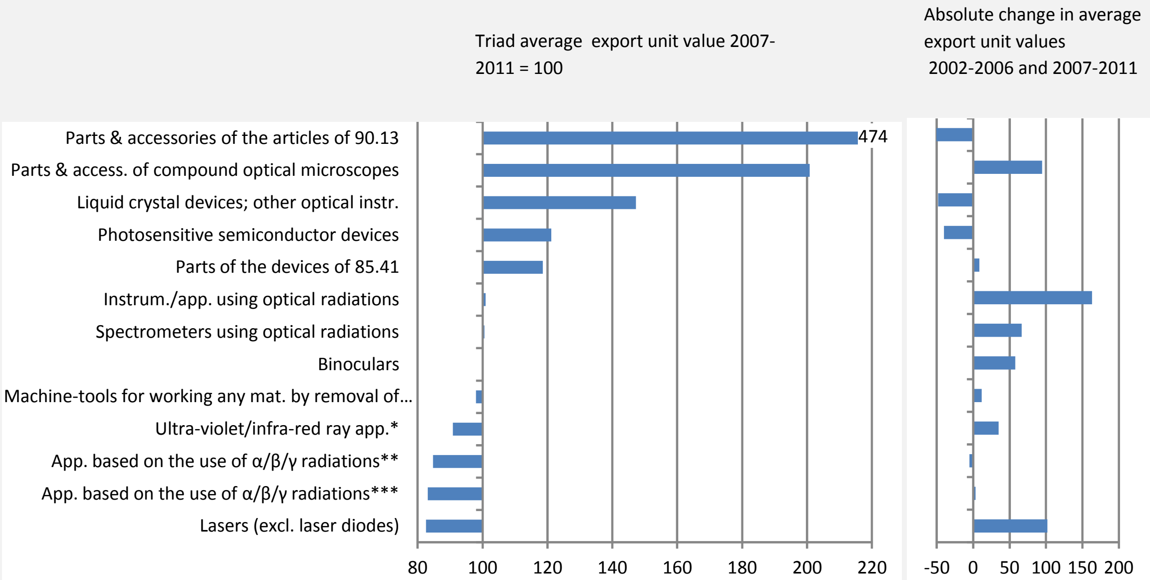
Note: * used as fluorescent brightening agents. ** based on acrylic/vinyl polymer.
Source: COMTRADE Database. NIW calculations.

Figure 8.6: East Asia's performance and dynamics of export unit values in nanotechnology, product level



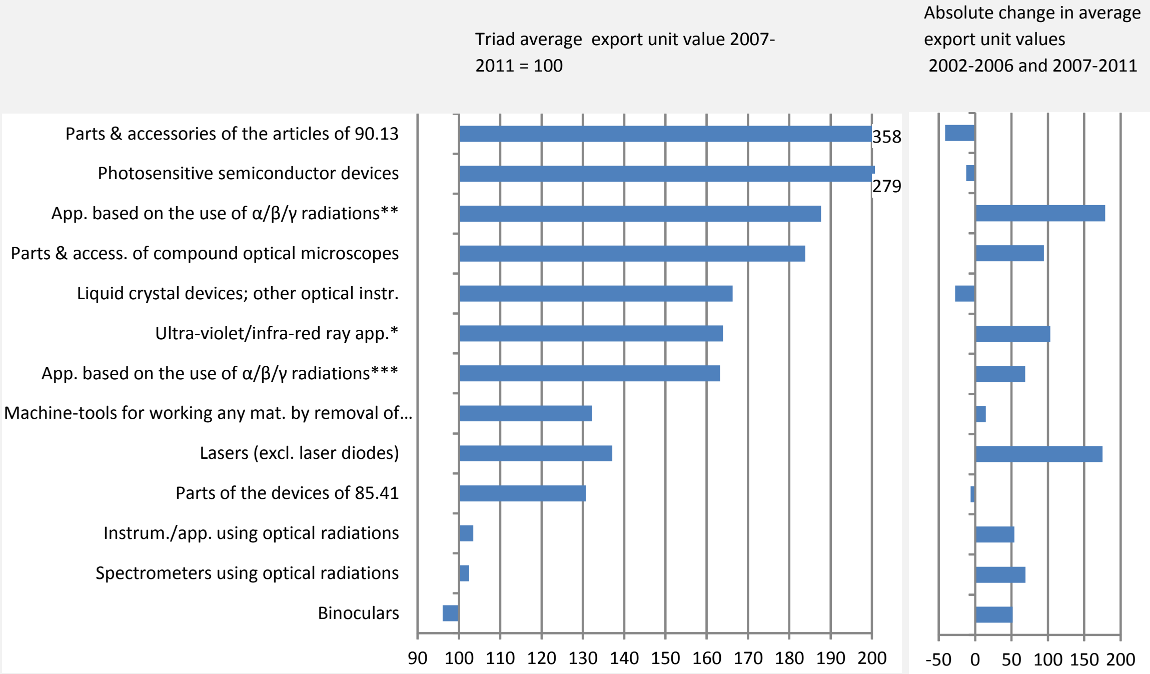
Note: * used as fluorescent brightening agents. ** based on acrylic/vinyl polymer.
Source: COMTRADE Database. NIW calculations.

