Zentrum für Europäische Wirtschaftsforschung GmbH
Centre for European Economic Research

# European Competitiveness in Key Enabling Technologies

FINAL REPORT

Authors: Birgit Aschhoff, Dirk Crass, Katrin Cremers, Christoph Grimpe, Christian Rammer
***Centre for European Economic Research (ZEW)****, Mannheim, Germany*

Felix Brandes, Fernando Diaz-Lopez, Rosalinde Klein Woolthuis, Michael Mayer, Carlos Montalvo
***TNO****, Delft, the Netherlands*

Date: May 28th, 2010

This report is a background study to the European Competitiveness Report 2010. The study was commissioned by the European Commission, DG Enterprise within a Framework Contract co-ordinated by the Austrian Institute for Economic Research (Wifo) (co-ordinator: Michael Peneder).

**Contact**

Dr Christian Rammer
Department of Industrial Economics and International Management
Centre for European Economic Research (ZEW)
L 7, 1
D-68161 Mannheim
Germany
Phone: +49 621 1235 184
Fax: +49 621 1235 170
E-Mail: rammer@zew.de

## List of Figures



# Content

## List of Figures

## List of Figures



## List of Figures

## List of Figures

## List of Figures

## List of Figures

## List of Figures



## List of Tables

## List of Figures

## List of Figures



# 1 INTRODUCTION

## 1.1 Background

Strengthening the innovative performance of the EU economy is a main goal of both the European Commission and the governments of EU member states. Fostering innovation demands a multi-dimensional approach that takes into account both the incentives for firms to innovate, the internal and external drivers and barriers for innovation, and the framework conditions conducive to innovation, including financing, skills, competition, regulation and public funding.

Among the many factors that drive innovation, emerging new technologies have always played a key role in the history of innovation. New technological developments open up new paths for inventing new products and processes and advancing current technology. Particularly important in this respect are those technologies that have a great potential to affect innovation in many different industries and fields of application. These so-called "key enabling technologies" (KETs) have spurred invention and technical progress in the past tremendously, including technologies such as the steam engine, electricity, synthetic materials or computing, and will most likely do so in the future.

Common characteristics of KETs include a high demand for R&D, skills and capital expenditure, a multidisciplinary approach cutting across many technology areas, long time horizons between basic research results and implementable innovations, high multiplier effects and high spillovers to other emerging technologies, and a great potential for enabling product and process innovation (EC, 2009a,b). KETs are closely linked to the concept of general purpose technologies (see Lipsey et al., 2005). They are expected to provide significant improvements in economic terms, offer a widening variety of uses in an increasing number of application areas and industries. Most often, the scope of their impacts depend on the development of other complementary technologies and innovations.

This report deliberately focuses on KETs that are likely to drive innovation in *manufacturing* while discounting those KETs that primarily affect innovation in services. In addition, KETs are confined to fields of science and technology that provide new technological principles on which more complex product and process innovation can rest upon and that prepare the ground for further technological developments in individual industries. Finally, KETs are supposed to offering both significant economic potentials in terms of opening up new markets and contributing to the main societal challenges of our today's world.

Based on this reasoning, the European Commission came up with a list of five KETs (see EC, 2009a,b):

**Nanotechnology**

**Industrial biotechnology**

**Advanced materials**

**Micro- and nanoelectronics** (including semiconductors)

**Photonics**

All five KETs have in common that they are important enabler for new products as they offer new approaches to design and process materials and alter their functionality. With regard to process innovation, a highly important enabler is **advanced manufacturing technologies**, e.g. robotics, automation and process control technology. Since process innovation is an important dimension of industrial competitiveness, advanced manufacturing technologies are regarded as another KET in this report.

Provided that these technologies will effectively exert a major impact on industrial innovation on a global level, it is critical for the EU economy to keep pace with the technological

## List of Figures



development in these KETs in order to benefit from their innovative potentials and spillovers to other sectors of the economy. Although new knowledge emerging in these technology areas may be acquired from sources outside the EU, either by co-operation with external partners or through technology acquisition, there are many arguments why a strong position in *generating* new technologies is important for leveraging the economic benefits of these technologies. On the one hand, developing commercial applications based on KETs often requires a close interaction between fundamental research and industrial innovation as well as a certain degree of technological competence in order to absorb and apply new knowledge. On the other hand, first mover advantages do play a major role, particularly when it comes to path-breaking technologies. These advantages include learning and reputation effects as well as standard settings and developing innovation-friendly regulation.

It is both these close links between R&D and commercial use and the expected high impacts of KETs on productivity and competitiveness that motivate governments across all highly developed countries to provide a fruitful ground for both developing and using KETs within their territory. Most EU Member States as well as the European Commission have implemented policy approaches in favour of KETs, combining a variety of instruments from different policy areas. Analyses of the current state of technology in Europe, the technological performance vis-à-vis the main competitors in North America and East Asia, and the obstacles in terms of market and system failures that hinder the advance of KETs can help to further develop these policy approaches and to increase the coherence of policies at regional, national and EU levels. This study aims to deliver some of these analyses.

## 1.2 Objective

The purpose of this study is to analyse the technological competitiveness of Europe in six KETs: nanotechnology, industrial biotechnology, advanced materials, micro- and nanoelectronics, photonics, and advanced manufacturing technologies. While there are many studies on technological performance and dynamics for each of these technologies and their subfields, a comparative study that evaluates the situation in each KET based on a common methodology and metrics is still lacking: This report attempts to close this gap to some extent.

In addition to analysing the state of technological competitiveness, we explore the challenges and weaknesses that may affect future prospects of these KETs in Europe and discuss the policy actions that may be needed to strengthen technology performance and advance commercial applications. In particular, the study investigates, for each KET,

the performance of actors from Europe (both enterprises and public institutions) in producing new technology compared to the main competing regions (North America, East Asia);

the industrial sectors and fields of applications that are most affected by a certain KET;

the likely medium-term market potentials and application prospects;

the factors that are likely to drive technological and commercial success;

the market and system failures and other barriers that may impede technological progress, and how these failures are tackled by policy activities;

the role of governments for the development of each KET, focussing on public funding of R&D, fiscal incentives, public procurement and lead markets;

Based on these findings we derive policy conclusions on how to strengthen the EU's technological competitiveness in these KETs.

## 1.3 Empirical Approach

A major challenge of this study is related to the fact that most of the KETs considered are in a premature state of commercialisation. Only few commercial applications have been developed so far, and many product markets are still to emerge. In addition, KETs are difficult to assign to individual sectors owing to their general purpose character. As a consequence, analysing

## List of Figures



strengths and weaknesses of KETs in Europe cannot rest on traditional competitiveness analyses based on industry statistics.

We attempt to respond to these challenges by combining quantitative and qualitative analyses. Technological competitiveness and the links between KETs and industrial sectors are explored through patent data. The rationale for this choice is given below and explored in more detail in section 2.2. Market potentials and application prospects are summarised based on existing reports and studies. Barriers and challenges as well as the role of governments are explored through case studies of successful clusters

Analysing competitiveness of emerging technologies is anything but straightforward. While the concept of competitiveness is related to markets, upcoming technologies are typically at a pre-competitive stage with no or only a very few applications yet on the market, and only a few firms competing in markets with products or technologies clearly based on one of the KETs. Consequently, traditional concepts of analysing competitiveness such as market shares, trade performance, productivity and growth in value added cannot be applied to analyse competitiveness in emerging KETs. In order to provide an empirical assessment of the current situation of international competitiveness in each KET, patent data seem to be the most relevant source. Patent applications refer to technical inventions that have reached a certain state of feasibility and thus represent the successful completion of some stage of R&D efforts. Most patents are applied by firms and are linked to their competitive strategies. Although comparability of patent data is limited due to different economic values a patent may represent, different degrees of technological novelty and different degrees of actual applicability, patent data are nevertheless a widely used source to analyse dynamics in certain fields of technology and identify the regional distribution of new knowledge generation, including specialisation of countries on certain fields of technology (see Moed et al., 2004).

Exploring barriers, challenges and the role of government for each KET is another demanding task. Given the short time frame of just nine weeks to produce this report, case study approach has been chosen. Case studies focus on regional clusters that have proved to be successful in generating innovations in the respective KET. When looking at successful clusters we expect to learn on how barriers (i.e. market and system failures that may hinder technological development and the application of new technologies) can be overcome through private and public actions, including policy activities. The types of market and system failures and how these could be identified is explored in section 2.3 in more detail.

For each KET, a cluster from Europe and one from outside Europe (North America, East Asia) was selected and studied in detail based on studies, reports, presentations and other documents. Cluster here denotes a group of actors within a certain region which interact in developing and applying new technologies. Actors typically include manufacturing companies, research institutions, private and public users of technologies, intermediaries (e.g. technology centres, financing institutions) and other stakeholders (e.g. from education, the broader public).

The report is organised along KETs. For each of the five KETs mentioned in the EU communication, we present a standard set of analyses in a separate chapter:

definition and state of technology;

technological competitiveness of Europe and EU member states vis-à-vis the main competitors (North America, East Asia);

links to sectors and other fields of technology;

market potentials and application prospects (as given in the literature);

success factors, barriers and challenges;

policy conclusions.

Advanced manufacturing technologies are captured in a less comprehensive way, focussing on technological competitiveness and links to industrial sectors.

## List of Figures



The final chapter summarises generic findings from each KET study and derives policy conclusions on how Europe could improve its competitiveness in the area of KETs.

The following chapter 2 discusses some generic issues on the link between KETs and competitiveness.

# 2 METHODOLOGICAL ISSUES

## 2.1 KETs, Innovation and Competitiveness

There is no doubt that technical progress is the singly most important source for increasing productivity and wealth (Romer, 1986; Lucas, 1988; Färe et al., 1994; Fagerberg, 2000). Technical progress can take a variety of forms, ranging from developing and applying fundamentally new technologies to adopting organisational concepts through learning and copying. History has shown that the emergence of certain new technologies has spurred innovation and technical progress tremendously, leading to significantly higher levels of productivity and enabling radically new types of products and services. Such path-breaking technologies may be termed "key enabling technologies" (KETs). The most prominent historical examples include technologies such as the steam engine, electricity, synthetics, semiconductors, computing and the Internet. These technologies did not only drive industrial innovation, they also offered more effective responses to societal challenges, e.g. in health, communication or the environment, though new technologies often were also raising new concerns on their potentially negative implications on safety, health and the environment as well as on ethical, legal and social issues.

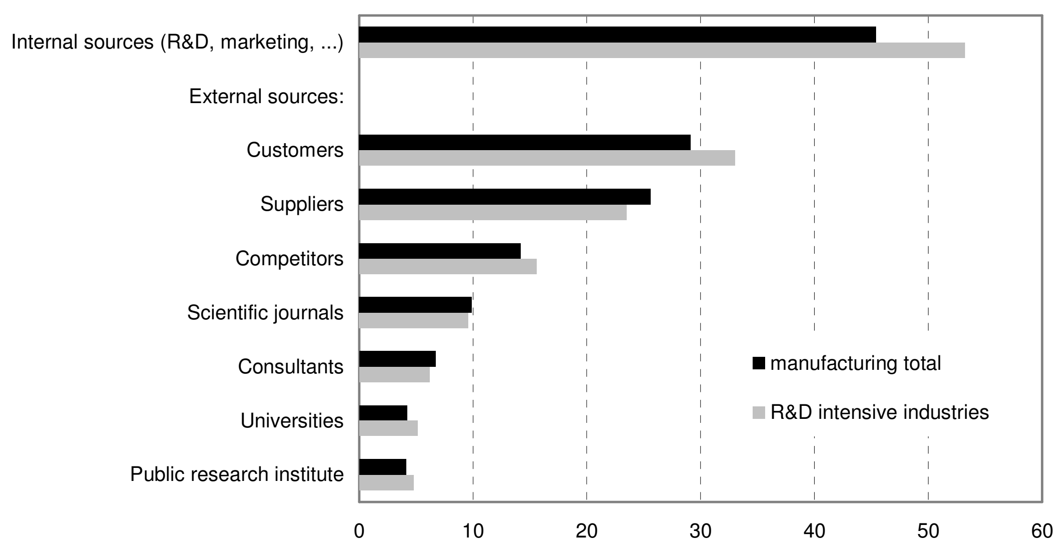
This report focuses on new technologies that are likely to serve as KETs today and in the years coming, and how their contribution to Europe's competitiveness can be fully exploited. The role of KETs for competitiveness can be analysed from a firm and a macroeconomic perspective. From a firm perspective, the main impact of KETs is to drive innovation, enabling firms to introduce new products and new processes. From a macroeconomic perspective, KETs can raise an economy’s level of productivity, allowing for higher per-capita income and increase in wealth. Both dimensions are discusses below.

***KETs and Innovation in Firms***

The link between KETs and firm competitiveness basically rests on the role of KETs as a driver for innovation. First, KETs offer opportunities for product and process innovation to many firms, particularly in manufacturing. The emergence of KETs can be viewed as a technology-push to innovation efforts of firms and raise the overall level of innovation activities in an economy (see Helpman, 1998; see also van Ark and Piatkowski, 2004, on the role of ICT, and Baptista, 1999, on the role of new process technology as drivers for innovation). Secondly, innovation research has shown that innovative firms are often more productive and grow faster than non-innovative firms, indicating a higher level of firm competitiveness (see Crépon et al., 1998; Griffith et al., 2006; Harrison et al., 2008; Janz et al., 2004). A higher level of innovativeness in terms of the degree of novelty and the amount of R&D effort tends to be associated with higher economic performance in terms of productivity and growth (Peters, 2008; Hall and Mairesse, 2004) which underpins the special role of developing and applying new technologies for raising competitiveness. Thirdly, applying new technologies early and broadly often requires a close interaction between the producers and users of new technologies (see Fagerberg, 1995; Porter, 1990). Competitiveness effects of new technologies strongly depend on the speed of their diffusion and on the rate at which innovative opportunities of these technologies are explored and implemented. Being first in generating new scientific findings is no sufficient condition for generating economic returns from new technologies. The main challenge for any innovation project, including innovations based on KETs, is to balance technological opportunities originating from research with the user needs, a cost-efficient production and the capabilities of business partners (suppliers, distributors, users), having in view the innovative strategies of competitors.

This complex system of interlinked sources of innovation is revealed by the information sources firms typically use for their innovation activities (see Figure 2-1). Sources that are more closely linked to technology pushes from KETs -scientific journals, universities and public research institutes- are less often assessed as highly important while competitors, suppliers and customers are clearly more important, as are internal sources.

**Figure 2-1: Information sources for innovation (per cent of innovative enterprises citing the respective source as highly important), 2004-2006**




*Note: Multiple sources per enterprise allowed. R&D intensive industries: NACE (rev. 1.2) divisions 23-24, 29-35. Figures based on data from AT, BE, CY, CZ, EE, ES, FR, GR, HR, HU, LT, LU, NL, PL, PT, RO, SK, TR.*

*Source: Community Innovation Survey 2006, weighted figures.*

This result is not surprising as it reflects two important aspects of the role of KETs for innovation. First, new technologies in their early stage are developed and transferred into commercial innovations only by a few firms ("technology leaders"). These firms need to combine a high level of technology competence with the ability to accept a high financial risk since new, radical technological developments take long time, afford high investment and are likely to fail. Only large firms with high R&D budgets and laboratories or small, specialised and venture capital backed firms will be able to go this way. Consequently, direct economic impacts of KETs in their early stages tend to be low. High macroeconomic effects of KETs result from their spread through the economy which can take considerable time. A high rate of diffusion requires a low level of technological uncertainty and a low price. Technological uncertainty is typically reduced through learning, standardisation and the experiences made in applying a new technology to various fields of applications. Lowering prices for new technologies depend on the degree of competition and the ability to utilise economies of scale at various stages of production. In addition, a broad adoption of new technologies is supported by many incremental innovations that transfer advantages of a certain technology into user-specific designs of new products and processes. The number of innovating firms is much higher in this diffusion stage of a new technology than in its introduction stage, and the impulses from suppliers, competitors and customers are much more important than pure technology impulses.

***KETs and Productivity***

From a macroeconomic point of view, KETs can help to increase productivity, and thus wealth, through enabling a more efficient use of production factors and through structural change. Within a production function environment, positive productivity effects of KETs may be reflected by a higher rate of technical progress. Alternatively, one may model KET effects as a separate input factor, e.g. as a stock of new knowledge that resulted from R&D on KETs. Higher efforts to develop KETs result in larger knowledge stocks and likewise higher output levels. Within a sector-specific production function environment, KETs will most likely shift sector shares since output of sectors that produce KETs and that can obtain productivity advantages from KETs are likely to grow faster. Whether this structural change transfers into higher productivity will depend on productivity levels compared to traditional sectors that are little affected by KETs. In a dynamic perspective, positive productivity effects from a KET-driven structural change is most likely since technology sectors will experience above-average productivity growth.

A main impact of KETs is to accelerate technical progress. KETs as defined in this report are new technologies that enable product and process innovation in manufacturing. In general, applying KETs will enable producers to using labour, capital, energy and other inputs more efficiently. It is important to stress that in contrast to other sources for technical progress diffusion of existing technologies, improving skills through education and training, learning from good practice- KETs are more likely to result in a leap upwards in efficiency levels, particularly when the use of KETs affect many sections of the economy simultaneously. A prominent example of an escalating technical progress in the recent past was information and communication technologies (ICTs). ICTs have accelerated productivity growth in the 1990s considerably and widely. They account for almost 70 percent of total factor productivity growth in 1995-2001 (see Timmer and van Ark, 2005). The main momentum for the contribution of ICTs to productivity growth were its wide diffusion across many different industries, including sectors with traditionally low technology intensities (in terms of the amount of new technology used in production) such as retail or transportation.

In addition, the particularly strong productivity impacts of ICTs resulted from the network characteristics of this technology. Productivity effects in one firm did not only originate from the use of ICT within this firm, but also from ICT use by business partners (suppliers and customers) since ICTs have allowed to design external business processes more efficiently. KETs that exert less significant network effects are likely to result in lower economy-wide productivity gains.

ICTs also have shown, however, that there may be substantial time lags between the invention and first application of a new KET, and its economic impacts. The basic inventions for state-of-the-art ICTs today have been made decades ago, such as digital data processing (the first computer was invented in the 1940s) or cellular telephone communication (the technological principles have been discovered in the 1920s). For many new technologies, the most important applications are often out of sight in early stages of technology development. Application potentials typically emerge from the interaction of suppliers, producers and users of a new technology, through learning from using (Rosenberg, 1982) and from a fierce competition among technology producers who are seeking competitive advantages by customising new technologies to the needs of users. More complex technologies in particular tend to generate increasing returns to adoption (Arthur, 1989).

One may thus conclude that magnitude of macroeconomic productivity effects from KETs will depend on

the **speed of diffusion** of KETs;

the **breadth of diffusion** across many sectors and user groups;

the occurrence of **network effects** when using a certain KET;

the **maturation** of a KET in terms of the variety of technological applications and innovative solutions that have been developed over time.

A second important dimension of KETs' macroeconomic contribution is to open up entirely new markets, or at least to shift product quality in existing markets to higher levels. KETs advance industrial change, which is likely to involve higher levels of input-output relations since entirely new products and higher-quality products are likely to obtain higher output prices per unit. Opening-up new markets can also help to unlock additional demand and new resources for production, thus increasing net output.

An important issue in this respect is the timing of the emergence of new markets. Economies that are able to open-up new KET-based markets earlier than others could gain a temporary monopoly which can provide a source for additional income. More importantly, in a dynamic perspective these first mover advantages can translate into positive cumulative effects (see Porter, 1990). Such cumulative effects may result from network effects among producers, suppliers and users who can learn from each other and leverage economies of scale and scope. In addition, first movers may be able to defining global standards, establishing global distribution channels and building up reputation as technology leaders. Another source is follow-up innovations which build upon the accumulated technological knowledge in the respective field of technology. These cumulative effects will also act as entry barriers to other economies and can secure a long term lead in a certain KET.

History provides many examples for such cumulative technological advantages of economies, e.g. the U.S. in aircraft, space and defence technologies, Japan in microelectronic household applications, or Germany in mechanical engineering. Cumulative technological advantages can be reinforced by adaptations of the education, innovation, production and policy system to the specific needs of the leading technology sector. While such adaptations in the behaviour of actors, the working of institutions and the layout of regulations help to further advance these technologies, they may also be a source of lock-in effects and path dependence which can make it more difficult to adjust to new upcoming technologies.

***KETs and Policy***

Provided that economy-wide productivity and wealth effects of KETs primarily depend on the speed and breadth of their diffusion, the issue of technological competitiveness could be linked to the ability of adopting and adapting KETs rather than on generating them. However, both dimensions are closely interlinked. Firms and countries that have been able to develop and adopt KETs early and broadly often have gained long term advantages in terms of competitiveness and income. Although new knowledge emerging in these technology areas may be acquired from external sources and need not be produced by those commercialising this knowledge, there are several barriers to such a pure technology absorption and diffusion approach:

First, the development of commercial applications originating from KETs typically requires a close interaction between fundamental research (often conducted at governmental laboratories or universities) and industrial R&D and innovation. An appropriate framework is needed to exchange knowledge between these two sectors, including incentives for researchers in the public sector to actively engage in technology transfer.

Secondly, in order to fully utilise the innovative potential of KETs, firms need to have a certain (often high) degree of technological competence in order to absorb and effectively apply these technologies. Absorptive capacities include the ability to conduct in-house R&D as well as organisational skills to manage innovation processes and to integrate new technologies into existing business practices. Skills of employees, and the ability to further develop these skills, are often a key resource in this respect.

Thirdly, commercial success of applications based on KETs is often subject to time, and first movers can often gain long term competitive advantages through early learning and reputation building.

Finally, commercialisation calls for an adequate regulatory framework which needs to be developed and adapted parallel to the technological progress achieved in each KET. Interaction between actors who develop new technologies and actors who design the regulatory framework facilitates an innovation oriented regulatory framework. Introducing such a framework early can also generate a competitive advantage if other countries later adopt the regulatory setting.

Given these arguments, it is important for the EU economy to keep pace with the technological development in KETs. Member States as well as the European Commission have recognised the need for active support of KETs. Public support includes a wide variety of policy activities, ranging from funding of academic research and industrial R&D projects to cluster initiatives, public awareness measures, standardisation, promotion of venture capital supply, and education and training activities (see OECD, 2009c). In some KETs, Member States have developed national technology strategies, particularly in nanotechnology and (industrial) biotechnology. Policies of Member States tend to define country-specific technological priorities within each KET and implement different sets of instrument. They also rarely coordinate their activities within a specific field of technology.

While offering policies that fit to the specific strengths and weaknesses of national science and technology systems is certainly a main asset of research and innovation policy in Europe. Nevertheless, advancing KETs may require joint efforts of European economies, particularly in the areas of regulation and standardisation. International coordination and cooperation in KET-related policies could also help to better utilise synergies and economies of scale in developing and applying KETs.

## 2.2 Measuring Technological Competitiveness

The concept of technological competitiveness used in this report refers to the ability of knowledge producing actors (in a certain region or sector) to produce economically relevant new technological knowledge. This view of competitiveness is related to technology markets. It attempts to measure the ability of actors to add new, commercially relevant knowledge to these markets, i.e. to be faster than others in developing a certain new technology, or to identify a way of technological advance not followed by anyone else. This understanding of competitiveness is different from competitiveness in the market, which refers to the ability to sell goods under a competitive environment, i.e. to prevail over competitors.

Analysing technological competitiveness in emerging technologies is anything but straightforward. Upcoming technologies are typically at a pre-competitive stage with no or only a few applications yet on the market. There also only few firms that can clearly be linked to one field of technology and that are not dealing with other technologies or products. Mostly, KET applications are commercialised by multi-technology firms with a product portfolio that includes many products based on other technologies. KETs also cannot be linked to industry classifications (for which statistical data would be available) since the cross-sectional nature of KETs implies that firms from different industries develop and apply a certain KET. Consequently, traditional concepts of analysing competitiveness based on industry data such as market shares, trade performance, productivity and growth in value added cannot be applied to analyse competitiveness in emerging KETs.

In order to provide an empirical assessment of the current situation of international competitiveness in each KET, patent data seem to be the most relevant source. Patent applications refer to technical inventions that have reached a certain state of feasibility and thus represent the successful completion of some stage of R&D efforts. Most patents are applied by firms and so are linked to their competitive strategies. Although comparability of patent data is limited due to different economic values a patent may represent, different degrees of technological novelty and different regulations of national patent offices, patent data are nevertheless a useful source to analyse dynamics in certain fields of technology and identify the regional distribution of new knowledge generation, including specialisation of countries on certain fields of technology (see Moed et al., 2004). Patent data have widely been used to analyse technological performance particularly for KETs, such as nanotechnology (see Palmberg et al., 2009; Igami and Okazaki, 2007; Li et al., 2007; Hullmann, 2006; Huang et al., 2004; Heinze, 2004; Noyons et al., 2003). Compared to other indicators of technological performance such as scientific publications or R&D expenditures, patent data are more closely related to innovations and product markets.

***Patent Data as Technology Indicators***

Using patent data as empirical base for analysing technological competitiveness of KETs has several advantages:

Patent data contain information on the technological area(s) a certain patent is related to, based on an internationally standardised classification system (International Patent Classification - IPC). Since IPC classes are highly disaggregated, most KETs can be directly identified through a number of IPC codes. Patent data also contain text information of the technical content of a patent (patent abstracts) which would provide an alternative source to identify patents that are related to certain fields of technology by applying a text search. The latter approach is, however, time consuming and requires an in-depth technical knowledge of each KET and is thus not feasible for this study.

Patent data allow to determining the "market share" of the EU in the total production of new technical knowledge in each KET in the past two decades or so, and how these market shares have developed over time. Patent data also enable to differentiating by country of applicant and thus to pattern technological competitiveness in each KET by EU member state.

Patent data contain information on the applicants which can be linked to other data in order to identify the institutional background of an applicant (higher education institution, public sector research institution, private firm, individuals) or the sector affiliation. Sector affiliation of applicants is important information to evaluate the role of each KET for different sectors.

Patent data allow to some degree an analysis of technological links between certain fields of technology, e.g. by looking at the different IPC classes assigned to a certain patent, or by looking at patent citations.

However, patent data also have a number of limitations (see Griliches, 1990; Moed et al., 2004) that limit their applicability as technology indicators and that complicate their analysis:

Not all commercially promising inventions are patented. Many firms opt to protect new knowledge by other means than patenting, particularly by keeping the knowledge secret. This is especially relevant for process technology which is difficult to observe and thus to imitate.

Patents represent different economic values and different degrees of technological novelty. Though many efforts have been made to quantify the value of patents, e.g. through analysing patent renewals, patent citations, opposition procedures, size of patent families or the number of IPC classes (see Harhoff et al., 1999, 2003), none has produced a result that could be applied across different fields of technology, different patent authorities and different groups of applicants. In particular, most measures can not accurately capture the high skewness of the value distribution, i.e. that only a few patents are really very valuable, and most are economically irrelevant. As a result, any count of patent data, whether weighted by a "relevance factor" or not, is problematic as it is likely to compare entities of completely different values.

Not all patents are applied to seek protection but are used to block competitors' patenting activities or to disinform others about one's own technological strategy. This "strategic patenting" seems to have become more important in recent years. Patents applied for strategic reasons are likely to be less accurate indicators for technological advance since most of these patents won't result in innovations on the market.

Patent data applied at different patent authorities are difficult to compare because of different patent national laws, different practices at patent offices and different application procedures. As a consequence want cannot simply add up patent data applied at different patent offices.

Applying for patent protection at a specific patent office is linked to the applicant's strategy for commercialising this invention, which depends on the applicant's market orientation as well as on the attractiveness of a particular market for this invention at a particular point in time.

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 invention and patent application which is due to the process of preparing a patent file. More importantly, patent applications are disclosed only 18 months after the date of application. The time lag becomes even larger when one wants to consider only patents that have been applied at more than one patent office (e.g. so-called triadic patents applied in Europe, the USA and Japan) since many applicants apply for patent protection in other countries 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.

Changes in patent laws can make it difficult to analyse long term trends in patenting. The introduction of the Patent Cooperation Treaty (PCT), for instance, changed application behaviour in the way that an increasing share of patents is applied through the PCT procedure.

We try to tackle some of these shortcomings of patent data in the following way:

We analyse **patent families** rather than individual patents. A patent family is a group of patent applications filed by the same applicant(s) in one or more countries that are related to a single invention. By doing this, we reduce the incidence of double-counting of one and the same invention in patent data. In the following, the term "patent" always refers to a patent family. For each patent we identify the year of application (i.e. the oldest priority year of all applications belonging to one family) and the countries for which patent protection has been sought as well as the names of the patent applicants.

We focus on patents that include an application at the EPO or a PCT application (so-called **EPO/PCT patents**). These patents are likely to represent higher economic values since these applications are more costly than applying just at a single national patent office.

In addition, we run parallel analysis for **regional patent applications** in Europe, North America and East Asia in order to avoid likely biases from different attractiveness of regions for commercialising inventions in a certain field of technology.[1] For this purpose we look separately at patent families that have been filed at the EPO, at the USPTO and the JPO (including patents transferred to these authorities through the PCT procedure). In addition, triadic patents are determined as patent families that have been filed at each of the three patent offices or at any other combination of national patent offices including at least one patent office from each region.

We refrain from weighting patent applications by patent value indicators such as patent citations or opposition 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.

All patent analysis rest on the Patstat database generated by the EPO. We use the September 2009 edition of Patstat.

***Identifying KETs in Patent Data***

There are two approaches to assign patents to technology areas. One is to identify key words (and combination of these) that characterise a certain technology and to search in patent abstracts for the occurrence of these key words. Another one is to use patent classes. Patent classes describe for which fields of technology a patent is relevant to. They are assigned by patent examiners, using a hierarchical classification system. The most commonly used one is the International Patent Classification (IPC). Both approaches have advantages and disadvantages. The key word based approach is more flexible for applying tailor-made definitions of technology fields but requires an in-depth knowledge of all subareas within

[1] To illustrate the point, suppose Europe is unattractive for commercialising certain inventions in green biotechnology (a field which is not analysed in this report). Inventors from the USA and Japan will see little need to protect their inventions in the European market and only apply for patent protection in the USA and Japan (and maybe some other markets outside Europe). As a consequence, the share of European applicants in all patent applications in Europe (i.e. at national patent offices of European countries or at EPO) in this technology field is likely to be rather high. In case Europe is becoming more unattractive over time, it is likely that the share of European applicants in Europe is further increasing. Both facts could be misinterpreted as a technology advantage of Europe.

each technology field and great experience on how certain technology content is typically phrased in the patent abstract. Different strategies of applicants to phrase patent abstracts as well as different standards for patent abstracts at different patent offices can limit its applicability. A key word search can also be very time consuming when it comes to combining key words and searching across patent data from various patent authorities.

Given the large number of technology fields to be covered and the short time that was available for conducting the empirical analyses for this report, we decided to use the patent classification system to assign patents to KETs. Based on the literature and input from experts, each KET has been defined by a list of IPC codes or a combination of them (see Table 2-1).

Identifying **nanotechnology** is rather straightforward since patent offices have introduced separate classes to mark patent applications related to that field of technology. EPO uses the tag class Y01N which has been introduced in 2003 and is also used to classify patents applied prior to 2003 (see Palmberg et al., 2009). In addition, the IPC class B82B covers the manufacture of nanostructures.

The KET **micro- and nanoelectronics** covers new technologies related to semiconductors, piezo-electrics and nanoelectronics which all are easily to identify through IPC classes. We include the nanotechnology trap class Y01N 12 (nanoelectronics) deliberately to this KET which results in a certain overlap between patents assigned to nanotechnology and to microelectronics.

The field of **photonics** relates to optical technology applications in the areas of lasers, lithography, optical measurement systems, microscopes, lenses, optical communication, digital photography, LEDs and OLEDs, displays and solar cells. All these areas can be identified through IPC classes. There is some overlap to micro- and nanoelectronics in the area of optical communication.

**Industrial biotechnology** is more difficult to identify through IPC classes since many classes covering inventions related to industrial biotechnology are also related to red and green biotechnology (see van Beuzekom and Arundel, 2009). We apply a rather narrow definition which focuses on enzymes, micro-organisms, amino acids and fermentation processes and only consider patents that are not related to the fields of medicine or agriculture. Some subfields of industrial biotechnology such as biopolymers and biotechnologically produced vitamins are poorly covered because they are difficult to distinguish from chemical polymers and chemically produced vitamins. Despite the narrow definition, industrial biotechnology patents as defined in Table 2-1 still include patents applied by applicants from the pharmaceutical or seed industry, reflecting the close link between industrial, red and green biotechnology. These patents are excluded from the analysis.

**Table 2-1: IPC classes used to delineate KETs**

| *KET* | *IPC* |
|---|---|
| Nanotechnology | Y01N, B82B |
| Micro- and nanoelectronics | H01H 57/7, H01L, H05K 1, H05K 3, H03B 5/32, Y01N 12 |
| Photonics | F21K, F21V, G02B 1, G02B 5, G02B 6, G02B 13/14, H01L 25/00, H01L 31, H01L 51/50, H01L 33, H01S 3, H01S 4, H01S 5, H02N 6, H05B 31, H05B 33 |
| Industrial biotechnology | C02F 3/34, C07C 29/00, C07D 475/00, C07K 2/00, C08B 3/00, C08B 7/00, C08H 1/00, C08L 89/00, C09D 11/04, C09D 189/00, C09J 189/00, C12M, C12N, C12P, C12Q, C12S, G01N 27/327; except for co-occurrence with A01, A61 and some subclasses of C07K, C12N, C12P C12Q, G01N; except patents applied by applicants from the pharmaceutical and seed industry |
| Advanced materials | B32B 9, B32B 15, B32B 17, B32B 18, B32B 19, B32B 25, B32B 27, C01B 31, C04B 35, C08F, C08J 5, C08L, C22C, D21H 17, H01B 3, H01F 1, H01F 1/12, H01F 1/34, H01F 1/44, Y01N 6 |
| Advanced manufacturing technologies | a) robotics/automation: B03C, B06B 1/6, B06B 3/00, B07C, B23H, B23K, B23P, B23Q, B25J, G01D, G01F, G01H, G01L, G01M, G01P, G01Q, G05B, G05D, G05F, G05G, G06M, G07C, G08C; except for co-occurrence with sub-classes directly related to the manufacture of automobiles or electronics; b) computer-integrated manufacturing: co-occurrence of G06 and any of A21C, A22B, A22C, A23N, A24C, A41H, A42C, A43D, B01F, B02B, B02C, B03B, B03D, B05C, B05D, B07B, B08B, B21B, B21D, B21F, B21H, B21J, B22C, B23B, B23C, B23D, B23G, B24B, B24C, B25D, B26D, B26F, B27B, B27C, B27F, B27J, B28D, B30B, B31B, B31C, B31D, B31F, B41B, B41C, B41D, B41F, B41G, B41L, B41N, B42B, B42C, B44B, B65B, B65C, B65H, B67B, B67C, B68F, C13C, C13D, C13G, C13H, C14B, C23C, D01B, D01D, D01G, D01H, D02G, D02H, D02J, D03C, D03D, D03J, D04B, D04C, D05B, D05C, D06B, D06G, D06H, D21B, D21D, D21F, D21G, E01C, E02D, E02F, E21B, E21C, E21D, E21F, F04F, F16N, F26B, G01K, H05H |

*Source: ZEW*

**Advanced materials** can cover a broad area of innovation in materials, including polymers, macromolecular compounds, rubber, metals, glass, ceramics, other non-metallic materials and fibres as well as the whole field of nanomaterials and speciality materials for electric or magnetic applications. We focus on material innovations in the areas of layered products, compounds, allays and nanomaterials (see Schumacher et al., 2007).

The most difficult KET to identify through patent classes is **advanced manufacturing technologies**. The main challenge here is to delineate standard inventions in manufacturing technologies from "advanced" ones. We distinguish two types of advance manufacturing technologies. One relates to robotics, automation and control, measurement and steering systems. The other refers to computer-integrated manufacturing processes. While the former can be directly identified through IPC classes, the latter group consists of patents that both are assigned to computing technology (G06) and to one of the many IPC classes that relate to mechanical engineering (according to the definition of Schmoch et al., 2003).

Each KET is divided into several subareas. Details are given in the respective KET chapters.

### *“Market Shares” and Patent Dynamics*

We measure technological competitiveness of European applicants by two indicators, the “market share” and the dynamics of patent applications. The market share is the share of patents from Europe in the total number of patents of a certain KET in a specific year. Market shares are calculated for the three main world regions separately: Europe, North America and East Asia.[2]

The dynamics of patent applications refers to the change in the number of patents over time. Patent dynamics are analysed for the 1990s and 2000s. Owing to the time lag between patent application and disclosure, the last year that is fully covered is 2005. The number of patent applications from 2006 and 2007 is generally biased towards applicants from the respective region since patents are typically first applied in the home region, while many patents seek protection in other regions only some time after their initial application.

When looking at patent dynamics for patents applied at the EPO or through the PCT procedure, one should note that there is a general upwards trend in this figure until the early 2000s for most fields of technology, including the KETs considered here. This is basically due to a change in patent application behaviour that resulted in an increasing share of patents applied at the EPO and - since the mid of the 1990s - through the PCT procedure in the total number of patent applications across all patent offices. This dynamics does not necessarily reflect an increasing patent output. However, during the 1990s the number of patent applications did increase on a global level (see Eaton et al., 2004). This general trend in patent output has to be kept in mind when interpreting the dynamics in a specific KET.

An important issue for determining market shares is how to regionalise patents. 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. In this study, we apply both approaches. For analysing market shares and patent dynamics between Europe, North America and East Asia, patents are assigned to regions according to the location of the applicant (applying fractional counting in case one patent has applicants from more than one region). Note that we do not consolidate patent applicants by company groups (except for producing lists of largest applicants). This implies that patents applied by

[2] Europe inlcudes all EU member states as well as Albania, Andorra, Bosnia-Hercegovina, Croatia, Iceland, Liechtenstein, Macedonia, Monaco, Montenegro, Norway, San Marino, Serbia and Switzerland. North America includes the USA, Canada and Mexico. East Asia covers Japan, China (incl. Hong Kong), Korea, Singapore and Taiwan. For all six KETs, these three regions generate more than 95 percent of all patents.

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 analyses would be based on country of inventor. At the same time, relying on applicant countries enlarges the analytical potential of patent data since patents only applied at USPTO or JPO often miss address information on inventors.

Analyses of patenting by country in Europe are based on the country of the inventors. This procedure assures that we capture the actual production of patents within the territory of each European country (though some imprecision may occur in border regions when inventors reside in another country than the country of the workplace.

***Industry Impacts and Market Potentials***

A key issue in evaluating the role of KETs for competitiveness is the link between KETs and industries. Since KETs are by definition general purpose technologies, they are likely to be relevant for many industrial sectors and trigger innovation in many product markets and fields of applications. While some of these markets are already in sight at the time new technologies are developed, some other fields of application are to emerge later. This complicates a clear assignment of KETs to industrial sectors.

We pursue two empirical approaches. First, we apply the IPC-to-industry assignment of Schmoch et al. (2003) which links each IPC 4-digit class to a single industry sector based on NACE rev. 1.1. This produces a sector pattern for each KET which shows the **technological relevance of patents for certain sectors**. Secondly, likely industry impacts will be discussed based on the sector a patent applicant belongs to. For this purpose, each applicant is assigned to an industry (including separate "industries" for public research, government authorities and private individuals). Firms are assigned to industries based on NACE rev. 2.0, though we apply tailor-made sector groupings for each KET in order to best represent sector priorities of applicants. The resulting KET-to-sector patterns allow to assessing the **sectors from which technological advance emerges** in each KET. These sector links of KETs may hint to likely impacts on a sector's growth and competitiveness originating from each KET.

A related issue concerns likely **synergy effects between KETs**. While each KET represents a distinct field of technology, some KETs may cross-fertilise. As a consequence, strengths and weaknesses in one KET may affect the performance of another. An obvious case is nanotechnology which provides important technological stimuli for micro- and nanoelectronics, advanced materials, photonics and some areas of industrial biotechnology. We analyse potential synergy effects empirically by analysing for each patent from a given KET whether this patent was also assigned to other KETs. This analysis uses the fact that most patents are assigned to several IPC classes, some may relate to one KET, some to others. A large share of patents having IPC classes of two KETs indicate that there are rather close technological relations between these two KETs insofar inventive activity tends to affect both KETs to a significant extent.

Industry impacts of KETs are also reflected in their **market potentials**, i.e. the size of current and expected sales that products based on a specific KET generate. Determining the current and likely future market size of KETs is challenging. First, KETs are *technologies* rather than products, i.e. they indicate the way how something is produced. Technologies can be used for producing various products, which is particularly true for KETs. Secondly, products based on KETs often are raw materials, components or intermediaries of more complex products. For instance, nanomaterials may by used in a wide variety of manufactured products from different industries. Semiconductors can be applied to a wide range of instruments, machinery and equipment. Biotechnologically produced enzymes may be found in a number of food or chemical products. New photonic applications such as OLED displays can be used in electronic, automotive and telecommunication devices. Advanced materials as well as dvanced manufacturing technologies can virtually be employed for producing any kind of commodity. As a consequence, market potentials strongly depend on the underlying definition of a KET and which sections of a value added chain are considered. Thirdly, technologies and products for which market potentials are estimated often have not been introduced to the market yet. Most of these *potential* applications areas are derived from concepts driven by technological opportunities rather than the likely preferences of users. Market acceptance of these concepts is largely unknown and it may well be that there will be no market at all for some of these concepts. Historical experience with new technologies shows that many of the most important applications areas were not envisaged in the infant stage of technological development but emerged later through interaction of users and producers, and sometimes just by chance. All this complicates to foresee future market development and results in low accuracy of forecasts.

In this report, we compile figures on market potentials of KETs from various market forecasts and technology outlooks which have been produced by various industry analysts and consultants in recent years. The main purpose of this exercise is to determine how large market volumes in the medium term (e.g. 2015/2020) for KETs and their subfields may be. Most market forecasts used in this report are based on estimates made in the years 2006 to 2009, and hardly any has systematically considered the impacts of the economic crisis, which further limits the accuracy of market forecasts.

The analysis of market potentials of KETs done in this report suffer from several weaknesses. First, there are no established and commonly used definitions for each KET. Secondly, most market forecasts refer to subfields of KETs, many of these subfields overlap, but the degree of overlapping is not known. Thirdly, market forecasts tend to report rather the maximum potential under favourable market conditions and often overestimate the actual development. Fourthly, establishing the accuracy of past market forecasts is complicated by either a lack of clear definitions of the technologies and products for which market forecasts are given, or by applying definitions which are not reported in sales statistics or market analysis, impeding a later evaluation of how well the forecast met the real market development. Finally, almost all market forecasts refrain from determining to what extent future sales figures of new technologies/products are associated with a decline in sales of established products (i.e. the degree of substitution). As long as substitution elasticities are unknown, net growth of markets resulting from KETs cannot be established which clearly limits the conclusions of likely growth impacts of KETs.

In an ideal world, market potentials for KETs could be established by pursuing the following methodology:

(1) Defining a KET based on a set of subfields/technology areas which are clearly delineated and do not overlap.

(2) Determining the current volume of production and sales as well as for each subfield/technology area (e.g. based on market research and industry survey).

(3) Establishing the degree to which a new technology/product is substituting existing technologies/products and which factors drive the speed of substitution.

(4) Determining the current sales volume of technologies/products that are likely to be substituted by new technologies/products.

(5) Identifying the most important factors that influence future demand for new applications that emerge from a KET and making an attempt to determine the relative weight of each factor (based on past experience and expert assessment).

(6) Developing scenarios how these factors may develop within the next say ten years, distinguishing between pessimistic and optimistic scenarios (and a "realistic" between the two extremes).

(7) Calculating likely market volumes for each subfield/technology area and for different scenarios by differentiating between substitutive demand and additional demand.

## 2.3 Strengths, Weaknesses, Challenges and Policy Intervention

A main aim of this report is to analyse the strengths, weaknesses and challenges for each KET and to derive conclusions for policy intervention. For this purpose we apply a methodology that is based on a "System and Market Failure Framework". Within this framework, factors that are likely to drive or impede the development of a certain technology are identified and evaluated in a systematic way. The analysis is based on existing publications on each KET and own research of successful clusters in Europe and overseas. In particular, we discuss the types of market and system failures that may hinder the advance of a certain KET and how these failures have been tackled. Based on these findings, upcoming challenges in each KET area are discussed based on existing reports and reviews as well as expert assessments.

***System and Market Failure Framework***

To unveil the systemic and market characteristics that may influence the performance of each KET area, we build upon an improved "system failure framework for innovation policy design" as adopted the European Innovation Progress Report 2008 (EC, 2009c). The framework has since been developed to include market failures and should hence serve as a solid basis for the analysis for relative weaknesses in the KET areas in Europe. The framework also explicitly includes the topics like the role of public funding, tax incentives and the role of lead markets and public procurement that are of Interest in this study. The main dimensions and criteria of the framework are shown in Figure 2-2.

The vertical axis contains the potential system and market failures. Essential to the framework is that these characteristics are seen as the product of the actions and interactions of the system's actors that are identified on the horizontal axis. This detailed framework will enable us to identify the system's weaknesses, but also the actors that are involved or that are missing and may create these weaknesses. A system failure, for instance, can be the lack of interaction between companies and knowledge providers, i.e. an ill functioning knowledge triangle. Such a failure may constitute a barrier for knowledge exchange and innovation.