Figure 8.7: EU-28's performance and dynamics of export unit values in photonics, product level



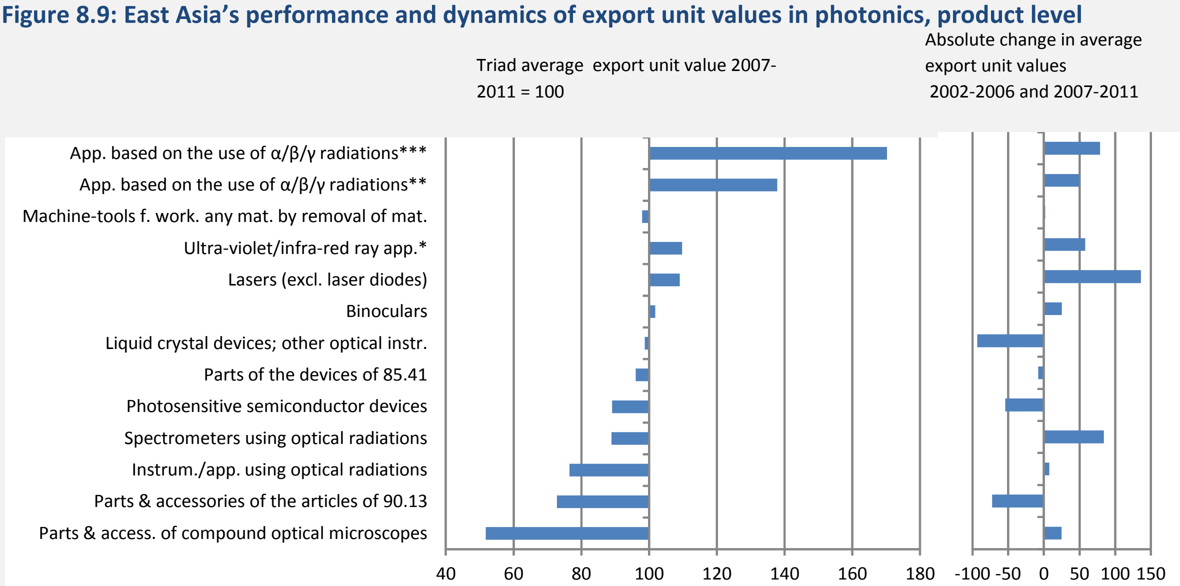
Note: * used in medical/surgical/dental/veterinary. ** for medical use. *** for uses other than medical.
Source: COMTRADE Database. NIW calculations.

Figure 8.8: North America's performance and dynamics of export unit values in photonics, product level



Note: * used in medical/surgical/dental/veterinary. ** for medical use. *** for uses other than medical.
Source: COMTRADE Database. NIW calculations.