**Figure 2-2: System and market failure framework**

| System & Market failures / Actors | | Consumers, end-users, lead-markets, public procurement **(demand)** | Manufacturers, entre-preneurs, SME's, MNC's **(supply)** | Knowledge institutes: Universities, schools **(knowledge providers)** | Third parties: Banks, VC, lawyers (service providers) | Government: Policy makers, legislators **(rule & policy makers)** |
|---|---|---|---|---|---|---|
| **System failures** | | | | | | |
| Infra-structure | Enabling structures (roads, harbors, IT etc.) | | | | | |
| Institutions | Regulative institutions (rules & regulations, policy, tax-incentives) | | | | | |
| | Social institutions (norms, values, culture, social pressures) | | | | | |
| | Competitive institutions (mimicking competitors, shareholder pressure) | | | | | |
| Interaction | Strong network failure, closed group think hinders innovation | | | | | |
| | Weak network failure, lack of connections for learning and innovation | | | | | |
| Capabilities | Technical knowledge and know-how to enable innovation | | | | | |
| | Organisational / Marketing knowledge and know-how to enable innovation | | | | | |
| **Market failures** | | | | | | |
| Market structure | Barriers to entry / Market power blocking new entrants | | | | | |
| | Externalities / Split incentives hampering investments in innovation | | | | | |
| | Transparency / perfect information hampering the right market functioning | | | | | |
| Market demand | Quality of demand hampering the level of innovation | | | | | |
| | Quantity of demand hampering the diffusion of innovation | | | | | |

*Source: Klein Woolthuis (2010).*

The framework helps to analyse the barriers and drivers within a KET area that affect the successful adaptation and commercialisation of the respective technologies and that facilitate systemic innovation and the development of the industries producing these technologies. For newly emerging fields of technology, several dimensions are critical:

Actors have to be in place, ranging from innovative entrepreneurs to supportive policy makers, and specialist consultants.

System characteristics have to be supportive, including the right infrastructure, well-trained staff, a right mix of collaboration as well as competition to stimulate innovation.

Market characteristics should be right to enable actors to reap the benefits of their investments and hence markets should not be blocked, prices should reflects costs, and demand should be big enough and of enough quality to support innovation.

Interactions between the different actors should be present and of sufficient quality to make the system work.

An analysis of how KETs stimulate innovation according to this framework will unveil the system's functioning and the weaknesses when compared to the theoretical insights into successful innovation systems and vis-à-vis more successful KETs outside the EU.

***Analysing successful clusters***

The relevant elements of the system, the prevailing failures and the challenges resulting from these challenges will be identified based on a literature survey. In order to empirically assess the significance of various system and market failures and the factors that drive success in KETs, a set of successful clusters will be analysed in more detail. We have chosen to look at clusters since high technological developments almost always takes place in collaborative relationships between companies, research institutes, and specialist service providers such as venture capitalists. In other words, whereas the technologies and their applications are world-wide and footloose, their origins very often lie in regional concentrations of collaborative relationship s between the science, industry and public triangle.

To distill the key factors that are considered to be at the basis of their success, we will examine the history and development of these successful clusters. We do so, on the basis of secondary data: scientific and vocational cluster publications, and publically available information. We structure the analysis along the systemic and market characteristics presented above. The analysis will also explicitly address the role of public funding, tax incentives and the role of lead markets and public procurement. The main dimensions and criteria of the framework are shown in the diagram below.

The choice of KET clusters is based on the following criteria:

The cluster has to have an established reputation, must be internationally recognised as a leading cluster in that KET field

For comparing between EU and Non-EU policies towards KETs, each EU cluster is compared to a non-EU cluster

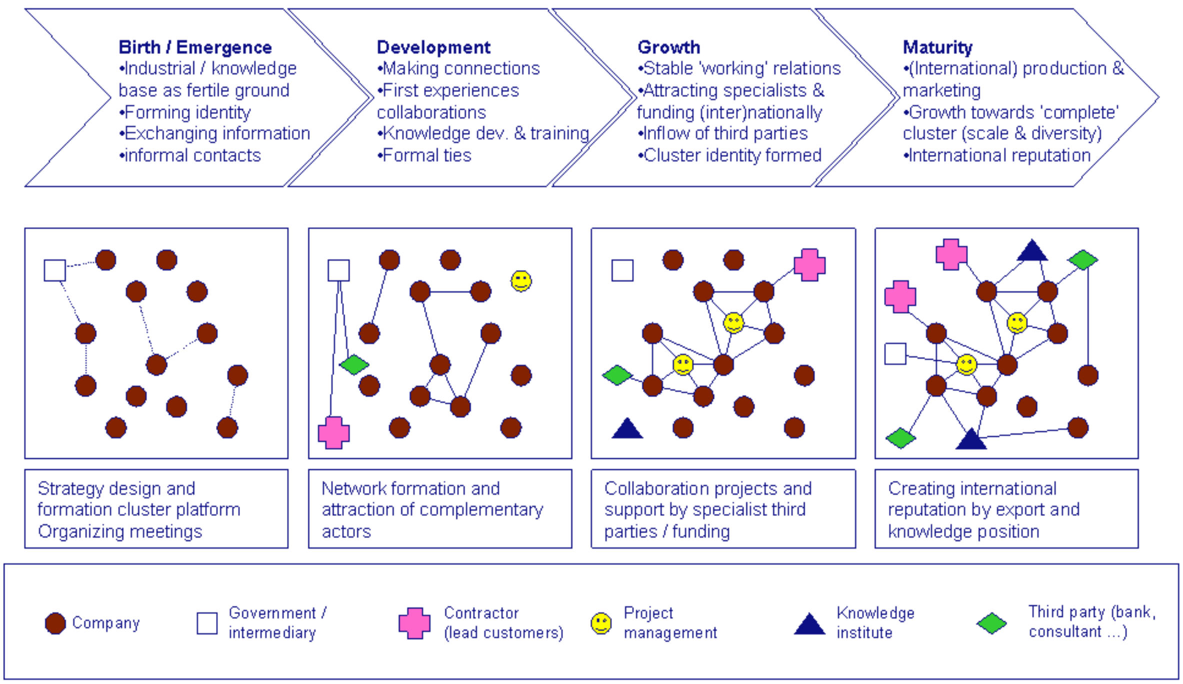
The cluster must be successful, but the clusters do have to vary on their degree of maturity

We do not 'put' boundaries to the clusters. Clusters are dynamic conglomerations of actors and activities which constantly change. Linkages and relationships do not keep to geographical boundaries, and boundaries will shift as activities develop. Generally though, activities do tend to cluster in a geographical area.

We categorise the clusters according to their phase of maturity, as a cluster in different stages has different traits and requires different support. For the cluster development process, we assume that clusters and the technologies they are based upon develop over time, as shown in Figure 2-3. While newly emerging clusters tend to focus on a smaller number of actors, more mature clusters have a wider variation of parties involved. Cluster that reach maturity may start to act as a magnet attracting specialists from all over the world in fields of research and commercialisation, but also lawyers, investors, and other specialists will want to 'share the pie'. It is with this inflow of knowledge and capital that the cluster reaches its maturity phase as public funding and support looses importance compared to private sources.

The analysis of successful clusters will also be used to examine the role of public policy for developing KETs. Three types of public intervention will be considered: the role of direct public funding, the relevance of specific tax incentives, and the role of public procurement and lead markets.

**Figure 2-3: Development of technology clusters**




*Source: TNO*

The KET clusters that we have chosen for this study are the following:

*Nanotechnology*

North Rhine Westphalia - Germany: A relatively young and dispersed cluster centred around Aachen, Munster and Duisburg/Essen, each city area represented in different cluster bodies and focussing on different markets.

Kyoto – Japan: A mature and concentrated cluster around Kyoto strongly promoted by national strategy, public policy and funding. There is an abundance of private sector involvement and venture capital and a strong focus on a limited number of knowledge domains.

*Industrial biotechnology*

Cambridge – United Kingdom: The Cambridge cluster has spontaneously developed and has become the leading biotechnology cluster in Europe. Cluster (industry) development has slowed down in recent years but the cluster remains world leading through top research and very strong relationships between industry, science and public spheres, and a strong entrepreneurial spirit.

Bay Area – United States: This is the leading biotechnology cluster in the world. Like Cambridge, the cluster has developed spontaneously and is characterised by strong industry – science linkages and an entrepreneurial culture (linked with private financing opportunities).

*Advanced materials*

Wallonia's Plastiwin cluster: This cluster brings together chemical manufacturers along the plastics value chain, research centres, training centres and industrial associations.

Changsha material cluster: This cluster has emerged rather recently and is linked to other strong industries in the region, including machinery, electronic and ICT industries. The Changsha advanced materials cluster focuses on the integration of industry, training and research, accompanied by active industrial policy which provides financial incentives and promote SMEs in the advanced materials sector.

*Micro- and nanoelectronics, including semiconductors*

Grenoble – France: A large, mature cluster that originated as a result of the presence of the National Nuclear Institute that served as lead customer and knowledge accelerator. The cluster developed by carefully planned public policy and funding, and has become an international magnet.

Ontario – Canada: A rather dispersed and recovering cluster (after the dotcom burst). Public policy aimed at revitalizing the cluster, substantiated by very low costs for investment in research and development as a result of tax breaks and incentives.

*Photonics*

Berlin-Brandenburg – Germany: A fast developing cluster that has its base in the earlier relationships, knowledge and culture of the long established optical industry in the region. In last decades, it rapidly developed into a high tech KET cluster, also with help of well funded cluster platform OpTecBB.

Quebec – Canada: Very fast developing cluster that – like Berlin – is founded on a long industrial tradition of optical technologies in the area. Cluster is still small and has a strong focused on a limited number of knowledge fields and applications.

For studying the development of clusters we rely on scientific and vocational publications on the cluster, publications of the cluster management and other publically available information.

# 3 NANOTECHNOLOGY

## 3.1 Definition and State of Technology

Nanotechnology is a cross-sectional field of technology that combines scientific approaches from physics, chemistry and biology to discover and develop processes and substances for a wide variety of applications, ranging from materials, electronics and chemicals to process engineering, transportation and medicine. Nanotechnology deals with methods to analysing, controlling and manufacturing structures on a molecular or atomic scale, i.e. of a size of 100 nanometers or less. The innovative power of nanotechnology rests on the fact that physical and chemical properties of materials tend to change dramatically in this range of sizes. Nanoscaled structures often alter in terms of electrical and magnetic properties, surface and mechanical properties, stability, chemical processes, biological processes and optical features, allowing for radically new technological solutions in many different industries. New characteristics of nanostructures can be observed for many materials which adds to the variety of application areas and implies that nanotechnology can have a significant impact for all industries that process and use materials.

Nanotechnology is a rather new field of technology, though the start of systematic research in nanotechnology may be dated back to the 1960s. Originally, nanotechnology was confined to the idea to construct complex materials and devices out of single atoms (molecular nanotechnology), but since the 1990s, all work related to nanostructures is regarded as a part of this field of technology. Since the mid 1990s, nanotechnology research has been developing an increasing number of industrial applications, reflected in a fast growing number of nanotechnology patents and growing sales of products using nanomaterials or produced with the help of nanotechnological processes. Today, two types of nanotechnology approaches are distinguished. Top-down nanotechnology is used to describe attempts to scale down materials to a nanolevel through physical techniques such as lithography, cutting, etching, electro-spinning or milling. In electronics, for example, this approach has yet led to arrive at 32 nanometers structures in semiconductor production. The bottom-up approach tries to create new materials directly at a nanoscale, typically using physical, chemical and biological approaches such as deposition, nanoparticle synthesis or liquid-phase processes. It is envisaged that controlled self-assembly of molecules and their macrostructures based on the manipulation of individual atoms can lead to completely new dimensions of nanotechnology.

Although the technological potentials of nanotechnology are huge, the majority of nanotechnological products and processes that have been commercialised so far rest on a few nanomaterials such as carbon nanostructures, silver and gold nanoparticles and nanowires and nanoscaled metal oxides (see PCAST, 2008). The world market for nanotechnology products is estimated to exceed some tens of billions €, though sales figures strongly vary according to the underlying definitions and concepts (see Luther and Bachmann, 2009; Palmberg et al., 2009). All market studies on nanotechnology have in common that they expect an exponential increase in sales of nanotechnology products in the next ten years. In terms of sales volumes, nanoelectronics is currently to most important field of application (e.g. piezoelectrics, chemical/physical vapor deposition technologies, lithography steppers). Current application areas include nanofilms used on computer displays, dendrimers in pharmaceuticals, scratch-resistant coatings, water filtration based on nanomembranes, nanoscale transistors, carbon nanotubes for producing lighter and stronger materials. More importantly, a vast variety of applications are currently in the stage of prototype and pre-market entry. Table 3-1 presents examples of current, planned and projected nanotechnology applications by industries.

Given the broad spectrum of scientific disciplines and application areas, nanotechnology can be divided in a number of sub-areas, though no commonly used division has emerged so far. There are basically two ways to identify sub-areas. From a science and technology perspective, one may distinguish different research areas in nanotechnology related to physics, chemistry, pharmacology and biology. From a use perspective, one can differentiate by application area, e.g. industry sectors that apply nanotechnology in their products and processes. Often these two perspectives are combined to delineate subareas such as nanomaterials, nanoelectronics, nanobiotechnology, nanoscaled devices and systems (incl. nanooptics) and nanomanufacturing.

As any new technology, nanotechnology does not only offer new perspectives for commercial applications of new products and processes, but also raises issues of risks and safety. Assessing safety impacts of nanostructured materials is complicated by the fact that traditional testing and assessment methods may be not fully applicable to nanomaterials. Main concerns relate to potential damaging effects of certain nanomaterials on lung tissues, the brain or DNA, particularly with respect to carbon nanotubes or buckyballs (spherical fullerines) (see Sargent, 2008). Research and technological development in nanotechnology has to consider risk and safety issues seriously, and regulation needs to balance between considering health and safety issues and stimulating innovation.

**Table 3-1: Examples for current and planned nanotechnology products by industry**

| *Industry* | *Established nanoproducts* | *Recent market launch* | *Prototype stage* | *Concept stage* |
|---|---|---|---|---|
| Chemicals | - nanopowder<br>- nanostructured active agents<br>- nanodispersions | - carbon nanotubes<br>- nanopolymer composites<br>- hybrid composites | - nanoporous foams<br>- switchable adhesives<br>- electrospun nanofibers | - self-healing materials<br>- self-organising composites<br>- moleculare machines |
| Electronics | - silicon electronics<br>- nanoscaled transistors<br>- polymer electronics | - CNT field emission displays<br>- MRAM memories<br>- phase-change memory | - MEMS memory<br>- CNT data memory<br>- CNT inter-connected circuits | - moleculare electronics<br>- nanowires for producing electricity<br>- spintronic logics |
| Optics | - ultra-precision optics<br>- anti-reflection layers<br>- LED and diode lasers | - nanoresolution in microscopes<br>- OLED<br>- 2D photonic crystals | - EUV lithography optics<br>- quantum-dot lasers<br>- 3D photonic crystals | - all-optical computing<br>- optical meta-materials<br>- data transmission through surface plasmons |
| Medicine | - nanoparticles as contrast media<br>- nanoscale drug carriers<br>- nanomembranes for dialysis | - nanostructured hydroxylapatitie as bone substitute<br>- quantum-dot markers<br>- nano cancer therapy | - biocompatible implants<br>- selective drug carriers<br>- nanoprobes and nanomarkers for molecular imaging | - artificial organs through tissue engineering<br>- nanoengineered gels for supporting nerve cell growth<br>- neuro-coupled electronics for active implants |
| Environ-mental techno-logies | - nanostructured catalysts<br>- nanomembranes for sewerage<br>- anti-reflection layers for solar cells | - nanooptimised microfuel cells<br>- iron-nanoparticles for groundwater sanitation<br>- nano-titanoxyd for photo-catalytics | - large-area polymer solar cells<br>- nanosensorics for environmental monitoring<br>- nanocatalysts for hydrogen generation | - artificial photosynthesis<br>- quantum-dot solar cells<br>- nanocale rust for cleaning water |
| Auto-motive | - nanostructured coatings<br>- nanocoated Diesel injectors<br>- nanostructured admixtures for tires | - nanoparticles as Diesel additives<br>- nanooptimised lithium-ion batteries<br>- LED headlights | - thin-film solare cells for car roofs<br>- nanooptimised fuel cells<br>- nanoadhesives in production | - swithable, self-healing coatings<br>- adaptive bodyshell for lower air resistance |
| Textiles | - nanoparticles for dirt repellence<br>- nanosilver for antibacterial textiles<br>- nanocontainers for scent impregnation | - nano-titanoxyd for UV protection<br>- aerogels for thermal protection<br>- ceramic nanoparticles for abrasion resistance | - phase-change manterials for active thermal regulation<br>- textile-integrated OLEDs<br>- electrically conductive textiles | - textile-integrated sensorics and actorics for control of body functions<br>- textile-integrated digital assistance systems |

*Source: Luther and Bachmann (2009, p. 7), own research.*

## 3.2 Technological Competitiveness, Industry Links and Market Potentials

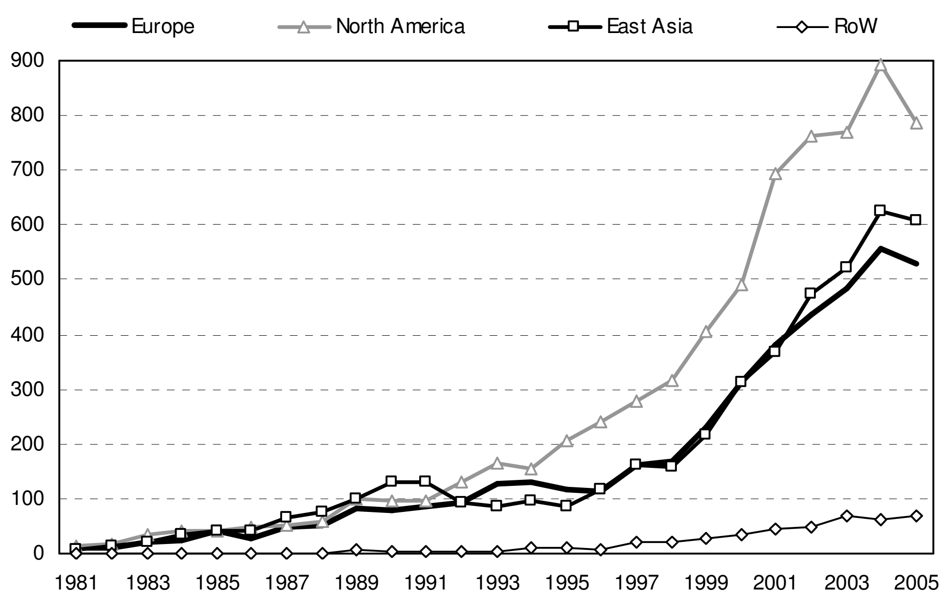
### 3.2.1. Technological Competitiveness

Patents are commonly used to assess technological developments and the performance of countries in the field of nanotechnology. While first studies were based on keyword searches (see Noyons et al., 2003; Huang et al., 2004; Heinze, 2004) more recent studies (Igami and Okazaki, 2007; Palmberg et al., 2009; Hullmann, 2006) did use the new tagging category for nanotechnology patents (Y01N) that has been introduced by EPO in 2003 (see Scheu et al., 2006). The tagging exercise was undertaken retroactively resulting in a full coverage of all patents related to nanotechnology.

*Market shares*

Measured in terms of patents applied at EPO or based on PCT (EPO/PCT patents), the number of nanotechnology patents applied per year increased markedly since the mid 1990s, exceeding 1,500 patents per year from 2002 on (Figure 3-1). Over the entire period from 1981 to 2005, more than 16,000 nanotechnology EPO/PCT patents were applied. Applicants from North American applied the largest number of nanotechnology patents, followed by East Asian and European applicants. Applicants from other than these three regions are of little significance, though the number of patents from the rest of the world has increased, too. Their market share is still below 10 percent.

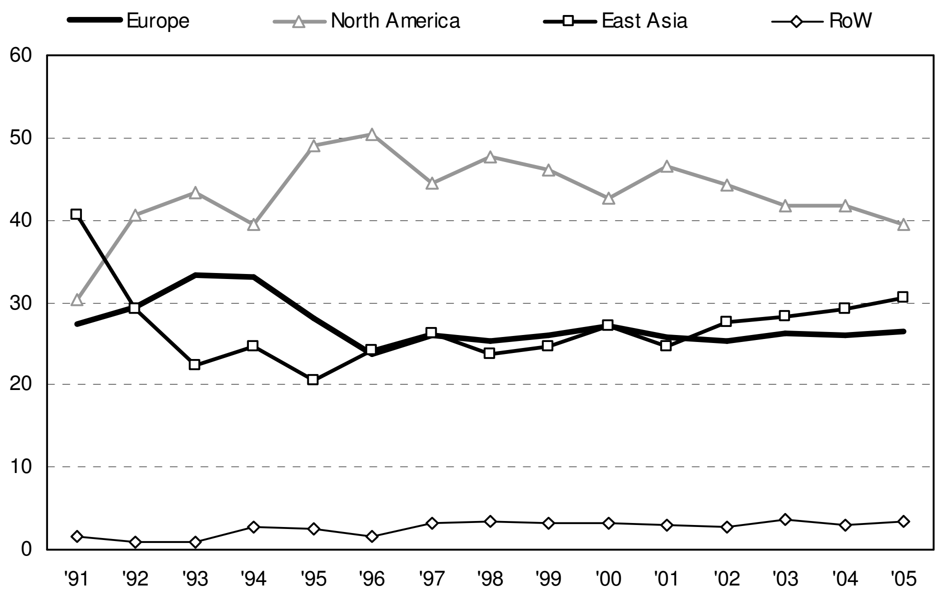
**Figure 3-1: Number of nanotechnology patents (EPO/PCT) 1981-2005, by region of applicant**




*Source: EPO: Patstat, ZEW calculations.*

North American applicants show the highest market share from 1992 onwards. Their dominance is decreasing, however. In 2005, their market share felt to 39 percent while East Asia could slightly increase its share in the total production of nanotechnology patents to 30 percent (Figure 3-2). Europe's market share peaked in the early 1990s. Since 1996, Europe contributes 26 to 27 percent to total nanotechnology patenting.