Figure 8.9: East Asia's performance and dynamics of export unit values in photonics, product level

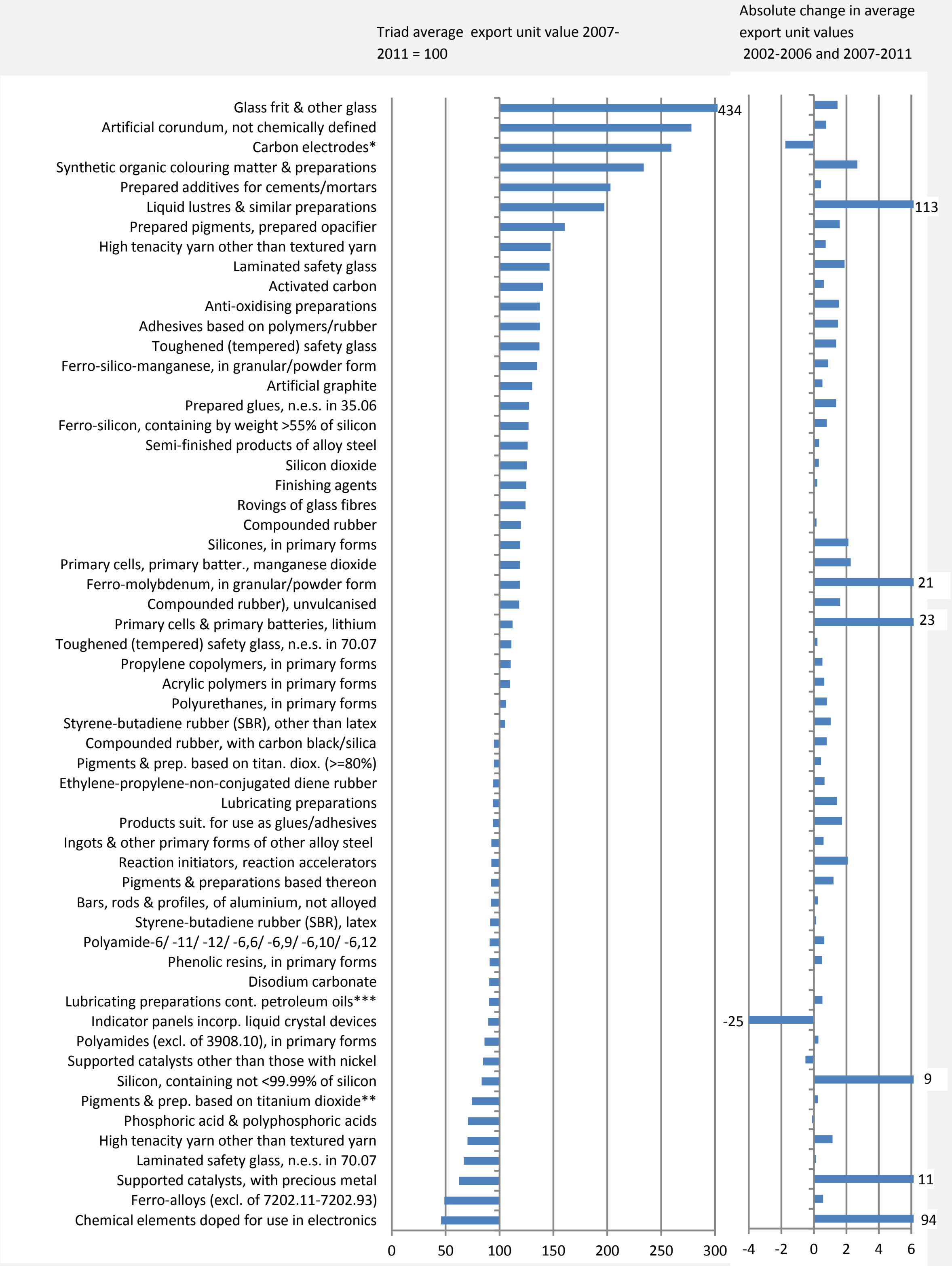


Note: * used in medical/surgical/dental/veterinary.- ** for medical use. *** for uses other than medical.
Source: COMTRADE Database. NIW calculations.

Figure 8.10: EU-28's performance and dynamics of export unit values in advanced materials, product level

Note: * other than of a kind used for furnaces. ** other than those containing 80%/more by weight of titanium dioxide calc. on the dry matter. *** other than for treatment of textile materials/leather/furskins/other materials.
Source: COMTRADE Database. NIW calculations.

Figure 8.11: North America's performance and dynamics of export unit values in advanced materials, product level

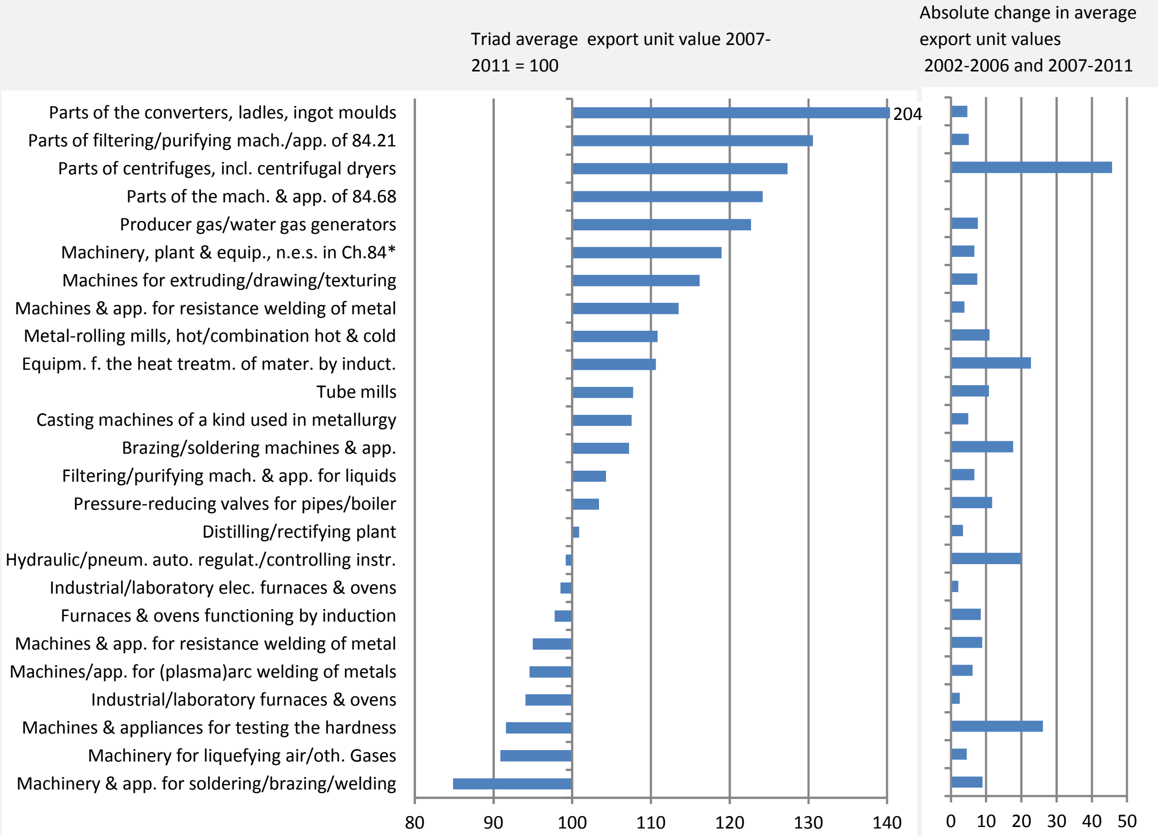


Note: * other than of a kind used for furnaces. ** other than those containing 80%/more by weight of titanium dioxide calc. on the dry matter. *** other than for treatment of textile materials/leather/furskins/other materials.
Source: COMTRADE Database. NIW calculations.