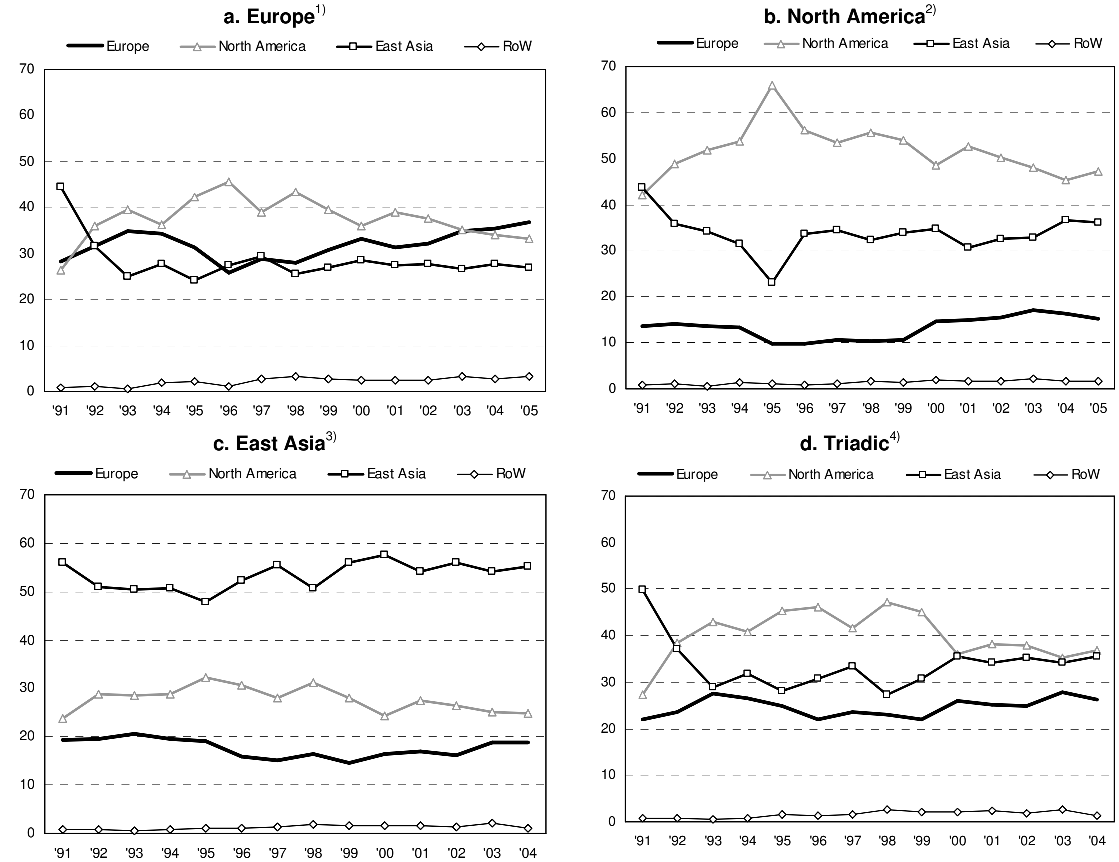
**Figure 3-2: Market shares of nanotechnology patents (EPO/PCT) 1991-2005 (percent)**




*Source: EPO: Patstat, ZEW calculations.*

Market shares for European applicants as presented in Figure 3-2 are likely to be overestimated, however, since European applicants have a higher propensity to apply at EPO while many applicants from North America and East Asia only apply at their home market offices (which is assumed to be the USPTO for North America and the JPO for East Asia). Market shares differ significantly when looking at regional patents (Figure 3-3). When only looking at EPO applications, Europe was ahead in 2005 with a share in total EPO nanotechnology patents of 37 percent. For USPTO applications, North American applicants show the highest share (47 percent in 2005), while European applicants only contribute 15 percent to the total. For JPO applications, East Asian applicants account for about 55 percent of all nanotechnology patents. European applicants are of less significance (19 percent in 2004) than North American applicants (25 percent). For triadic patents, i.e. patents that seek patent protection in all three regions, a similar picture as for EPO/PCT patents emerges, though the share of East Asia is higher (35 percent in 2004) and close to the one of North America (37 percent). Europe's market share is similar to the one for EPO/PCT patents (26 percent).

**Figure 3-3: Market shares in nanotechnology patents 1991-2005 for national applications and triadic patents (percent)**




*1) EPO applications*

*2) USPTO applications*

*3) JPO applications*

*4) Patents for which 1), 2) and 3) applies (including PCT applications transferred to national patent offices from all three regions).*

*Source: EPO: Patstat, ZEW calculations.*

In order to determine the relative importance of nanotechnology patents for a region, patent intensities can be calculated. These relate the annual number of EPO/PCT patents and triadic patents, respectively, from applicants of a certain region to the GDP of that region. This type of specialisation indicator shows that North America and East Asia produce the highest numbers of nanotechnology patents per GDP while Europe clearly follows behind. When looking at triadic patents, East Asia reports a higher nanotechnology patent intensity than North America are, indicating that North American nanotechnology patents are rather focused on the North American and European market, while East Asian applicants more often serve all three regions (Figure 3-4).

**Figure 3-4: Nanotechnology patent intensity 1991-2005 for EPO/PCT and triadic patents (number of patents per 1 trillion of GDP at constant PPP-$)**


*Source: EPO: Patstat, OECD: MSTI 02/2009. ZEW calculations.*

## *Patenting by subfields*

The tagging system Y01N separates six subclasses of nanotechnology. These six subclasses are used to delineate subfields within nanotechnology:

Nanobiotechnology

Nanoelectronics

Nanomaterials

Nanoanalytics (nanotools, nanoinstruments, nanomeasuring)

Nanooptics

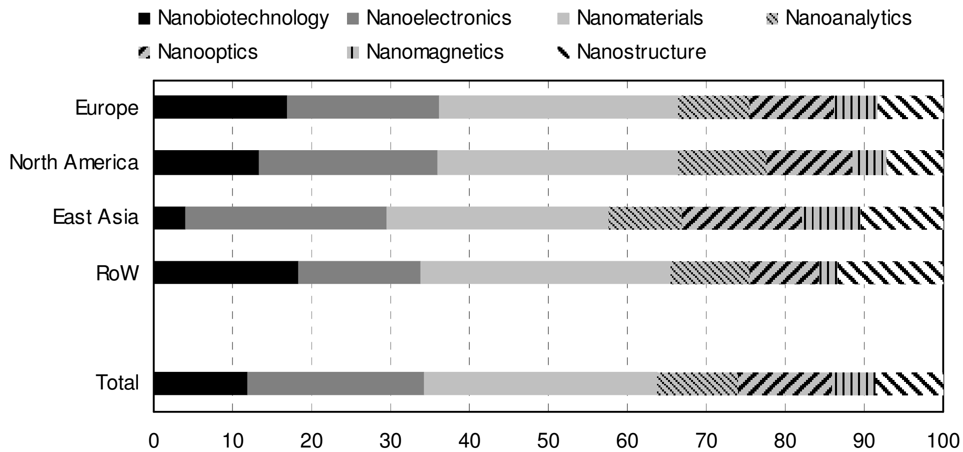
Nanomagnetics

Furthermore, patents assigned to the IPC class B82B (nanostructures) form a seventh subclass. Note that one and the same nanotechnology patent may be assigned to more than one subclass. This overlap is rather high for nanostructures and nanooptics (47 and 40 percent, respectively, of all patents are also assigned to another nanotechnology subfield) and low for nanobiotechnology (only 10 percent of patents falling in this subfield are classified under another nanotechnology subfield)l.

The largest subfield is nanomaterials, accounting 30 percent of all nanotechnology patents (Figure 3-5). All three main regions show similar shares for this subfield. 22 percent of all nanotechnology patents fall in the subfield of nanoelectronics. Nanooptics and nanobiotechnology follow with 12 percent each. Nanoanalytics (10 percent), nanostructures (9 percent) and nanomagnetics (5 percent) are the smallest subfields in terms of patent counts.

East Asia reports well above average shares for nanoelectronics, nanooptics and nanomagnetics while the shares for Europe are significantly smaller in these subfields. The share of nanobiotechnology in total nanotechnology patenting in Europe is rather high, even exceeding the respective share for North America.

**Figure 3-5: Composition of nanotechnology patents (EPO/PCT) by subfields (percent)**

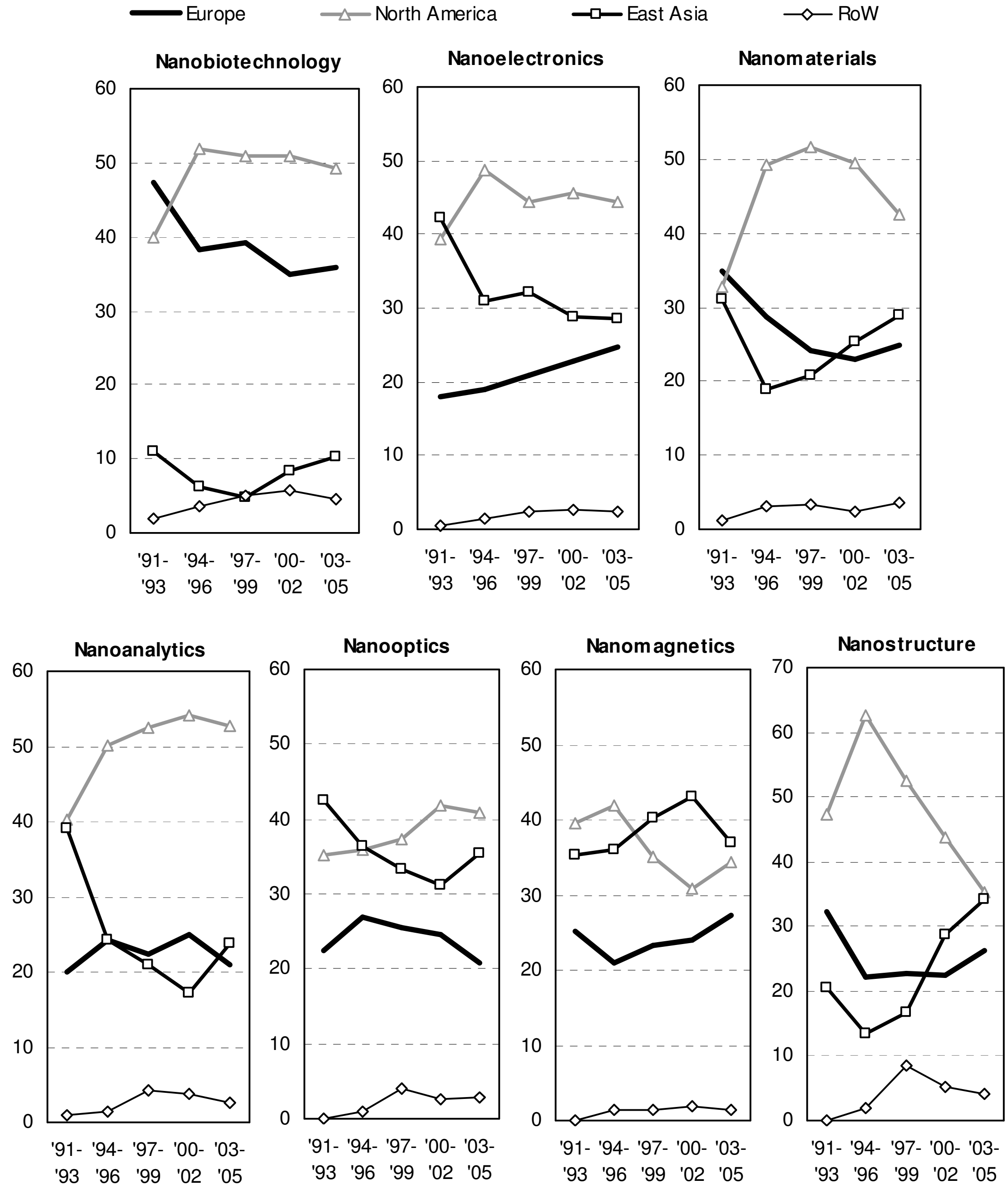



*Source: EPO: Patstat. ZEW calculations.*

When looking at the technology market shares by subfield over time (Figure 3-6), Europe shows rather high, though falling market shares in nanobiotechnology and low but increasing ones in nanoelectronics. In nanomaterials, patenting market shares fell from the early 1990s to the early 2000s, but have been increasing recently. A similar pattern emerges for the small subfields of nanostructures and nanomagnetics. In nanooptics and nanoanalytics, Europe's market shares are rather low and fell in the most recent period.

North America reports high market shares in nanobiotechnology, nanoelectronics, nanomaterials and nanoanalytics. Previously high shares in nanostructures have been diminishing. East Asia is strong in nanooptics and nanomagnetics and has significantly improved its position in nanomaterials and nanostructures.

**Figure 3-6: Market shares for nanotechnology patents (EPO/PCT) 1991-2005, by subfields (per cent)**

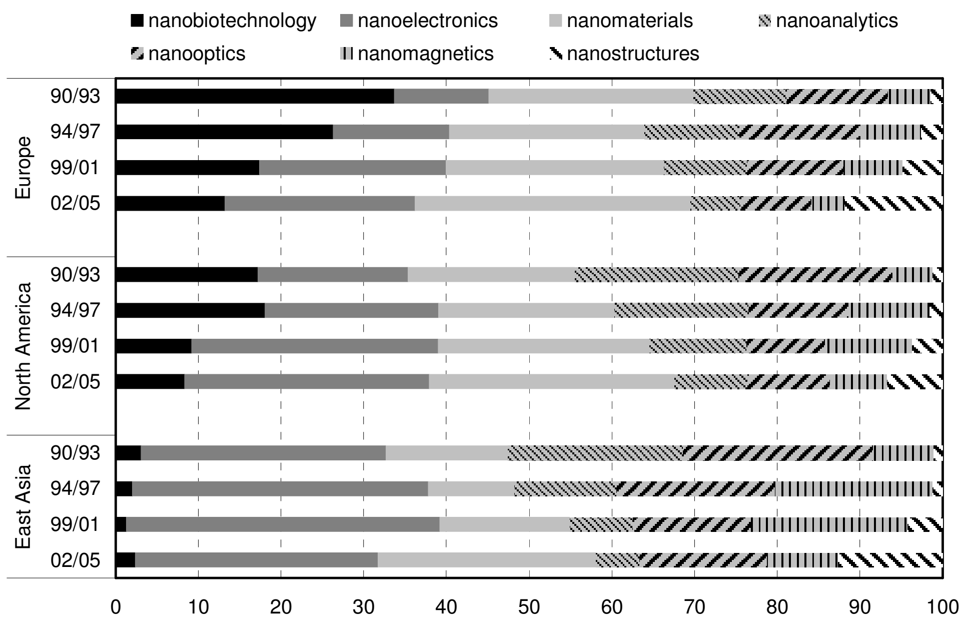



*Source: EPO: Patstat, ZEW calculations.*

Analysing technological dynamics by subfields based on EPO/PCT patents may be biased from varying attractiveness of the European market. For instance, a rise in demand for nanotechnology in Europe may stimulate patenting by North American and East Asian applicants at EPO, thus raising the number of EPO/PCT patents. A decreased attractiveness of the European market may result in the opposite effect. In order to avoid such biases from the market environment, we evaluate technological dynamics in nanotechnology by looking at patent applications by European, North American and East Asian applicants at their respective "home patent office" (EPO, USPTO and JPO, respectively).

For all three regions we find a trend in patenting towards nanomaterials, nanoelectronics and nanostructures while the share of nanobiotechnology, nanoanalytics, nanooptics and nanomagnetics is decreasing over time (Figure 3-7). The strong increase of the share of nanostructures may be associated with an increasing use of the respective IPC class (B82B) over time by patent examiners and patent applicants and may exaggerate the real growth in patenting in this subfield.

**Figure 3-7: Composition of nanotechnology patents (applications at home patent offices), by region, subfield and period (percent)**




*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

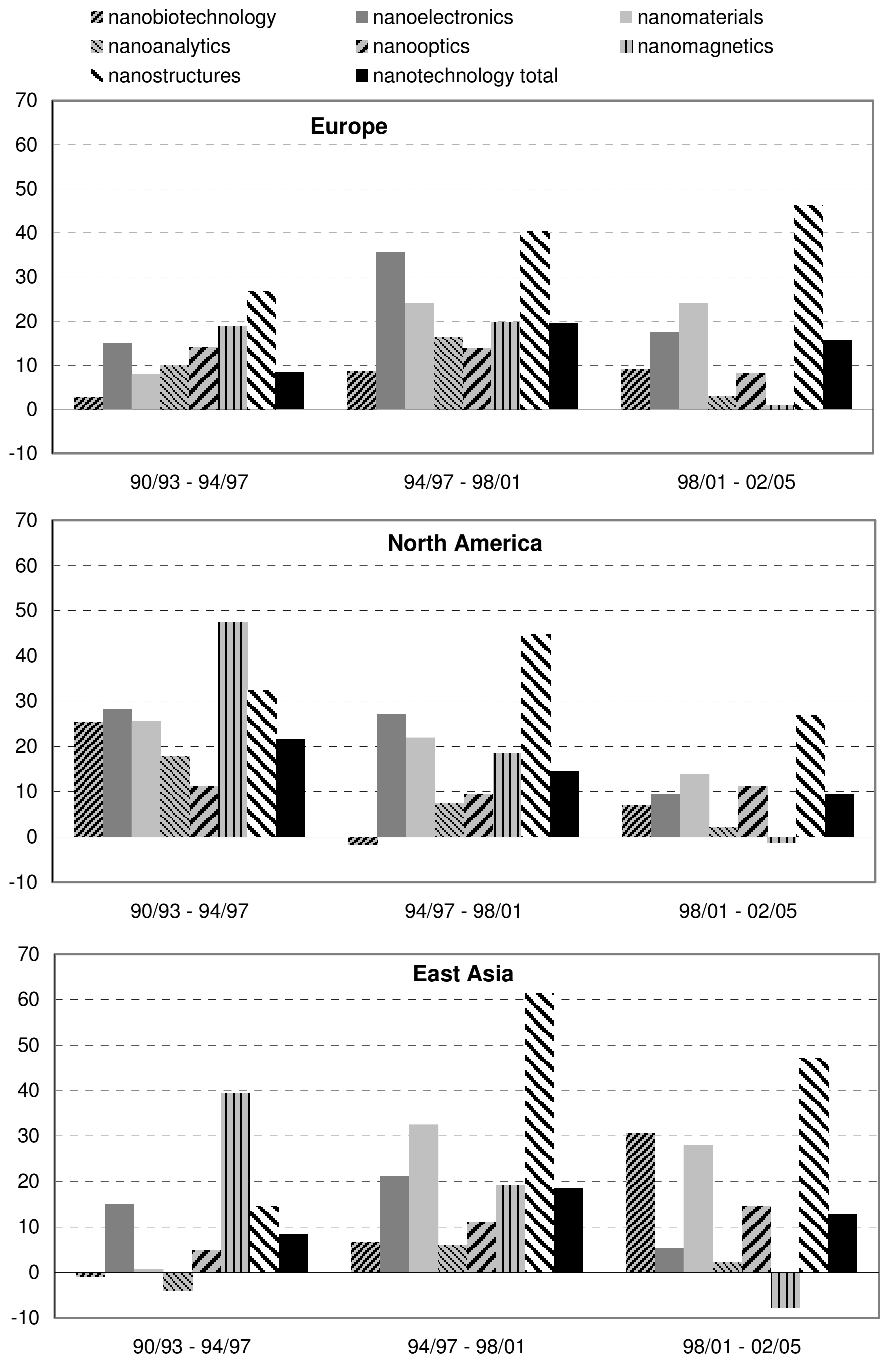
Figure 7-7 reveals the specialisation of Europe with nanotechnology on nanobiotechnology and nanomaterials while North American applicants focus on nanoelectronics and show an above average share for nanoanalytics. East Asia reports the highest share of all three regions for the subfields of nanoelectronics, nanooptics, nanomagnetics and nanostructures.

The specialisation pattern of East Asia was even more pronounced in the 1990s and has since then diminished, particularly owing to a high growth in nanomaterials patenting. The very low share for nanobiotechnology patenting remained stable, however. Europe's pattern of specialisation also tends to converge towards the world average. In the early 1990s, nanobiotechnology and nanomaterials accounted for almost 60 percent of all nanotechnology patents, a share which felt to below 50 percent in the mid 2000s.

The average annual rate of change in the number of nanotechnology patents by subfield shows high growth rates for nanostructures (which may be exaggerated owing to an increased used of the respective IPC class over time) and nanomaterials in all three regions since the mid 1990s (Figure 7-8).[3] Growth rates for nanoelectronics were particularly high in the second half of the 1990s but were lower in the first half of the 2000s. Nanomagnetics experienced highest growth rates in the first half of the 1990s. In the 2000s, the number of nanomagnetic patents did not increase anymore. Nanobiotechnology shows a heterogeneous picture, with high current growth in East Asia, while growth in North America was highest in the early 1990s. Nanoanalytics shows higher growth rates in the 1990s compared to the first half of the 2000s. For nanooptics growth rates in Europe are currently lower than during the 1990s whereas North America reports stable growth rates in this subfield and East Asia reports increasing ones.

[3] In order to avoid erratic growth rates when considering year-to-year changes, we grouped patent applications to four periods and calculated compound annual growth rates between two periods.

**Figure 3-8: Average annual rate of change in the number of nanotechnology patents (applications at home patent offices), by region, subfield and period (percent)**



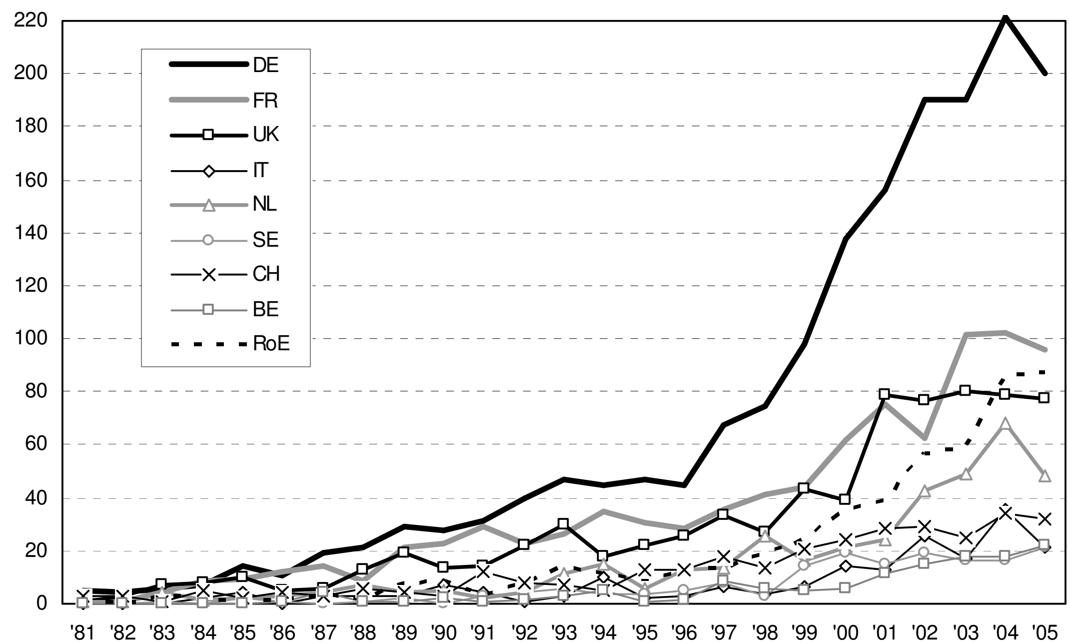

*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

For assessing the potentials and strengths of advanced material patenting by country in Europe, we assign nanotechnology patents to countries based on the location of inventors (regardless of the country of the applicant). In case a patent is applied by inventors from different European countries we apply fractional counting. We only look at EPO/PCT patents.

***Patenting at the country level in Europe***

Within Europe, inventors from Germany represent the largest group of producers of nanotechnology patents. Over the past three decades, 34 percent of all nanotechnology patents applied at EPO/PCT and having European inventors came from Germany, followed by France (17 percent), the United Kingdom (14 percent) and the Netherlands (8 percent) (see Figure 3-9). The number of nanotechnology patents from Germany grew particularly fast from 1997 onwards. Patenting by UK inventors showed a rapid increase from 1998 to 2001, while nanotechnology patents from France peaked in 2003. In recent years, applications from European countries that are not among the eight countries with the largest number of nanotechnology patents increased markedly, indicating stronger efforts in nanotechnology in these countries.