Figure 8.12: East Asia's performance and dynamics of export unit values in advanced materials, product level

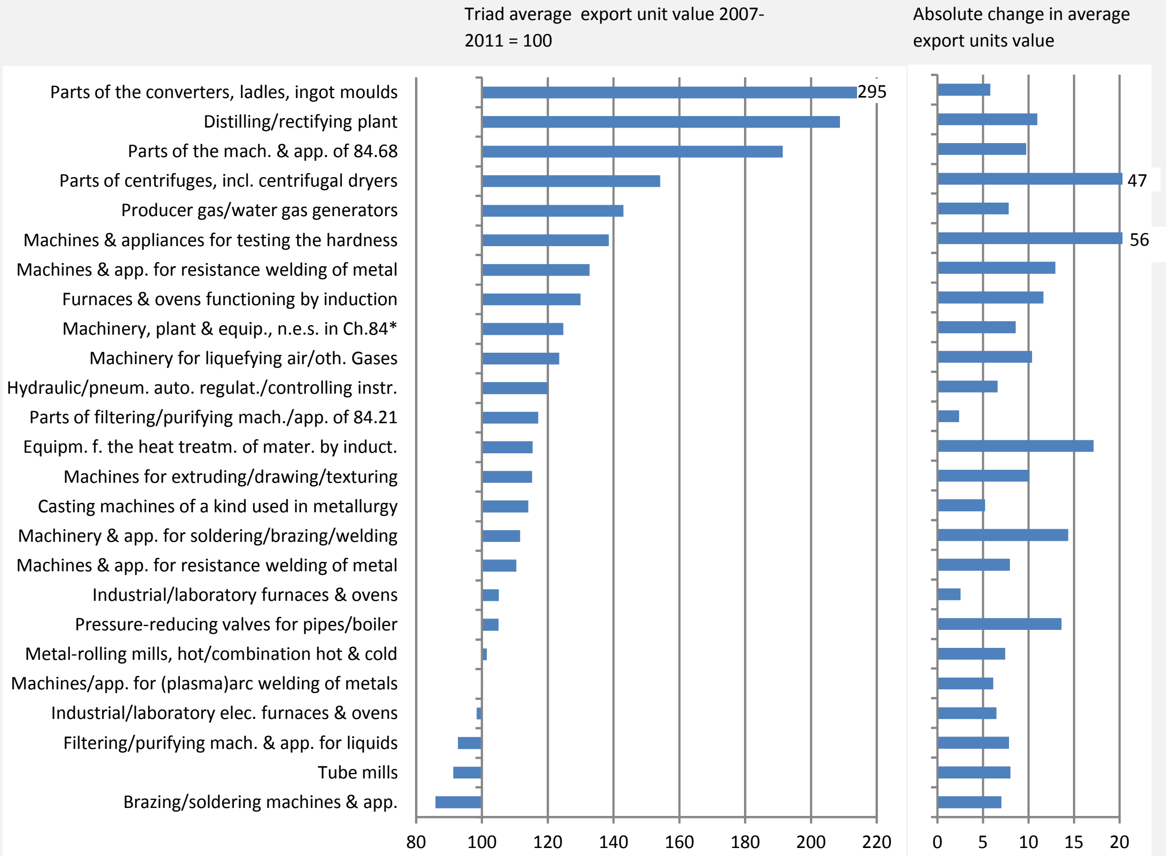
Note: * other than of a kind used for furnaces. ** other than those containing 80%/more by weight of titanium dioxide calc. on the dry matter. *** other than for treatment of textile materials/leather/furskins/other materials.
Source: COMTRADE Database. NIW calculations.