**Figure 3-9: Nanotechnology patents (EPO/PCT) in Europe 1981-2005, by eight largest countries (based on location of inventors)**

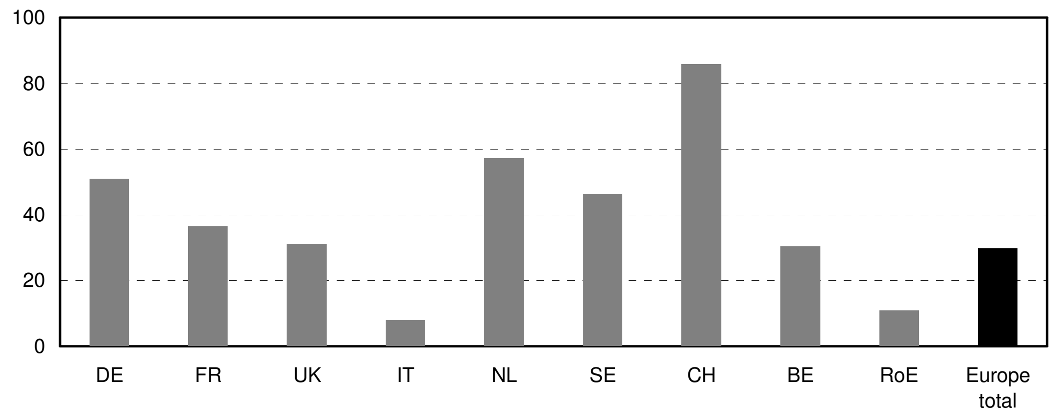



*Eight European countries with the largest number of nanotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The economic significance of nanotechnology patenting differs substantially by country (Figure 3-10). Nanotechnology patent intensity -that is the ratio of the number of nanotechnology patents to GDP- is highest in Switzerland and clearly above the European average in the Netherlands, Sweden and Germany. France produces somewhat more nanotechnology patents per GDP than the European average whereas the UK and Belgium report average patent intensities. Italy and the total of all other European countries show low nanotechnology patent intensities.

**Figure 3-10: Patent intensity in nanotechnology 1991-2005 of European countries (EPO/PCT patents)**




*Patent intensity: number of EPO/PCT patents applied between 1991 and 2005 per trillion GDP at constant PPP-$ in the same period.*

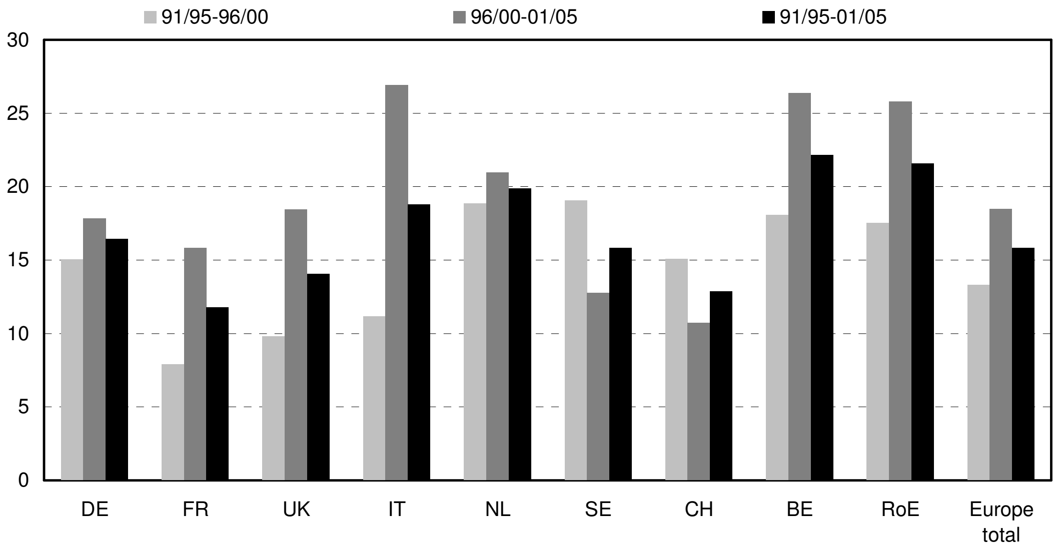
*Eight European countries with the largest number of nanotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The differences in the absolute number of nanotechnology patents and in patent intensities have to be kept in mind when looking at patenting dynamics since countries with low patent activities can more easily generate high growth rates. Among the eight countries that produce the largest number of nanotechnology patents, Belgium and the Netherlands could increase their patent output at an annual growth rate of 22 and 20 percent, respectively, between the first half of the 1990s (1991-95) and the first half of the 2000s (2001-05) (Figure 3-11). A similarly high growth rate was experienced by the group of European countries not qualifying for the eight largest patent producers in nanotechnology and by Italy. Nanotechnology patenting increased at the average European rate in Germany and Sweden. In France, the UK and Switzerland nanotechnology patenting grew slower compared to the European average.

In most countries, growth rates were higher in the most recent period (1996/00 to 2001/05) than in the previous period (1991/95 to 1996/00), indicating an acceleration in patenting output. Sweden and Switzerland do not follow this pattern, however. High growth rates in the 1990s were followed by rate low growth rates in the early 2000s (though still impressive at an annual rate of 10 to 12 percent).

**Figure 3-11: Change in the number of nanotechnology patents between 1991/95 to 1996/00 and 1996/00 to 2001/05, by country (EPO/PCT patents; compound annual growth rate in percent)**

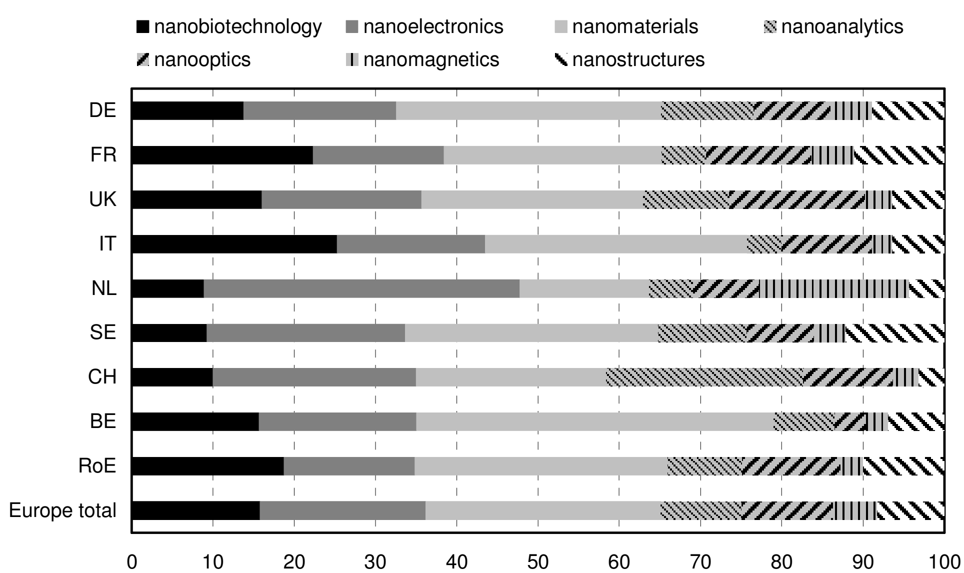



*Eight European countries with the largest number of nanotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The composition of nanotechnology patent applications by subfields markedly differs by country of inventor (see Figure 3-12). Patents from Germany and Belgium show a very high share in nanomaterials. France and Italy are both specialised on nanobiotechnology and the Netherlands on nanoelectronics and nanomagnetics. UK reports a high share in nanooptics while Switzerland is specialised on nanoanalytics and Sweden on nanostructures.

**Figure 3-12: Composition of nanotechnology patents in Europe, by subfield and country (percent)**

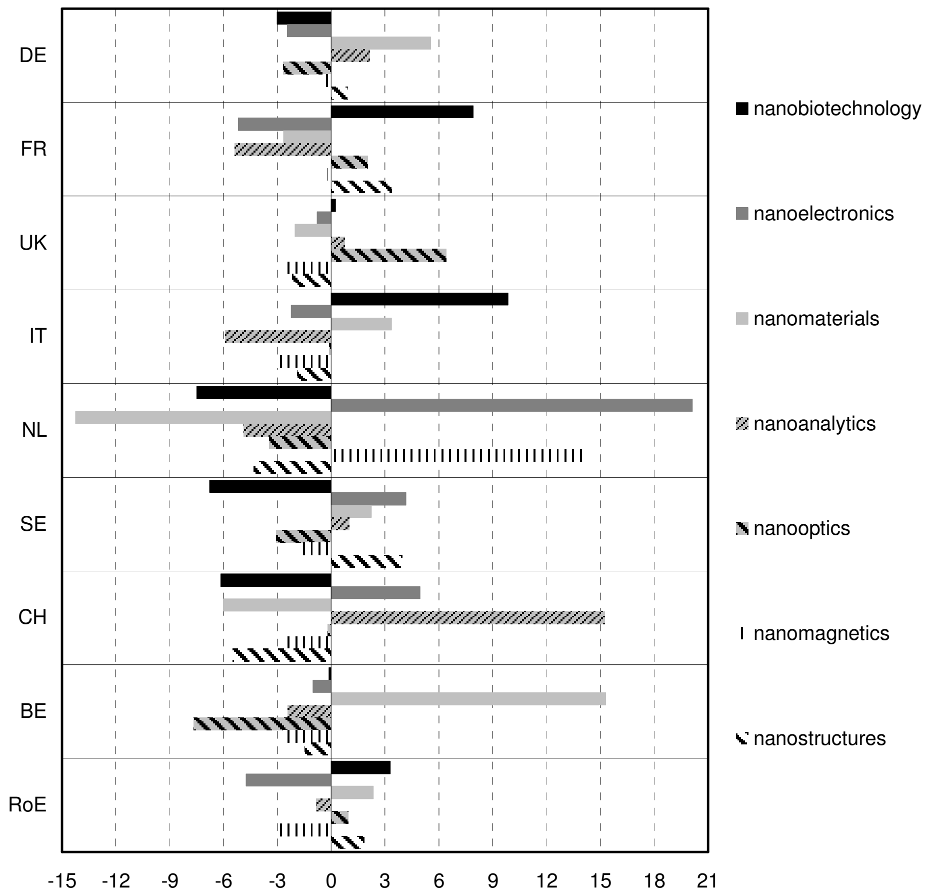



*Eight European countries with the largest number of nanotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Figure 3-13 provides a more detailed picture of country-specific specialisation by subfield within nanotechnology. The specialisation pattern of Germany in nanotechnology patenting does not differ a lot from the one of Europe as a whole, reflecting the high share of patents from Germany for nanotechnology patenting in Europe. Also the group of countries not belonging to the eight largest nanotechnology patent producers in Europe shows a specialisation by subfield that is much alike the one of Europe in total. The other large nanotechnology patent producing countries show rather peculiar specialisation patterns.

**Figure 3-13: Specialisation patterns of nanotechnology patenting in Europe, by subfield and country of inventor (percent)**




*Difference between the share of a subfield in a country's total nanotechnology patents and the respective share for Europe total (excluding the country under consideration).*

*Eight European countries with the largest number of nanotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

European countries show different trends in nanotechnology patenting (Table 3-2). When comparing the growth in the number of patents applied by subfield for the 1990s (i.e. between the number of patents over the 1991-95 and the 1996-2000 periods) and the early 2000s (i.e. between 1996-00 and 2001-05), one can see a strong increase in nanoelectronics and nanostructures in both periods while nanomaterials patenting grew particularly strong in the more recent period. Most countries do follow this pattern, except for Switzerland and Belgium (early growth in nanomaterials, strong increase in nanoelectronics in the 2000s). Patenting in nanoanalytics, nanooptics and nanomagnetics grew at a slower pace in the early 2000s compared to the 1990s except for the Netherlands ajnd Belgium which report a strong growth in nanooptics and nanoanalytics patenting in the 2000s. The Netherlands also increased their output in nanobiotechnology patents in the 2000s considerably. The countries forming the "rest of Europe" show a high growth in nanotechnology patenting in all subfields in the 2000s, indicating a catching-up strategy.

**Table 3-2: Change in the number of nanotechnology patents between 1991/95 to 1996/00 and 1996/00 to 2001/05 by subfield and country(EPO/PCT patents, compound annual growth rate in percent)**

| | DE | | FR | | UK | | IT | | NL | | SE | | CH | | BE | | RoE | | Europe total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Nanobiotechnology | 16 | 9 | 4 | 8 | 3 | 7 | 0 | 23 | -13 | 29 | 3 | -4 | 0 | 15 | -2 | 14 | -2 | 10 | 5 | 10 |
| Nanoelectronics | 27 | 22 | 21 | 19 | 13 | 24 | 45 | 36 | 46 | 18 | 81 | 12 | 19 | 15 | 18 | 46 | 47 | 30 | 27 | 21 |
| Nanomaterials | 8 | 28 | 18 | 25 | 10 | 31 | 7 | 33 | 31 | 37 | 9 | 25 | 49 | 21 | 35 | 27 | 39 | 29 | 15 | 28 |
| Nanoanalytics | 11 | -1 | 17 | 7 | 14 | 11 | 15 | 18 | -3 | 29 | 22 | 10 | 7 | 2 | 11 | 24 | 34 | 28 | 12 | 7 |
| Nanooptics | 12 | 9 | 7 | 0 | 17 | 6 | 35 | 4 | -8 | 32 | 14 | -3 | 27 | -2 | ∞ | 42 | 86 | 20 | 15 | 8 |
| Nanomagnetics | 18 | 8 | 5 | 0 | 21 | -2 | 0 | 25 | 22 | 9 | ∞ | 7 | 25 | -10 | 25 | 11 | -6 | 44 | 16 | 7 |
| Nanostructures | 49 | 34 | 63 | 55 | 23 | 19 | ∞ | 94 | ∞ | 44 | ∞ | 22 | ∞ | 14 | 0 | ∞ | 38 | 40 | 45 | 36 |
| Nanotechnology total | 15 | 18 | 8 | 16 | 10 | 18 | 11 | 27 | 19 | 21 | 19 | 13 | 15 | 11 | 18 | 26 | 18 | 26 | 13 | 18 |

*a: compound annual growth rate of patent applications between 1991/95 to 1996/00*
*b: compound annual growth rate of patent applications between 1996/00 to 2001/05*
*"∞": not available due to zero value in base period.*

*Eight European countries with the largest number of nanotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

### 3.2.2. Links to Sectors and other Fields of Technologies

#### *Technological links to sectors*

When linking nanotechnology patents to industrial sectors based on the IPC classes a patent was assigned to (so-called "technological sector links"), we find a broad sector relevance of nanotechnology. 31 percent of all nanotechnology patents are linked to the electronics industry, 19 percent to the chemical industry, also 19 percent to the manufacture of instruments (optical, medical, measurement, steering instruments) and 9 percent to pharmaceuticals (Table 3-4). Nanotechnology patents are also technologically linked to the metals, machinery and glass/ceramics/concrete industry. Nanotechnology patents from European applicants show stronger links to chemicals and pharmaceuticals while patents from East Asia are much more linked to the electronics industry which is reflecting the higher significance of nanoelectronics in this region.

**Table 3-3: Technological sector affiliation of nanotechnology patents (EPO/PCT), by region (1981-2007 applications, percent)**

| | Europe | North America | East Asia | **Nanotechnology total** |
|---|---|---|---|---|
| Food | 0 | 0 | 0 | **0** |
| Textiles | 0 | 0 | 0 | **0** |
| Wood/Paper | 1 | 0 | 0 | **1** |
| Chemicals | 20 | 17 | 12 | **19** |
| Pharmaceuticals | 12 | 9 | 2 | **9** |
| Rubber/Plastics | 1 | 1 | 1 | **1** |
| Glass/Ceramics/Concrete | 4 | 3 | 3 | **4** |
| Metals | 7 | 6 | 8 | **8** |
| Machinery | 7 | 6 | 5 | **6** |
| Electronics | 28 | 36 | 47 | **31** |
| Instruments | 19 | 21 | 20 | **19** |
| Vehicles | 1 | 1 | 0 | **0** |
| Total | 100 | 100 | 100 | **100** |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

Patents in the field of nanobiotechnology are primarily linked to the pharmaceutical industry as well as to chemicals and instruments (Table 3-4). Nanoelectronics show strong technological links to the electronics industry and important one to the instruments industry. Most nanomaterial patents are related to the chemical industry, but a significant fraction is also linked to electronics, metals, instruments and machinery. Nanodevices are mostly linked to the manufacture of instruments as well as to electronics. Nanooptics are both linked to the electronics and instruments industry while the vast majority of nanomagnetics patents show a link to the electronics industry. Nanostructures relate to the metals industry as well as to chemicals and electronics.

**Table 3-4: Technological sector affiliation of nanotechnology patents (EPO/PCT), by subfield (1981-2007 applications, percent)**

| Sector | Nano-biotech-nology | Nano-electro-nics | Nano-mate-rials | Nano-devices | Nano-optics | Nano-magne-tics | Nano-struc-tures | **Nano-techno-logy total** |
|---|---|---|---|---|---|---|---|---|
| Food | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Textiles | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Wood/Paper | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Chemicals | 19 | 9 | **36** | 12 | 5 | 4 | 20 | 19 |
| Pharmaceuticals | **49** | 3 | 7 | 7 | 1 | 2 | 4 | 9 |
| Rubber/plastics | 0 | 2 | 1 | 0 | 1 | 0 | 2 | 1 |
| Glass/ceramics | 1 | 2 | 7 | 2 | 2 | 2 | 4 | 4 |
| Metals | 3 | 7 | 11 | 5 | 4 | 6 | **32** | 8 |
| Machinery | 4 | 5 | 10 | 5 | 3 | 3 | 8 | 6 |
| Electronics | 7 | **54** | 16 | 26 | **43** | **69** | 20 | 31 |
| Instruments | 14 | 17 | 11 | **41** | 42 | 14 | 10 | 19 |
| Vehicles | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

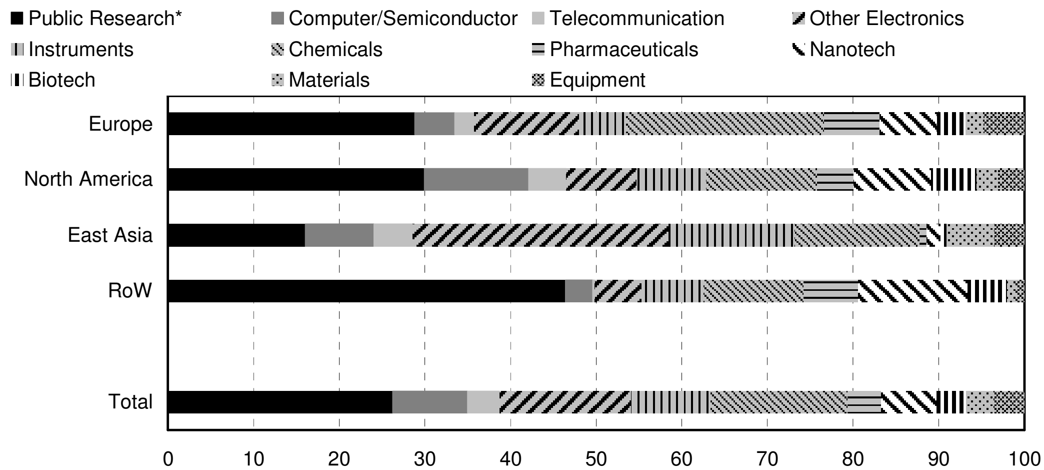
*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

### *Sector affiliation of applicants*

If one looks at the sector affiliation of nanotechnology applicants, i.e. if one assigns industry sectors to nanotechnology patents based on the main market an applicant is present, the picture becomes more disperse.[4] The largest share of applicants from Europe and North America are public research institutions (universities and governmental laboratories, including government agencies). In Europe, the share of applicants from the chemical industry is significantly higher than in North America or East Asia. Applicants from East Asia have a very strong industry focus on electronics (incl. computer, semiconductor and telecommunication) and instruments (optical, medical, measurement). North American applicants comprise to a significant extent young enterprises in the fields of biotechnology and nanotechnology, including a number of research companies.

[4] This analysis is based on the full sample of 18,294 nanotechnology patents (EPO/PCT).

**Figure 3-14: Sector affiliation of nanotechnology patent applicants, by region (EPO/PCT, 1981-2007 applications, percent)**



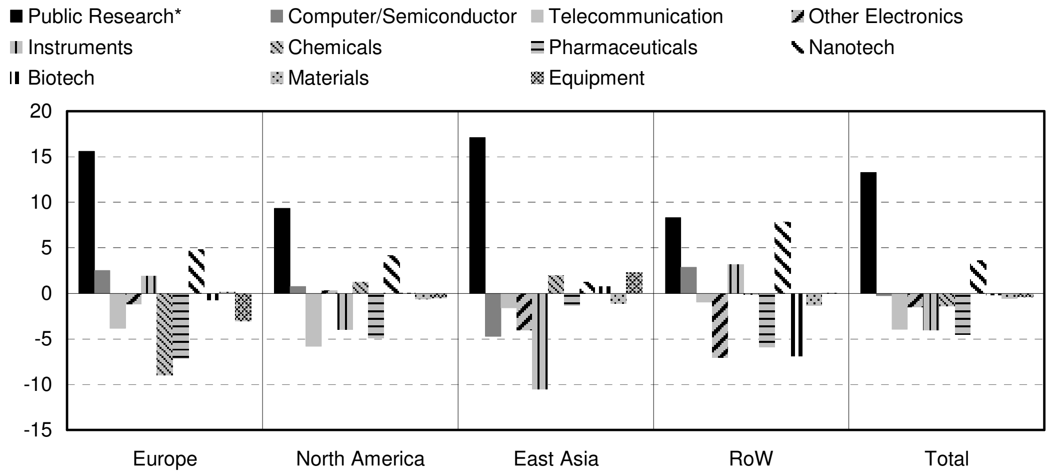

** including patents by government authorities and by private individuals.*

*Source: EPO: Patstat. ZEW calculations.*

Comparing the sector affiliation of nanotechnology patent applications before and after the end of 1999 reveals a strong shift of nanotechnology patenting towards public research. The public research sector was able to increase its share in the total number of nanotechnology patents from 17 to 31 percent. Significantly decreasing shares in total nanotechnology patenting (of around 5 percentage points between the two periods 1981-1999 and 2000-2007) are reported for the electronics industry (particularly telecommunication), the instruments industry and the pharmaceutical industry. While all three regions experienced a gain in relative importance for the research sector, the increase was particularly strong in East Asia (+17 percentage points) and Europe (+16 percentage points), but less in North America. This development implies a converging trend in the significance of public research for nanotechnology patenting in the three regions.

Another trend is the growing importance of young dedicated nanotechnology companies as producers of patents. Their share in total patenting increased from 4 to 8 percent. Both Europe and North America experienced a growing importance of nanotechnology start-ups as a source of new technological knowledge while their importance remained low in East Asia.

**Figure 3-15: Change in the sector affiliation of nanotechnology patent applicants before and after the end of 2001, by region (EPO/PCT, percentage points)**




** including patents by government authorities and by private individuals.*
*Source: EPO: Patstat. ZEW calculations.*

Among the sectors that lost in relative importance, trends are different among the three regions. In Europe, the chemical and pharmaceutical industry experienced a marked decrease in their share in total nanotechnology patenting while electronics and instruments show about the same shares in both periods. In North America, sector shares are more stable. The increase of the public research sector's share by 9 percentage points stands vis-à-vis a small decrease in telecommunication, instruments and pharmaceuticals, while the chemical industry gained in relative importance. In East Asia, the strong gain in importance of public research was opposed by a significant loss in the shares of the electronics and instrument industries.

Public research is the most important applicant sector for most subfields in nanotechnology. 45 percent of all nanostructure patents (EPO/PCT applications, sum of all regions) were filed by public research organisations (Table 3-5). High shares are reported also for nanoanalytics (39 percent), nanomaterials (33 percent) and nanobiotechnology (31 percent). The electronics industry (sum of computer, semiconductor, telecommunication and other electronics) is the largest applicant sector for nanoelectronics, nanooptics and nanomagnetics. The chemical industry is an important source for nanomaterials and nanobiotechnology patents. A substantial share of nanobiotechnology patents originates from the pharmaceutical industry.

Dedicated nanotechnology firms are active in all seven subfields of nanotechnology. Their share in the total number of patents ranges from 3 percent (nanooptics) to 12 percent (nanostructures). Dedicated biotechnology firms are an important producer of nanobiotechnology patents and are relevant for nanomaterials and nanoanalytics.

**Table 3-5: Sector affiliation of applicants of nanotechnology patents, by subfield (EPO/PCT, 1981-2007 applications, percent)**

| | Nano-biotech-nology | Nano-electro-nics | Nano-materials | Nano-analytics | Nano-optics | Nano-magne-tics | Nano-structure |
|---|---|---|---|---|---|---|---|
| Public research | 31 | 25 | 33 | 39 | 25 | 22 | 45 |
| Computer/semiconductor | 1 | 18 | 3 | 8 | 8 | 19 | 6 |
| Telecommunication | 0 | 4 | 2 | 2 | 12 | 3 | 2 |
| Other electronics | 2 | 23 | 9 | 10 | 24 | 30 | 12 |
| Instruments | 4 | 12 | 6 | 21 | 11 | 4 | 4 |
| Chemicals | 24 | 5 | 25 | 5 | 8 | 4 | 13 |
| Pharmaceuticals | 21 | 0 | 1 | 2 | 0 | 0 | 1 |
| Nanotechnology firms* | 7 | 7 | 7 | 6 | 3 | 5 | 12 |
| Biotechnology firms* | 10 | 2 | 5 | 3 | 1 | 1 | 1 |
| Materials | 2 | 1 | 5 | 1 | 2 | 4 | 1 |
| Equipment | 0 | 2 | 4 | 2 | 5 | 6 | 3 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

** Dedicated nanotechnology and biotechnology firms, typically younger firms founded in the 1980s or later.*

*Source: EPO: Patstat. ZEW calculations.*

The list of the 15 largest current nanotechnology applicants by region (in terms of the number of patents applied since 2000) is given in Table 3-6 for information purposes. Applications by subsidiaries are assigned to the parent company. Patents applied by firms that later have been acquired by other companies are assigned to the latter. For patent applications by more than one applicant fractional accounting applies.

The three largest nanotechnology applicants in Europe all come from France, including a government agency and a large public research centre. The largest applicant in North America is a computer company, followed by a university and a diversified materials producer largely based on chemical technologies. In East Asia, the largest applicant is a diversified electronics producer, followed by a producer of optical instruments and a public research agency.

In all three regions, each applicant applied less than 200 nanotechnology patents within the past eight years. Applicants at the bottom end of the top 15 applicants by region applied less than 30 patents within this period.

**Table 3-6: 15 main patent applicants in nanotechnology by region (EPO/PCT, 2000-2007 applications)**

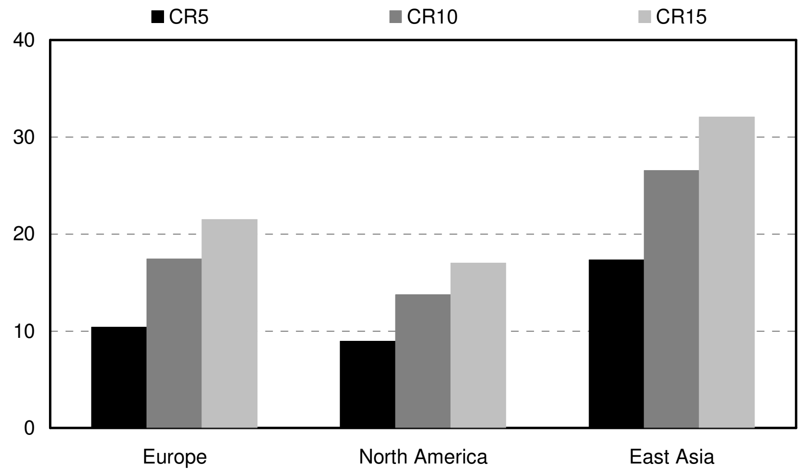
| Europe | | | | | North America | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | Name | Country | Sector | # pat. | Rank | Name | Country | Sector | # pat. |
| 1 | Comm. à l'energie atom. | FR | government | 111 | 1 | Hewlett-Packard | US | computer | 107 |
| 2 | L'Oreal | FR | chemicals | 57 | 2 | Univ. of California | US | research | 90 |
| 3 | CNRS | FR | research | 56 | 3 | 3M | US | chemicals | 80 |
| 4 | Infineon | DE | electronics | 51 | 4 | Agilent Technologies | US | electronics | 77 |
| 5 | Siemens | DE | electronics | 45 | 5 | Du Pont | US | chemicals | 52 |
| 6 | Evonik Degussa | DE | chemicals | 45 | 6 | Molecular Imprints | US | nanotech | 49 |
| 7 | BASF | DE | chemicals | 36 | 7 | MIT | US | research | 45 |
| 8 | Alcatel Lucent | FR | telecommunication | 35 | 8 | General Electric | US | chemicals | 42 |
| 9 | Philips | NL | electronics | 33 | 9 | IBM | US | computer | 37 |
| 10 | Arkema | FR | chemicals | 31 | 10 | Univ. of Illinois | US | research | 33 |
| 11 | Carl Zeiss | DE | instruments | 27 | 11 | Eastman Kodak | US | instruments | 32 |
| 12 | Interuniv. Microelektr. C. | BE | research | 27 | 12 | Motorola | US | telecommunication | 31 |
| 13 | Fraunhofer | DE | research | 26 | 13 | U.S. Government | US | government | 29 |
| 14 | ASML | NL | semiconductor | 24 | 14 | Intel | US | semiconductor | 27 |
| 15 | Sabic Innovative Plastics | NL | chemicals | 23 | 15 | Freescale Semiconductor | US | semiconductor | 27 |

| East Asia | | | | |
|---|---|---|---|---|
| Rank | Name | Country | Sector | # pat. |
| 1 | Samsung | KR | electronics | 169 |
| 2 | Canon | JP | instruments | 81 |
| 3 | JSTA | JP | research | 70 |
| 4 | Hitachi | JP | electronics | 70 |
| 5 | Sony | JP | electronics | 67 |
| 6 | Matsushita Electric | JP | electronics | 66 |
| 7 | NEC | JP | telecommunication | 56 |
| 8 | Fujitsu | JP | computer | 52 |
| 9 | Fujifilm | JP | chemicals | 47 |
| 10 | Seiko | JP | instruments | 40 |
| 11 | Pioneer | JP | electronics | 35 |
| 12 | Toshiba | JP | computer | 32 |
| 13 | Showa Denko | JP | chemicals | 29 |
| 14 | TDK | JP | electronics | 27 |
| 15 | Sumitomo Electric | JP | electronics | 27 |

*Source: EPO: Patstat. ZEW calculations.*

The small number of patents by applicant implies a low level of concentration of nanotechnology patenting. In the reference period 1981-2007, the five largest applicants from Europe have produced just 10 percent of the total number of nanotechnology patents filed by European applicants. In North America, this CR5 concentration ratio is even smaller (9 percent) while it is higher in East Asia (17 percent). Compared to other KETs, concentration ratios in nanotechnology are extremely low. This implies that new technology is spread across many different actors, putting the issue of exchanging technology among nanotechnology producers on the agenda. In addition, policy has to approach a large number of different actors in order to exert significant impact on the industry.

**Figure 3-16: Concentration of applicants in nanotechnology patenting 1981-2007, by region (EPO/PCT patents 1981-2007, percent)**



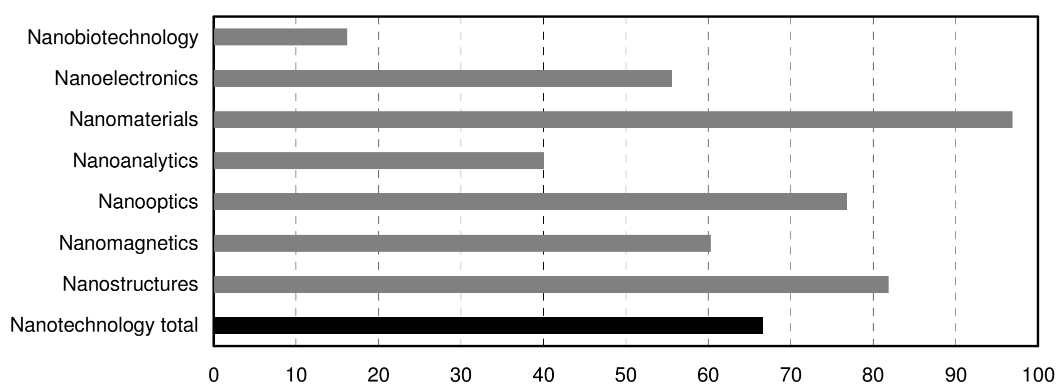

*CR5 is the number of patents applied by the 5 largest patent applicants in the total number of patent applications. CR10 and CR15 are calculated accordingly.*

*Source: EPO: Patstat. ZEW calculations.*

### *Links to other KETs*

Related to the issue of sector links is the degree to which nanotechnology patents are linked to other KETs. One way to assess likely direct technological relations is to determine the share of nanotechnology patents that are also assigned to other KETs (because some IPC classes assigned to a nanotechnology patent are classified under other KETs). The degree of overlap of nanotechnology patents with other KET patents by subfields is shown Figure 3-17. Two out of three nanotechnology patents have been assigned to other KETs, too. The highest share is reported for nanomaterials, followed by nanostructures and nanooptics. Overlaps are lower for nanoanalytics while nanobiotechnology patents are rarely linked to other KETs.

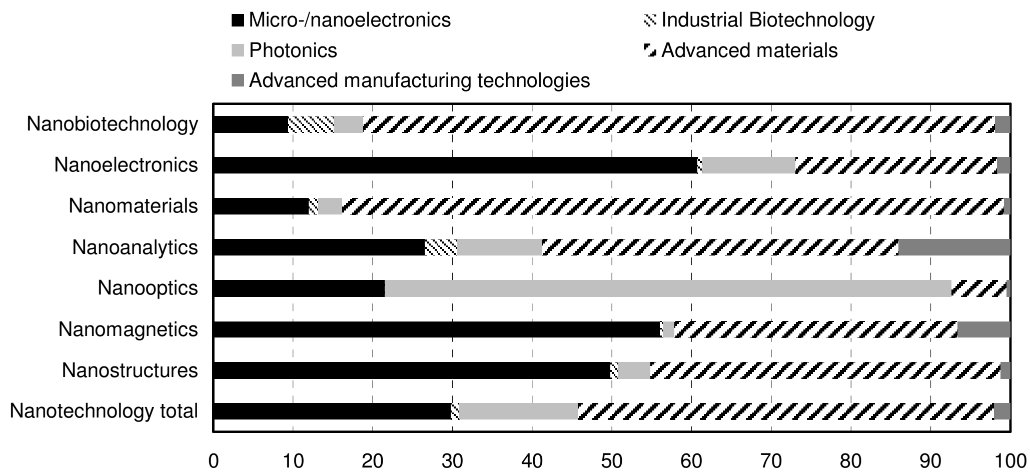
**Figure 3-17: Share of nanotechnology patents linked to other KETs by subfield (EPO/PCT patents 1981-2007, percent)**




*Source: EPO: Patstat. ZEW calculations.*

For those nanotechnology patents that are linked to other KETs, one can see that the largest overlap is with the field of advanced materials (particularly nanomaterials, nanostructures and nanobiotechnology) (Figure 3-18). Nanoelectronics naturally is closely linked to microelectronics, as is nanomagnetics and a significant fraction of nanostructures patents. Nanooptics patents often also fall under the field of photonics. Out of the 40 percent of nanoanalytics patents that overlap with other KETs, most are linked to advanced materials while a smaller part overlap with microelectronics and some relate to advanced manufacturing technologies.

**Figure 3-18: Links of nanotechnology patents to other KETs by subfields (EPO/PCT patents 1981-2007, only patents with links to other KETs, percent)**




*Source: EPO: Patstat. ZEW calculations.*

### 3.2.3. Market Potentials

Nanotechnology is receiving particular interest from policy and businesses because of the huge market that this technology is expected to generate in future. First forecasts of market potentials date back to the early 2000s (Roco and Bainbridge, 2001). In recent years, a number of market forecasts from consultancy companies have provided market figures for different subsectors of the nanotechnology market for different time horizons.

What is common to all these forecasts is the methodological challenge of how to delineate the nanotechnology market. On the one hand, one could restrict this market to nanoscaled raw materials and components (such as nanocoatings, nanotubes, quantum dots, fullerenes, piezoelectric devices). On the other hand, one could consider all end products that are using nanoscale raw materials and components as well as all products produced by using, at least partially, nanotechnology production methods. Moreover, one could also add tools, equipment and devices that are needed for producing nanoscaled products (e.g. microscopes, lithography steppers, PVD and CVD equipment) to the nanotechnology market. Depending on the nanotechnology market definition, market potentials vary significantly.

Following a narrow definition which focuses on the market for nanomaterials, the global market volume in 2007 was assessed to about $1.1 billion (see BCC, 2007; see also Freedonia, 2007) and is expected to grow to about $3 billion in 2012. This estimate was made prior to the current economic crises and is likely to overrate the actual development since 2007. These estimates show that nanomaterials still play a minor role in the global market for materials, and the market is growing at a rather moderate rate.

Applying a very broad definition of the nanotechnology market, some industry analysts came up with huge current market volumes of up to $150 billion in 2008 (see LuxResearch, 2006) and exponentially increasing market potentials in the near future. The most optimistic forecasts suggest a market potential for 2015 of $1 trillion (NSF, 2001) up to $3.1 trillion (LuxResearch, 2006, 2009). The latter figure would equal to 5 percent of the projected global GDP in that year, and to 15 percent of the global manufacturing output in 2015. This would imply that a significant part of manufactured goods will be based -at least partially on nanoscaled products or by applying nanotechnology techniques or devices in the production process.

Comparing different market forecasts for nanotechnology shows a wide variety of estimated current market sizes (Table 3-7) which reflects the absence of a commonly accepted definition of nanotechnology markets. A common feature of all forecasts is that they expect a strong increase in market size for nanotechnology products. The most conservative forecasts for specific product groups based on nanotechnology applications (radiation-cured coatings, lithium ion batteries) estimate an average annual growth rate (at current prices) of about 5 percent, which is still above the average growth rate for global total manufacturing. The most optimistic forecasts assume an expansion of nanotechnology markets at annual rates of up to 50 percent. Forecasts that that relate to the total nanotechnology market tend assume higher growth rates (34 percent in average) compared to forecasts for specific subfields and market segments (20 percent in average). This may mirror the general enthusiasm for the prospects of nanotechnology, while a more detailed look at production opportunities and market demands for certain applications leads to less euphoric, and presumably more realistic assessments of market potentials. Projections made in the early 2000s for the year 2010 (see Evolution Capital, 2001; MRI, 2002) have proved to overestimate the actual development considerably.

**Table 3-7: Estimates and forecasts for the size of the global nanotechnology market (billion US-$)**

| Subfield | Source[1)] | 2005/06 | 2007/08 | 2010/11 | 2012/13 | ~2015 | ~2020 | CAGR* |
|---|---|---|---|---|---|---|---|---|
| **Nanomaterials** | | | | | | | | |
| Total | BBC (2007) | | 1.1 | | 3.1 | | | 23 |
| Total | Freedonia (2007) | 1.0 | | 4.0 | | | | 32 |
| Sol-gel based mat. | BBC (2006) | 1.0 | | 1.4 | | | | 7 |
| Carbon nanotubes | Electronics et al. (2007) | 0.37 | | 5.6 | | | | 72 |
| Biomarkers | BBC (2007) | | 5.6 | | 12.8 | | | 18 |
| Rad.-cured coatings | Chemark (2007) | | 1.4 | | 1.8 | | | 5 |
| **Nanoelectronics** | | | | | | | | |
| Total | BBC (2007) | | 20.1 | | 33.6 | | | 11 |
| Lithography steppers | Frost (2007) | 7.8 | | 10.0 | | | | 6 |
| Piezoel. actuators | Innoresearch (2007) | | 10.6 | | 19.5 | | | 13 |
| Organic electronics | IDTechEX (2008) | | 1.2 | | | 48.2 | | 45 |
| Solar energy applic. | Solarbuzz (2008) | | 17.2 | 30.0 | | | | 20 |
| Lithium ion batteries | BCC (2007) | 4.6 | | | 6.3 | | | 5 |
| **Nanooptics** | | | | | | | | |
| Total | BBC (2007) | | 4.9 | | 7.9 | | | 10 |
| Microscopy | Frost (2007) | 1.9 | | | 3.5 | | | 9 |
| LED | BCC (2006) | 3.8 | | 6.8 | | | | 30 |
| OLED | LEDs Magazine (2005) | 0.6 | | 2.9 | | | | 30 |
| **Nanobiotechnology** | | | | | | | | |
| Nanomedicine | Ernst & Young (2007) | 6.0 | | | | | 70.0 | 18 |
| Nanomedicine | Freedonia (2007) | 18.0 | | 39.0 | | | | 17 |
| Nanodiagnostics | Ernst & Young (2007) | 1.9 | | | | | 6.0 | 8 |
| Nanodiagnostics | Freedonia (2007) | 3.1 | | 8.4 | | | | 22 |
| **Total market** | | | | | | | | |
| | NSF (2001) | 54 | | | | 1,000 | | 34 |
| | Evolution Cap. (2001) | 105 | | 700 | | | | 46 |
| | MRI (2002) | 66 | | | 148 | | | 18 |
| | BCC (2008) | | 12 | | 27 | | | 16 |
| | Cientifica (2008) | | 167 | | | 1,500 | | 37 |
| | LuxResearch (2006) | | 147 | | | 3,100 | | 46 |

*1) For references on the sources, see Palmberg et al. (2009) and Luther and Bachmann (2009).*

** Compound annual growth rate in nominal terms (percent).*

*Source: Palmberg et al. (2009: 22), Luther and Bachmann (2009: 10f).*

LuxResearch (2009) estimates the United States to be the largest market for nanotechnology with a current market share of 40 percent, followed by Europe (31 percent). Both regions are expected to amount to 35 percent of the worldwide market in 2015, closely followed by Asia.

## 3.3 Success Factors, Barriers and Challenges: Cluster Analysis

Nanotechnology has the potential to impact and shape many other industries through its multiple application possibilities. Advanced and novel materials can greatly benefit from the integration of biotechnology and nanotechnology, e.g. for coating/surface engineering.

Furthermore, electronic and optic equipment, healthcare and life science, energy and environment, communication and computing, scientific tools and industrial manufacturing will be largely affected by this emerging technology (Miyazaki and Islam, 2007).

However, commercialising nanotechnology research efforts is proving difficult in Europe. Private R&D investments amounts to only $1.7 billion in Europe compared to $2.7 billion in the US and $2.8 billion in Asia (LuxResearch, 2009). Moreover, EU nanotechnology patenting lags well behind the US where most of the significant developments in the creation and activity of nanotechnology companies and related jobs can be observed. Despite the potential interest from key EU industries such as aeronautics and space or automotive, a lack of engineering expertise seems to have held back adoption (BMBF, 2006). The EU market is fragmented, resulting in a lack of critical mass that reduces the effectiveness of the commercialisation of nanotechnology. Considering the state of technology maturity, issues related to environmental, health and safety (EHS) concerns, standardisation and public opinion needs to be addressed to ensure market acceptance and the deployment of nanotechnology.[5]

In Europe, over 240 research centres and 800 companies dedicated to the R&D of nanotechnology have been identified (Conseil Economique et Social, 2008; AFSSET, 2008). The most successful nanotechnology clusters (according to their international patenting activity) are located in the United States, Germany and Japan. Examples are Albany, Boston, Houston (US)[6], Northrhine Westphalia, Berlin, Munich (Germany)[7], Kyoto, Aichi, and Nagano (Japan)[8].

The two chosen cases for nanotechnology are Northrhine Westphalia and Kyoto. One reason for this choice is that, besides the United States, Germany and Japan are the strongest international players in this technology in terms of patenting and commercial activities. Furthermore, the distribution of nanotechnology research in Germany and Japan is different among actors (see Figure 3-19). Public research institutions play a much bigger role in Germany, while the industry in Japan contributes more to nanotechnology research.

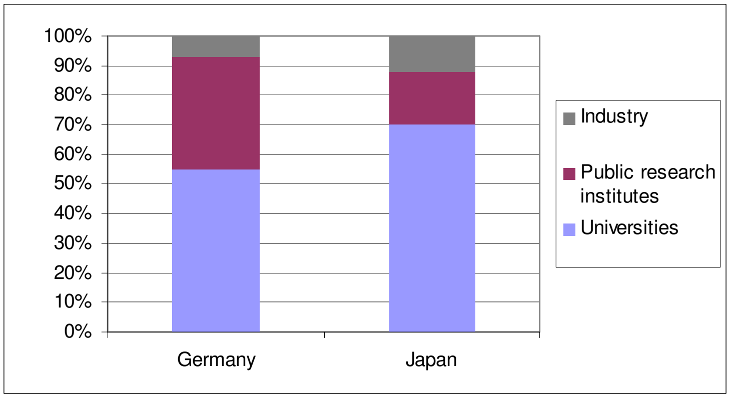
[5] The European Commission adopted in February 2008 the Code of Conduct for Responsible Nanosciences and Nanotechnologies Research.