Figure 8.13: EU-28's performance and dynamics of export unit values in AMT for other KETs, product level



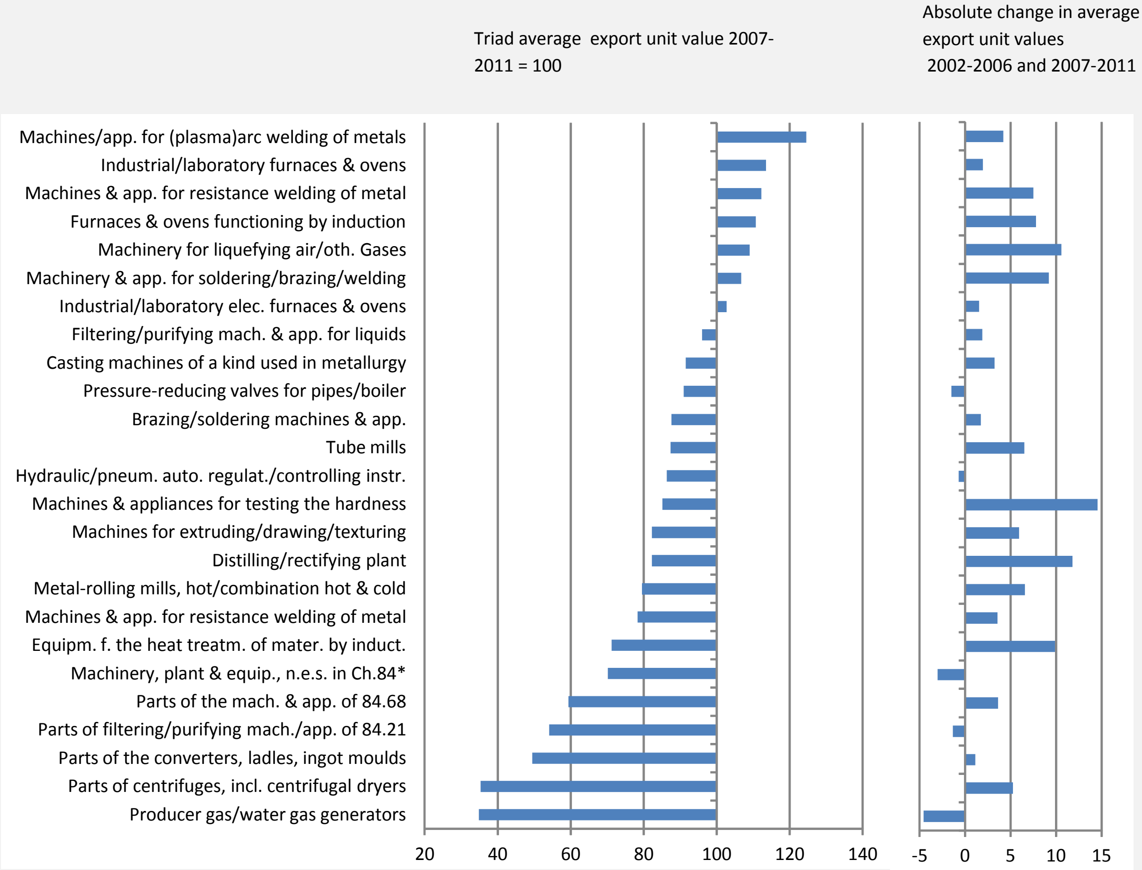
Note: * other than for making hot drinks/for cooking/heating food, whether/not electrically heated.
Source: COMTRADE Database. NIW calculations.

Figure 8.14: North America's performance and dynamics of export unit values in AMT for other KETs, product level



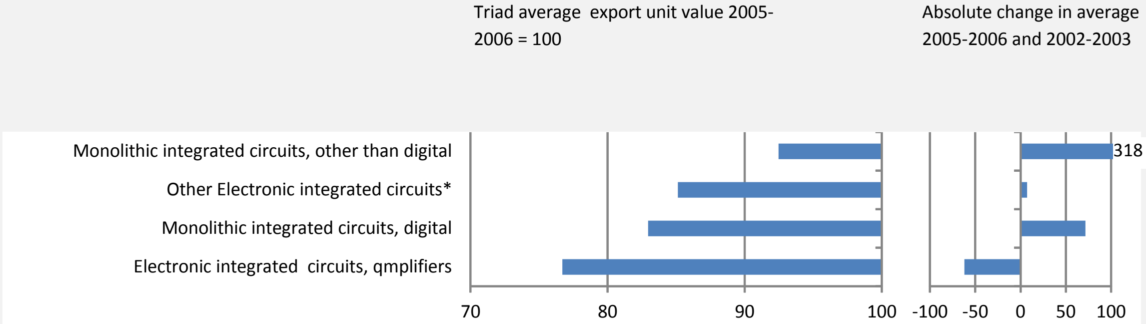
Note: * other than for making hot drinks/for cooking/heating food, whether/not electrically heated.
Source: COMTRADE Database. NIW calculations.

Figure 8.15: East Asia's performance and dynamics of export unit values in AMT for other KETs, product level



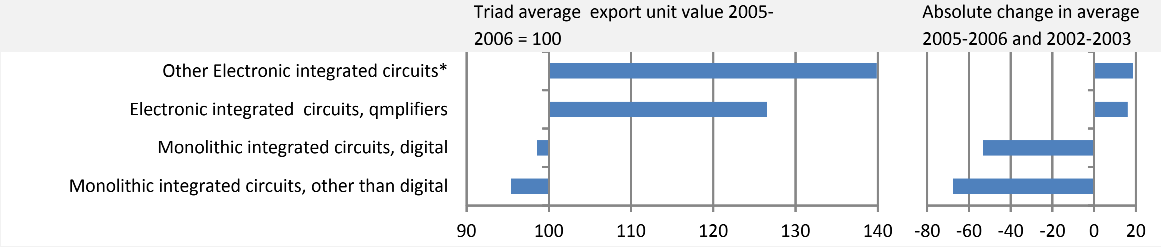
Note: * other than for making hot drinks/for cooking/heating food, whether/not electrically heated.
Source: COMTRADE Database. NIW calculations.

Figure 8.16: EU-28's performance of export unit values in micro- and nanoelectronics, product level (HS 2002)



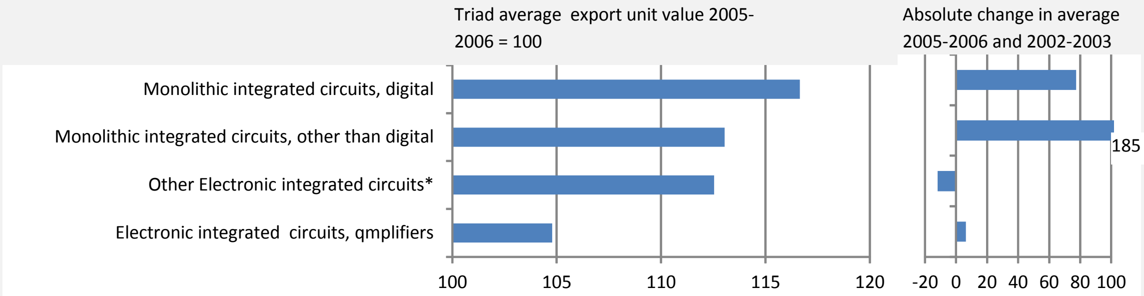
Note: * other than amplifiers/memories/processors & controllers.
Source: COMTRADE Database. NIW calculations.

Figure 8.17: North America's performance of export unit values in micro- and nanoelectronics, product level (HS 2002)



Note: * other than amplifiers/memories/processors & controllers.
Source: COMTRADE Database. NIW calculations.

Figure 8.18: East Asia's performance of export unit values in micro- and nanoelectronics, product level (HS 2002)



Note: * other than amplifiers/memories/processors & controllers.
Source: COMTRADE Database. NIW calculations.