[6] http://www.areadevelopment.com/HighTechNanoElectronics/oct08/nano-tech-centers-clusters.shtml

[7] http://www.nano-map.de

[8] http://www.japan-cluster.net/index.php?id=480

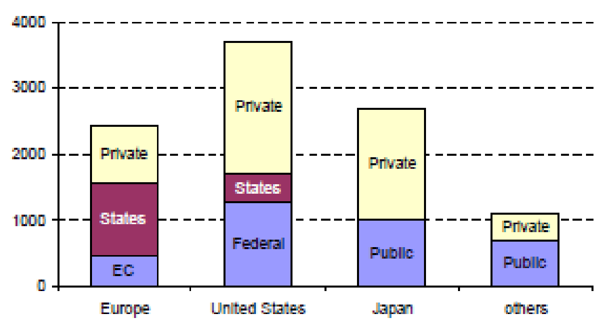
**Figure 3-19: Shares of nanotechnology research in Germany and Japan by actors (2004)**




*Source: modified from Miyazaki and Islam (2007).*

In addition to this, the composition of public and private funding is also different. Nanotechnology research in Germany is highly dependent on public funding from the EU and the state, while R&D in Japan is to 2/3 financed through venture capital (see Figure 3-20). Finally, these cases build a nice contrast between Germany's (and Europe's) academic and government-dominated research and Japan's commercial orientation (Miyazaki and Islam, 2007).

**Figure 3-20: Estimated public and private funding for nanotechnology R&D in 2005 by world regions (million €)**



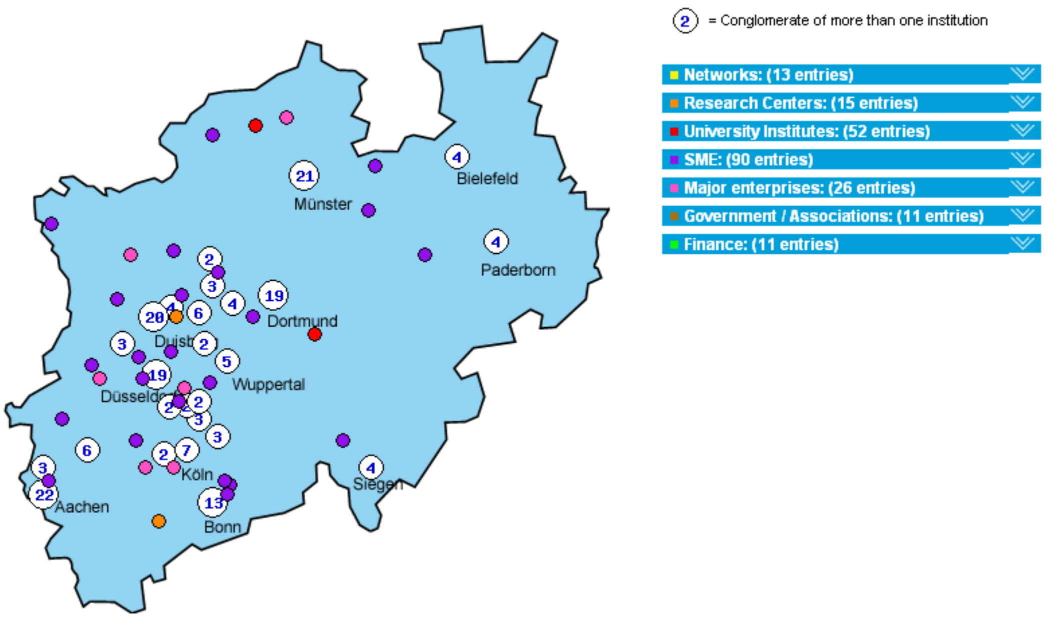

*Source: http://hesa.etui-rehs.org/uk/dossiers/files/Nano-economics.pdf*

### 3.3.1. Nanotechnology cluster Europe: Northrhine Westphalia (Germany)

Northrhine Westphalia (NRW) has a long economic history with significant structural changes. Until 1960, NRW (and the Ruhr area) was one of the main economic centres in the coal and mining industry in Europe and the motor of reconstruction after World War II. The coal crisis (1960s) and the oil crisis (1970s) made it necessary to refocus on education and traffic to overcome the structural crisis and to make economic adjustments to stimulate growth in new technologies, such as biotech, ICT, and nanotechnology.[9]

Today, Northrhine Westphalia has several years of experience in developing interdisciplinary research programmes in the field of nanotechnology. The nanotechnology research in NRW was so broad and covered so many different scientific fields that it was necessary to create an actually network of three clusters. One cluster is located in Aachen and focuses on the combination of nanotechnology and information technology. The second cluster in Muenster concentrates on the interface between nanotechnology and biotechnology. The field of nanobiotechnology has a large potential to be applied in many different industries. This opportunity is reflected in the high number of involved universities/research centres and interdisciplinary projects (more than 100). The third cluster in Duisburg/Essen conducts R&D in nanotechnology linked with energy systems.[10]

**Figure 3-21: Network of nanotechnology clusters in Northrhine-Westphalia**




All together, the NRW nanotechnology cluster network encompasses 30 university institutes, four research centres, six networks, 16 SMEs and six major enterprises. Main corporate players in this area include Philips GmbH, ThyssenKrupp Stainless AG and BASF coatings AG.

[9] http://www.icn-project.org/fileadmin/ressourcen/Dokumente/3_RIS/Regional_Profiles/NRW.pdf
[10] http://www.nanobio-nrw.de/index.php?Script=1&Lang=de&SW=1024

***Short history of the cluster***

The NRW nanotechnology cluster started in 2003 by implementing the first research cluster in Aachen for ‘nanotechnology for information technology’. In 2004, the other two pillars of the cluster network were founded in Muenster (nanobiotechnology) and Duisburg/Essen (nanotechnology for power engineering). Each cluster is linked to universities and research institutions in the surrounding area.[11] Over time, the ties between the three excellence centres grew stronger, resulting in regional research collaborations. In addition to this, also links to other German nanotechnology organisation were established and the clusters became members of national and international nanotechnology networks.

***System failures and system drivers for growth***

*Infrastructure*

Each cluster is embedded in a strong infrastructure of universities and research centres, which builds the scientific foundation for downstream nanotechnology activities. A few large multinational enterprises act as anchor companies to stimulate economic growth, while network organisations are in place to nurture academia-industry collaborations.

**Table 3-8: Overview of nanotechnology institutions in the NRW nanotechnology cluster network**

| | Networks | Research centres | University institutes | SMEs | Large enterprises | Finance |
|---|---|---|---|---|---|---|
| Aachen | 1 | 3 | 10 | 6 | 2 | 0 |
| Muenster | 3 | 1 | 7 | 8 | 1 | 1 |
| Duisburg/Essen | 2 | 0 | 13 | 2 | 3 | 0 |

*Source: http://www.innovations-report.de/html/berichte/informationstechnologie/bericht-32232.html*

*Rules and regulations*: The federal government increasingly supports nanotechnology projects, which aim on the standardisation of nanotechnology manufacturing processes and characteristic values of nanotechnology products. Standardisation procedures in nanotechnology became highly important in the diffusion process of the technology, because international competitiveness is largely determined by the ability to compare between product characteristics. The Ministry for Education and Research also has strong patent laws in place to ensure that utilisation opportunities are realised.[12]

*Norms and values:* Because of the very nature of nanotechnology and its environmental, health and safety concerns, cluster network organisation have to establish a certain work ethic to address these issues. Furthermore, external communication and public relation of these

[11] http://www.innovations-report.de/html/berichte/informationstechnologie/bericht-32232.html
[12] http://www.bmbf.de/pub/nanotechnology_conquers_markets.pdf

organisations have to be clear to ensure market acceptance and the deployment of nanotechnology.

*Public policy and funding*: The German Federal Ministry for Education and Research supports the development of nanotechnology competence centres by installing sufficient supporting infrastructure.[13] AgeNT-D (Arbeitsgemeinschaft der Nanotechnologie-Kompetenzzentren in Deutschland) is a consortium of all nine German nanotechnology clusters with the goal of increasing operational efficiency by setting R&D and commercial priorities.[14] In addition to this, several federal ministries agreed to harmonise funding procedures. The goal is to synchronise different funding policies to increase the transparency for universities and nanotechnology firms which seek for funding opportunities on a federal level.[15] A consortium of seven federal ministries developed a 'Nano-Initiative – Action Plan 2010', aiming on the acceleration of dissemination of nanotechnology R&D result into marketable products, recognizing socioeconomic implications and removing obstacles to innovation, supporting spin-offs and start-ups, and mobilising public funding and private venture capital.[16]

Regarding R&D investment from the government, Germany is the number one concerning public funding of nanotechnology in Europe, followed by France and the United Kingdom.[17] From 1998 to 2004, the volume of funded joint projects in nanotechnology quadrupled to about 120 million Euro.[18] Concerning the NRW nanotechnology cluster, it received over €9 million of direct public funding from the German government for nanotechnology and nano-related research in the period 2003-2008. In the same time period, the cluster attracted approximately €40 million of funding from the Sixth Framework Programme from the European Commission.[19]

*Venture capital:* Venture capital is not easily available in Germany for nanotechnology research and development. In Germany, only one third of the total research funding stems from private sources, compared to 54 percent in the US and almost two thirds in Japan. Therefore, research is highly dependent on public funding.

[13] http://www.bmbf.de/en/nanotechnologie.php

[14] http://www.gtai.com/homepage/info-service/publications/our-publications/germany-investment-magazine/vol-2008/vol-032008/cover-story1/size-isn-t everything3/?backlink=Back percent20to percent20Cover percent20Story

[15] http://www.bmbf.de/pub/nano_initiative_action_plan_2010.pdf

[16] http://www.bmbf.de/pub/nano_initiative_action_plan_2010.pdf

[17] http://hesa.etui-rehs.org/uk/dossiers/files/Nano-economics.pdf

[18] http://www.nanoforum.org/dateien/temp/European percent20Nanotechnology percent20Infrastructures percent20and percent20Networks percent20July percent202005.pdf?05082005163735

[19] http://www.innovations-report.de/html/berichte/informationstechnologie/bericht-32232.html

*Interactions*

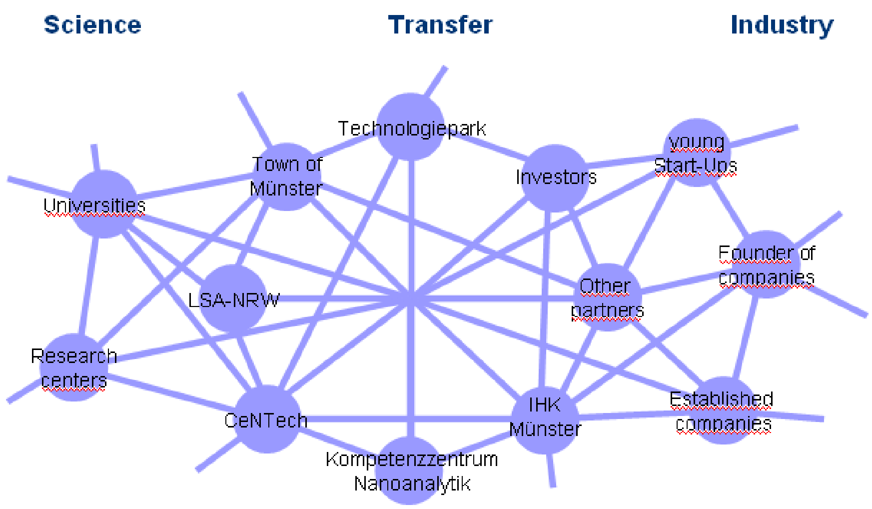
Each cluster in the network is coordinated through a separate organisation (Aachen: AMO, Muenster: CeNTech, Duisburg/Essen: CeNIDE). These organisations foster knowledge transfer, stimulate the formation of start-ups and the expansion of established nanotechnology companies with the aim to improve the utilisation of academic nanotechnology research. An example is the NETZ (NanoEnergieTechnikZentrum), which is an application-oriented research project with the aim to develop materials and processes to support the commercialisation and mass production of nanotechnologies for the industry.[20] Furthermore, they participate in other national and international networks and platforms to nurture interdisciplinary exchange.[21]

On top of this, the regional cluster organisation 'NanoMicro+InnovativeMaterials.NRW' represents and supports universities and firms in their research and development activities. Its goal is to create a competitive and dynamic R&D environment and to boost the knowledge-intensive industry on a national and international level. The cluster organisation nurtures the integration and networking of all actors to create synergy effects between research institutions and companies. The focus is to intensify the dialogue and cooperation between universities and industry, to identify markets and technological priorities, and to develop new marketing strategies and instruments.[22]

The NRW nanotechnology cluster is organised in a network structure, with strong ties between the three centres of excellence. In more detail, there is strong knowledge transfer and experience sharing among the centres to stimulate innovations on a scientific level. Furthermore, there are also joint efforts to create links to the commercial nanotechnology industry. This dynamic network is also important regarding the competitiveness for public funding on a European level, since it requires more and more to have a sophisticated and well developed research infrastructure system in place.[23]

**Figure 3-22: Knowledge transfer in the NRW nanotechnology cluster (example Muenster)**

[20] http://www.uni-due.de/cenide/netz.shtml
[21] http://www.centech.de/index.php?Script=1&Lang=en&SW=1024
[22] http://www.nmw.nrw.de/index.php?__lang=en&catalog=/cluster
[23] http://www.innovations-report.de/html/berichte/informationstechnologie/bericht-32232.html




*Source: http://www.mondiac.nl/presentations/Weltring.ppt*

*Capabilities:*

The NRW nanotechnology cluster network excels in their basic research activities. Universities and research institutions building an elaborate research landscape with regional and national networks, focusing on knowledge creation and generation. This is reflected in the large number of patents the cluster is issuing. Through this state-of-the-art research, they can compete with other excellence centres around the world.

***Market failures and drivers for growth***

*Market structure:*

In general, the European market for nanotechnology is fragmented, resulting in a lack of critical mass. This makes the commercialisation of nanotechnology less effective compared to markets in the US, which are more unified and less fragmented.

All of the three clusters in the network are dominated by the scientific research of universities and the high number of university institutions. There are a few large nanotechnology enterprises, such as Philips and BASF, which are located within the cluster network to stimulate economic growth. This market structure of a scientific base with MNEs acting as anchor companies offers start-ups a good opportunity to settle down on the interface between them in an intermediary role. But the lack of business angels and venture capital makes it difficult to create academic spin-offs to commercialise scientific results.

*Market demand:*

The nanotechnology cluster network in NRW consists of three geographically separated clusters, each with a different focus of nanotechnology (nanotech-IT, nanotech-biotech, nanotech-energy). This research specialisation makes it easier to get the major enterprises as lead customers or to establish more applied research collaborations.

***Conclusion***

Although the cluster network in NRW is relatively young, efforts in nanotechnology R&D have been made for years by individual university institutions and nanotechnology companies. In total, there are 30 university institutes, four research centres, 16 SMEs, and six large enterprises present. In addition to this, six different networks and one venture capital firm accompany cluster activities. The cluster is highly research-oriented with an excellence knowledge base, but it misses the market focus. It develops relatively little of the research results into marketable products and processes.

*System and market failures and drivers*

What this cluster lacks is a higher utilisation of knowledge for practical applications. Next to information deficits of companies, which do not see the potential of nanotechnology, there are also obstacles for building start-ups, which is due to insufficient risk capital and bureaucratic overload. This lack of private funding gives Germany a large disadvantage in the global market.[24]

Public funding: The public funding system is built on two pillars; the national government sponsors R&D project through its federal ministry of education and research, and on an European level, the European Commission funds nanotechnology research through its Seventh Framework Programme from the European Commission. This funding system proved to be successful in the past regarding excellence in basic and explorative research activities. In contrast to this, public funding related to the creation of nanotechnology start-ups is still not sufficient (although growing).

Tax incentives & Public procurement and lead markets: On the topic of tax incentives and public procurement we have not found specific information for this cluster.

### 3.3.2. Technology cluster Non-Europe: Kyoto (Japan)

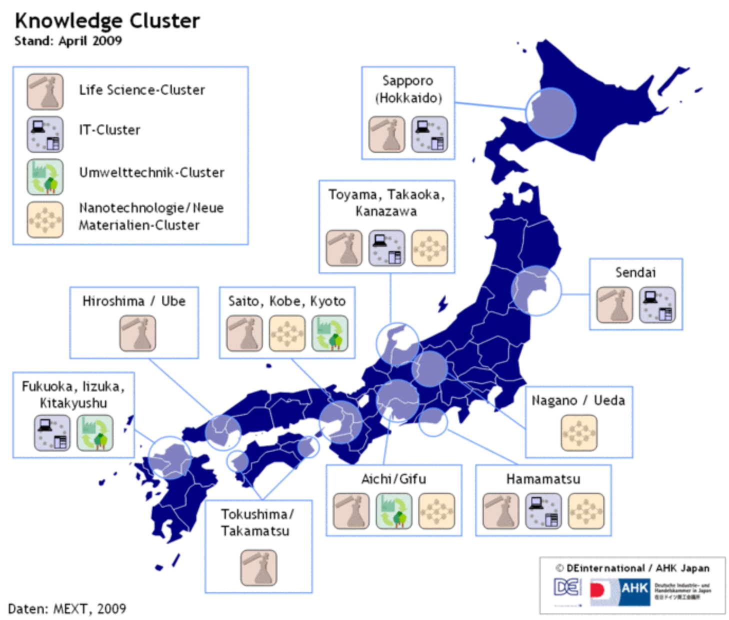
Kyoto has determined that nanotechnology is one of the fundamental technology for the future development of its region. The Kyoto nanotechnology cluster combines nano-related research and engineering with market-oriented nanotechnology products, systems and services. Their main research focus covers nano sciences, new nano materials, nano devices,

[24] http://hesa.etui-rehs.org/uk/dossiers/files/Nano-economics.pdf

and nano biochemicals.[25] The cluster established partnerships with local nanotechnology firms to create new businesses, also in other industries such as electronic devices, medical and biotechnology, textiles, mechatronics, and information technologies. The core of the cluster consists of the Kyoto University Katsura Campus and the Katsura Innovation Park, which promote and create several university-industry research activities.[26]

The Kyoto nanotechnology cluster is further embedded in a system of many other clusters, which also conduct R&D in nanotechnology or material science (see Figure 3-23).

**Figure 3-23: Knowledge clusters in Japan**




*Source: http://www.japan-cluster.net/index.php?id=480*

### *Short history of the cluster*

The development of the Kyoto nanotechnology cluster was policy-driven. It started in 2002 with the knowledge cluster initiative from MEXT (Japan's Ministry of education, culture, sports, science and technology) to support universities and research institutions in their research and innovation efforts.[27] More recently (in 2008), the Kyoto Environmental Nanotechnology Cluster was created to solve environmental problems through the application of advanced nanotechnology.

[25] http://www.mext.go.jp/a_menu/kagaku/chiiki/cluster/h16_pamphlet_e/13.pdf
[26] http://www.jetro.go.jp/en/invest/region/kyoto/
[27] http://www.clusterplast.eu/fileadmin/user/pdf/dissemination_event/BENCHMARKING.pdf

***System failures and system drivers for growth***

*Infrastructure*

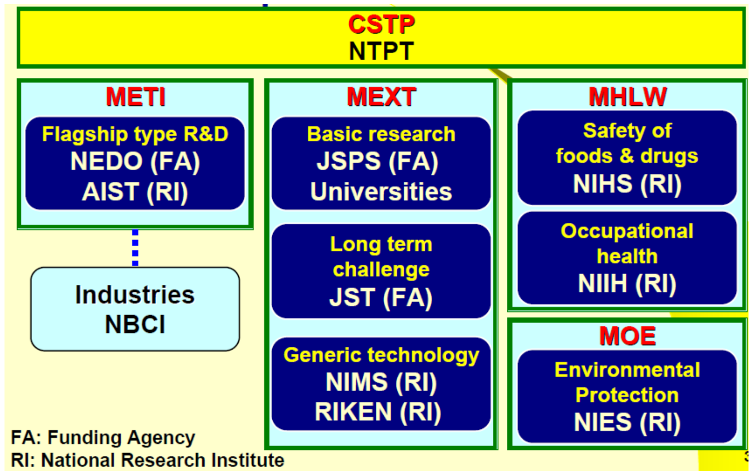
As stated in the previous chapter, the cluster consists of the Kyoto University Katsura Campus and the Katsura Innovation Park which promote and create several university-industry research activities and provide space for nine universities, three research institutions and 43 industrial and venture companies. The core organisation of the cluster is ASTEMRI (Advanced Software Technology & Mechatronics Research Institute of Kyoto). Next to the academic knowledge institutes, such as the Kyoto University, the Kyoto Institute of Technology, and the Ritsumeikan University there are many industrial players present, e.g. Murata Manufacturing, Shimadzu Corporation, Kyocera Corporation, Omron Corporation, etc. Furthermore, the government is also represented in the cluster with the Kyoto Municipal Industrial Research Institute.[28]

*Norms and values:* The cluster initiated several programmes to support cluster development. Examples are the 'KYO-NANO outreach', which facilitates the exchange of researchers between academia and firms by matching each others interests. Another example is 'KYO-NANO society', where joint seminars for industries and universities are organised.

*Public policy and funding:* Nanotechnology in Japan receives major attention from the government. Public policies support the development of this emerging technology through the 'Japanese Strategic Technology Roadmap' (2005) and the 'Third Science and Technology Basic Plan' (2006-2011). It is stated there that nanotechnology is one of the top priorities in Japan's National Growth Strategy. In 2002, the 'National Nanotechnology Research Network Center' was put in place, in order to coordinate the large number of initiatives within and between universities, national labs, and regions.[29] MEXT (education, culture, sports, science and technology) and METI (economy, trade and industry) are the main funding ministries, and JSPS (Japan Society for the Promotion of Science), JST (Japan Science and Technology Agency), NIMS (National Institute for Materials Science), RIKEN (Institute of Physical and Chemical Research), NEDO (New Energy and Industrial Technology Development Organisation) and AIST (National Institute of Advanced Industrial Science and Technology) are their organisations to promote the research programmes.

**Figure 3-24: Institutes for nanotechnology research, development and assessment**

[28] http://www.mext.go.jp/a_menu/kagaku/chiiki/cluster/h16_pamphlet_e/13.pdf
[29] http://www.czech-in.org/enf2009/ppt/E4_Johnson_Y.pdf




*Source: http://utsusemi.nims.go.jp/english/info/policy/20060602_1.pdf*

MEXT (Japan's Ministry of education, culture, sports, science and technology) implemented several measures to promote basic nanotechnology research and the development of practical nanotechnology application, including building a cooperative research system between industry-academia-government, conducting R&D in universities and independent institutions, and providing cross-sectional support.[30] Two MEXT actions are worth mentioning regarding technological cluster development: The 'knowledge cluster initiative' and the 'cooperation for innovative technology and advanced research in evolutional area' programme act as network interface between industry, university and government.

METI (Japan's Ministry of economy, trade and industry) accompanies cluster development in two ways. There are divisions in place to support self-sustaining development of regional (cluster) economies (regional technology division, business environment promotion division), and there are divisions to nurture technological development (research and development division, academia-industry cooperation promotion division).[31]

On a local level, the Kyoto municipality is in charge of the cluster organisation and development and promotes collaborative research activities between academia and industry.[32]

The government also supports nanotechnology through public funding ($900 million in 2004).[33] Public funding originates mainly from MEXT through three programmes; 'Special coordination funds for promoting Science and Technology', 'Grant-in aid for scientific research', and 'the 21st century center-of-excellence programme'.[34]

[30] http://www.mext.go.jp/english/org/struct/029.htm
[31] http://www.meti.go.jp/english/aboutmeti/data/aOrganizatione/pdf/chart2009.pdf
[32] http://www.kansai.meti.go.jp/english/politics/kyoto-municipal.pdf
[33] http://www.czech-in.org/enf2009/ppt/E4_Johnson_Y.pdf
[34] https://utsusemi.nims.go.jp/english/info/nanoproject.html?org=2080

**Table 3-9: Government funding categorised as nanotechnology & materials (billion Yen)**

| | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|
| MEXT | 65 | 72 | 75 | 78 | 81 |
| Others | 20 | 19 | 19 | 16 | 16 |
| Total | 85 | 91 | 94 | 94 | 97 |

*Source: http://utsusemi.nims.go.jp/english/info/policy/20060602_1.pdf*

On a local level, the Kyoto municipality actively fosters the development of the nanotechnology cluster by providing funds for locating or relocating firms and R&D laboratories within the Katsura Innovation Park, which is the core of the nanotechnology cluster. In addition to this, it stimulates university-industry collaborations by implementing business incubators and university-industry liaison facilities.[35]

*Venture capital:* In Japan, R&D in nanotechnology is also largely supported by private funding. Venture capital funding accounted for $2.8 billion in 2004. Overall, Japan has an advantage over Europe and US regarding private funding. Almost two thirds of the total funding originates from private sources. This is an indication for their strong market orientation.[36] Venture capital was not always available in the past. In the early 2000s, the Japanese government started to create programmes and incentives for firms to invest in nanotechnology start-ups, because there was a lack of entrepreneurship. Furthermore, large corporations got involved in several nanotechnologies, stimulating the mass to follow this direction. Finally, the growth of venture capital in the US also influenced the development of VC investment in Japan.[37]

*Interactions*

Scientists are supported by capital intensive equipment through spin-in operations, which allows them to share high-tech equipment in the Nano-Fabrication Center. Furthermore, research and development collaborations with the private sector are in place. The Kyoto Industry-Academia-Government Cooperative Organisation is a partnership platform of local universities, research institutions, economic organisation, industrial support groups and the local government in 2003, promoting the technology transfer and commercialisation of knowledge and creating spin-off venture business.[38] In addition to this, there are many informal links to other high-tech clusters, public sector programmes, and private sector programmes.[39]

[35] http://www.kansai.meti.go.jp/english/politics/kyoto-municipal.pdf
[36] http://hesa.etui-rehs.org/uk/dossiers/files/Nano-economics.pdf
[37] http://unit.aist.go.jp/nanotech/apnw/articles/library3/pdf/3-34.pdf
[38] http://www.jetro.go.jp/en/invest/region/kyoto
[39] http://www.mext.go.jp/a_menu/kagaku/chiiki/cluster/h16_pamphlet_e/13.pdf

*Capabilities*

The cluster combines scientific excellence with market orientation. The strong academic base generates knowledge, while the Innovation Park acts as an industrial incubator to stimulate business creation within the cluster and thus achieves a smooth transition to market.

***Market failures and drivers for growth***

Because large amounts of venture capital are available, new nanotechnology start-ups can easily be established. In this way, entrepreneurs do not face the obstacle of finding sufficient financial resources, but can apply their academic research results quickly to market needs.

The large share of private funding in Japan for nanotechnology is an indicator for the strong market demand, since these funds aim on supporting academic spin-offs and nanotechnology start-ups, which contributes to the economic success of the cluster by transforming research results into practical applications.[40] Furthermore, the Kyoto Environmental Nanotechnology Cluster has specific research topics involving 'conserving water environment', 'biodiesel through green sustainable methods' and 'pyroelectric infrared sensors'.[41] This focus on special (niche) markets and customers also shows the cluster's strong market orientation.

***Conclusion***

The Kyoto nanotech cluster is a relatively young cluster, with a development that was highly policy-driven. The government initiated the cluster and supported its further development through several public programmes. There are also certain public divisions within the ministries of technology and economy that combine technological development with regional (cluster) development. This synergy could be seen as one of the success factors of this cluster. In addition to this, the government nurtured the market orientation of the cluster by given financial incentives to private nanotech firms to locate within the cluster and by attracting venture capital to support academic spin-offs and nanotech start-ups. The combination of strong government support with large private funding is the second success factor of the Kyoto nanotech cluster.

[40] http://hesa.etui-rehs.org/uk/dossiers/files/Nano-economics.pdf
[41] http://eco-pro.biz/ecopro2009/events/E1000.php?tp=1&id=10760

*System and market failures and drivers*

Overall, Japan has an advantage over Europe and US regarding private funding. Almost two thirds of the total funding originates from private sources. This is an indication for their strong market orientation.[42]

*Public funding*

Nanotechnology in Japan receives major attention from the government. MEXT (Japan's Ministry of education, culture, sports, science and technology) and METI Japan's Ministry of economy, trade and industry) are the main funding ministries, which initiated several governmental organisations to promote research programmes. On the municipality level, Kyoto nurtures the development of the nanotech cluster by providing financial incentives for locating or relocating firms and R&D laboratories within the nanotech cluster.

### 3.3.3. Conclusion on nanotechnology cluster benchmark between Germany and Japan

*Strengths and weaknesses*

The nanotechnology clusters in Northrhine Westfalia and Kyoto are both clusters with relatively recently established cluster platforms. However, they both build upon a long established tradition of knowledge intensive industries that have evolved over many decades in these geographical areas. Characteristical for both areas is a strong knowledge infrastructure (universities, labs, etc.) and a good connection between the knowledge infrastructure and industry. The cluster platforms have an important function in supporting these collaborations and extending the cluster's connections both nationally and internationally. Both clusters concentrate on the integration of nanotechnology with other sciences (ICT, biotechnology, energy, etc.).

Both clusters are successful in the sense that they are steadily growing. However, Germany seems to have several weaknesses compared to the Kyoto cluster:

There are relatively many small firms and the cluster lacks a 'lead' or 'anchor' firm with the capacity for large-scale production and distribution.

The area seems to lack entrepreneurial spirit and financing of entrepreneurial activity, i.e. there is a lack of venture capital, business angels, etc.

There is a strong focus on basic research and a lack of commercialisation activity.

[42] http://hesa.etui-rehs.org/uk/dossiers/files/Nano-economics.pdf

Kyoto, on the other hand, has a very strong private funding infrastructure, with private funding consisting of 2/3 of all investments. The Japanese government has played an active role in promoting the VC market. This is combined with a very strong focus on commercialisation and with a variety of tax incentives to attract larger and international firms to the Kyoto area.

*Public policy, funding and tax incentives*

With the establishment of the cluster platforms just after 2002, there is also a strong signal from both the German and Japanese government that there is a desire to build new enabling technologies in these areas. The national and regional governments do have different strategies to do this though.

The involvement of the German government in the NRW nanotechnology cluster is focused on public funding for research activities: Germany is the largest public investor in nanotechnology in Europe. Also, they give generous funding for the cluster platform to stimulate this development. Furthermore, they harmonise their funding schemes to increase the transparency and accessibility of the funds.

The Japanese government takes a more pro-active role in the development of the cluster and takes a more directive role in the technology's application fields. Nanotechnology is a top priority in Japans national strategy. The government's actions do not focus only on knowledge development (through funding of R&D), but also on commercialisation (through incubators and liaison activities), private funding and financial/tax incentives for start-ups and (re)location to create greater cluster density and hence critical mass.

All in all we conclude that whereas the German government mainly takes the role of an investor in basic research, the Japanese government takes more the role of the orchestrator. The latter tries to motivate private actors to invest in nanotechnology by promoting the VC market, giving tax-incentives, and steering companies in the direction of commercialisation by indicating desired application areas (water, bio-fuels, sensors). In this way they make the chances for international commercialisation of developed technologies larger.

*Lead markets: The role of lead actors / anchor firms*

Whereas the question for lead markets cannot be answered for any of the KETs as the technologies are still in a too early stage of development and the fields of application are too divers, we see very different roles, in the different clusters, for lead firms in the cluster, which are often referred to as anchor firms.

As remarked earlier, the NRW cluster is mainly characterised by smaller firms. The Kyoto cluster –in contrast– has several large companies which are important for several reasons:

They invest in new development (private funding for development and commercialisation)

They act as lead customers for the smaller specialist companies in the cluster

They provide the international connections for new knowledge inflows

They are a platform for international marketing, sales and distribution

In other words, whereas lead markets do not play an identifiable role in the cluster, lead firms do, and they play an important role for clusters to grow and prosper.

Table 3-10 summarises the most important findings of the cluster comparison.

**Table 3-10: Summary of findings from nanotechnology cluster comparison**

| | **Nanotechnology**<br>**Northrhine Westfalia - Germany** | **Nanotechnology**<br>**Kyoto - Japan** |
|---|---|---|
| History | Cluster platform young, established in 2003/04<br>Cluster grows though on strong foundations of Northrhine Westfalia's industrial area | 'Knowledge cluster platform' established in 2002<br>'Kyoto Environmental Nanotechnology cluster platform' established 2008<br>Cluster embedded in strong industrial history of Kyoto area |
| Size | 3 universities (with 30 institutes), 4 research centres, 16 SMEs, 6 MNEs, 1 VC firm | 9 universities, 3 research centres, 43 industrial and venture firms |
| Classification | Developing | Developing |
| Infrastructure | Strong knowledge infrastructure: mainly publicly funded<br>Good mix between large firms and academia (but firms do not act as anchor companies) | Strong knowledge infrastructure<br>Large companies have strong R&D and fund further development |
| Institutions | *Rules and regulations*<br>Standardisation procedures highly important in the diffusion process of the technology (internat. competitiveness is largely determined by the ability to compare between product characteristics)<br><br>*Norms and values / culture*<br>Public acceptance is good, but has to be more developed at the interface/ intersection between biotechnology and nanotech.<br>Nanotechnology cluster has a strong identity among the research community, but is not highly visible in the private economy.<br>Lack of entrepreneurial spirit, strong research focus | *Rules and regulations*<br>The Japanese government defines rules and regulations to optimise the alignment of cluster activities according to the overall strategy.<br><br>*Norms and values / culture*<br>The Japanese collective society makes it possible that the strong government involvement is not rejected and proofs to be successful. It is questionable if the same government strategy would work in a more individualistic cultural environment. |
| Public policy / funding / taxation | Cluster dependent on public funding because of venture capital scarcity<br>Germany nr.1 for public funding of nanotech<br>Harmonised funding schemes for transparency and ease of access.<br>Public and cluster platform support for start-ups en commercialisation | Cluster platform initiated by MEXT (ministry) to support research and innovation.<br>Strong focus on Katsura Innovation Park, incubators, and liaison<br>Private funding strong point: 2/3 of funding from private sources. |

| | | |
|---|---|---|
| | Lack of business angels and venture capital | Government has actively stimulated development of VC market<br>Nanotechnology top-priority in national strategy<br>Many agencies to support research and commercialisation<br>Tax incentives to stimulate investments and stimulate (re)location to cluster area |
| Interactions | Cluster platforms play important role in stimulating collaboration<br>Platforms organised per city area:<br>AMO-Aachen,<br>CENTech-Munster<br>CeNIDE-Duisburg/ Essen<br>Platforms stimulate PPP partnerships, collaborative research | Geographically concentrated cluster<br>High density of companies and research facilities facilitate collaboration<br>Connections to large firms in the area facilitate international linkages |
| Capabilities | Strong scientific basis, focus on basic research | Combination of excellent scientific research with commercialisation abilities |
| Market demand | 3 subclusters focus on:<br>Munster: nanobiotech<br>Aachen: nanotechnology for information technology<br>Duisburg/Essen: nanotechnology for power engineering | Strong market orientation<br>Strong focus on application areas water, bio-fuel and sensors<br>Large companies play big role in funding new developments and acting as lead customers |
| Market structure | There are relative many small companies which is a potential weakness<br>Cluster open to new start-ups but relative lack of dynamics | Good mix of smaller firm, with large international companies |
| Cluster specificities | Cluster is dispersed: compositions of three cores, focusing on different knowledge & application fields<br>Lack of commercialisation and consequently lack of private funding | Cluster strongly managed by government<br>Unique in the strong market focus and strong funding infrastructure – both public and private |

*Source: TNO compilation.*

### 3.3.4. Factors influencing the future development of nanotechnology

***Factors influencing future market potentials***

Nanotechnology promises a great variety of new products in diverse fields of applications. So far, only a few of these potential innovations have been put to commercial use. While nanotechnology is currently applied on an industrial scale in microelectronics (semiconductors, nanowires, lithography), coatings and paints, some specific defence-related applications, telecommunication (displays, optoelectronics) and in some areas of advanced materials (e.g. carbon nanotubes), most innovation ideas based on nanotechnology still wait for their commercial exploitation. A number of studies have dealt with the factors that can drive or impede the commercialisation of nanotechnology (see EC, 2009d; PCAST, 2008; Palmberg et al., 2009 for an overview).

Maybe the single most important barrier to developing new markets for nanotechnology products is to clearly identify the commercial opportunities that may result from new research findings. Basic research constantly produces new ideas for new applications. Commercial benefits of these ideas are often unfavourable, however, owing to the fact that nanotechnology applications often constitute radical innovations, i.e. innovations that promise substantially higher user benefits or address entirely new needs, but also demand considerable changes in producing and using these innovations and may induce concerns about long-term benefits (including environment, healt and safety issues). As for all radical innovations, demand is highly uncertain and tends to be very low in the first years after an innovation has been successfully introduced to the market. As a consequence, production costs are very high due to small output volumes whereas willingness to pay by users will be low due to uncertainty over the real benefits of the innovation. Consequently, many firms engaged in developing nanotechnology-based innovations complain about high costs, a lack of scale economies and a lack of consumer acceptance (see Palmberg et al., 74ff; PCAST, 2008).

Developing nanotechnology innovations often requires long and costly R&D activities. Time to market is typically much longer than for other innovations. As a consequence, firms need substantial external capital to finance product development. Many nanotechnology firms report a lack of public funding and a lack of venture capital as main barriers to commercialisation.

In addition to fiancial capital, human capital tends to be a restricting factor, too. Nanotechnology R&D and commercialisation requires skilled people with a background in a variety of disciplines and business practices. The need for complex human capital makes nanotechnology particularly vulnerable to shortages in labour markets for qualified personnel. A lack of skilled labout is therefore one of the highest ranked barriers in the nanotechnology industry.

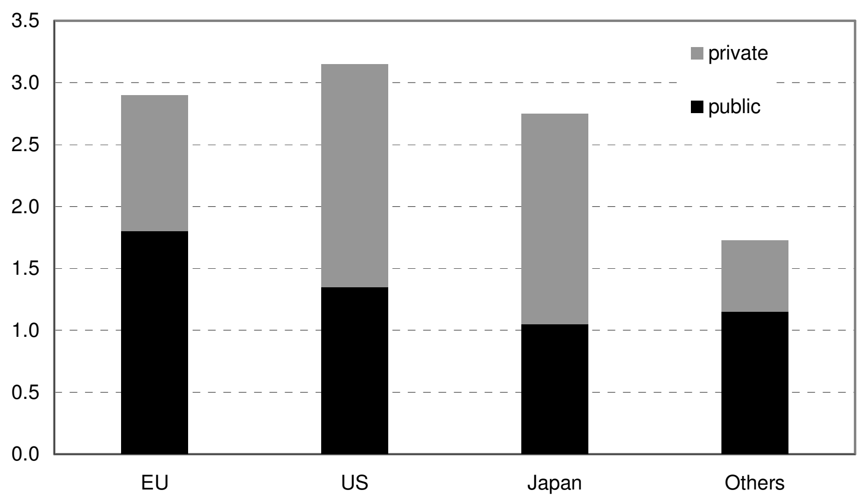
Since technological advance in nanotechnology is by and large driven by basic research typically performed at public research institutions, technology transfer between academia and the business world is particularly important for this KET. The main challenge here is to balance undirected basic research aiming at pure scientific progress with a view on commercialisation prospects and the specific needs of users and markets. Direct collaboration between science and industry often helps to in this respect, but raises the issue of how intellectual property is assigned to the individual partners.

A main issue in commercialising nanotechnology is the impacts of nanomaterials on environment, health and safety (EHS). There is a widespread concern of potential negative effects from nanostructures on the human organism as well as on other creatures. As a consequence, an increasing amount of nanotechnology research is devoted to EHS issues. In order to enhance commercialisation prospects of new nanotechnology applications measurement and testing methods have to be developed and validated. Based on this, standards have to be implemented and an effective regulatory framework should be put in place that takes into account EHS concerns while at the same time acknowledges the progress that nanotechnology innovations can have for the environment and health. An open dialogue between governments, industry, research and the wider society should address EHS concerns and how these ar dealt with.

### *The role of public support*

Being a young field of technology that is still very much driven by advance in basic research, nanotechnology R&D relies on public funding more than any other KET. In 2005 to 2008, it is estimated that about €42 billion have been spent on nanotechnology R&D on a global scale. 51 percent of this investment was funded from government sources while only 49 percent came from private sources, i.e. industry (see EC, 2009d; LuxResearch, 2009; Palmberg et al., 2009). In Europe, the share of government funding of nanotechnology R&D is significantly higher (62 percent) than in the USA (43 percent) and Japan (38 percent) (Figure 3-25). One should bear in mind, however, that identifying the volume of private R&D funding for nanotechnology R&D is extremely difficult since enterprise R&D surveys rarely collect data on R&D expenditure devoted to nanotechnology.

**Figure 3-25: Public and private funding of nanotechnology research 2005-2008 (annual average, billion Euro)**




*Source: EC (2009d: 9f), ZEW calculations.*

Public R&D funding of nanotechnology largely focusses on research performed at public institutions (universities, government labs) and on collaborative research linking science and industry. In addition to R&D funding, governments promote advance in nanotechnology through a number of other activities. Many governments have established national nanotechnology strategies that aim at coordinating various actors from public agencies, industry and science and provide a long-term view of the likely role of nanotechnology for economy and society. The most prominent example is the U.S. National Nanotechnology Initiative (NNI; see Box below). By 2008, another 16 OECD countries have published dedicated nanotechnology strategies (OECD, 2009c).

**Box: The U.S. National Nanotechnology Initiative (NNI)**

The NNI was established in 2001 and is the major federal R&D policy mechanism in nanotechnology in the US. The NNI is not a programme for funding R&D but it informs and influences the federal budget and planning processes through its member agencies. It offers all federal agencies a locus for communication and collaboration. NNI also provides a vision of the long-term opportunities and benefits of nanotechnlogy by producing Strategic Plans. The most recent one was published in December 2007 and defines four goals: advance a world-class R&D programme; foster the transfer of new technologies into products for commercial and public benefit; develop and sustain educaitonal resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; support responsible development of nanotechnology.

NNI promotes policy deliberation and, most importantly, coordinates federal R&D investment in nanotechnology. R&D investment by agencies under the NNI between 2001 and 2010 was $11.9 billion. More than 25 federal agencies participate in the initiative, including 13 agencies that provided R&D funding for nanotechnology. So far, the highest investment under NNI (2001-2010) was made by the Department of Defence ($3.4 billion), the National Science Foundation ( $3.3 billion), the Department of Energy ($2.1 billion) and the Department of Health and Human Services (incl. the National Institutes of Health, $1.8 billion). The Department of Commerce (incl. the National Institute of Standards and Technology) which mostly funds more application oriented, civil R&D, invested $0.8 billion.

The NNI has been subject to evaluations by the President's Council of Advisors on Science and Technology (PCAST) in 2004 and 2008. The evaluations were highly positive, stressing the NNI's important role in providing an effective coordination across agencies, with industry and with other nations; facilitating the expansion of technology transfer efforts and building connections across the the unparalleled innovation ecosystem in the U.S.; and prioritising encironmental, health and safety (EHS) research that facilitates appropriate risk analysis and risk management in step with technological innovation. PCAST recommended to expand outreach efforts to the wider public, particularly with respect to real and perceived benefits and risks; to develop and implement standards critical for nanomaterial identification, characterisation and risk assessment; and to coordinate strategically-guided research on nanotechnology related EHS issues, including a balanced assessment of risks and benefits.

NNI is a policy initiative within a wider framework of policy activities to promote nanotechnology in the USA, including dedicated nanotechnology funding as well as general R&D programmes which are also open to nanoscale research at the federal and state level; a specific legislative framework (21st Century Nanotechnology R&D Act); specific nanotechnology human capital initiatives; federal investments of nanotechnology centres and infrastructure for nanotechnology research and education networks; and support the consideration of environmental, health and safety issues associated with nanotechnology.

Imortant elements of nanotechnology support in the USA are nanotechnology initiatives at the state level. In 2008, 17 states run a total of 24 initiatives. While federal programmes are primarily focused on R&D and infrastructure development, state and regional programmes are active in facilitating nanotechnology commercialisation.

Sources: Shapira and Wang (2007), PCAST (2008), NNI (2007, 2010)

### *Contribution of nanotechnology to social wealth*

Nanotechnology promises great advance in many areas linked to social wealth (see EC, 2008c, 2009d). Nanomedicine offers substantial progress in true preventive medicine and precisely targeted intervention as well as regenerative therapy. Nanomedicine develops man-made functional structures that match the typical size of natural biological elements and allow for more effective and specific interactions. As a consequence, diagnosis, treatment, and monitoring of a number of diseases will be more efficient and targeted, including cancer, diabetes, cardiovascular, immunological, inflammatory, musculoskeletal and neurodegenerative disorders, and infectious diseases.

Another area for wealth enhancing effects of nanotechnology is energy and environment. Nanotechnology could contribute to a more efficient and less harmful production of energy through advancing photovoltaics, wind energy generation and thermoelectric conversion systems. One promising field, for instance, is solar cells based on dye-sensitised nanocrystalline titanium dioxide. Nanotechnology can also help to develop new generations of more effective accumulators to store electric energy. Further promising concepts are micro reactors and novel reactive media, such as ionic liquids. Nanomaterials can contribute to improving energy efficiency of buildings and thus lowering energy consumption. Nanotechnology can also help to increase efficiency in various fields of manufacturing and thus increasing productivity and lowering environmental impacts.

## 3.4 Conclusions and Policy Implications

***State of technology***

Nanotechnology is a rapidly emerging field of technology that is currently at its uptake in terms of unlocking commercial applications. While substantial scientific nanotechnology research started in the 1980s, application oriented R&D at a larger scale began not earlier than in the mid 1990s. The number of patent applications started to increase exponentially in the late 1990s and still has not reached its peak. While there is a large number of promising technologies in the development pipeline, the number of commercial products that have been successfully marketed is rather limited. Nanotechnology markets today mainly refer to a few application areas such as semiconductors and a limited number of nanomaterials. While the actual market size is rather small (about one billion US-$), prospects are expected to be tremendous.

***Europe's technological position***

Nanotechnology development is concentrated on three global regions, Europe, North America and East Asia. North America holds the highest market share, followed by East Asia. Europe contributes about 25 percent to total nanotechnology patenting. In terms of patents per GDP, Europe has a significantly lower nanotechnology patenting intensity than the other three regions. While East Asia was able to improve its technological competitiveness in terms of patent applications, Europe's market share remained stable over the past ten years.

The largest subfield in terms of patents is nanomaterials (about a third of all nanotechnology patents), followed by nanoelectronics, nanooptics and nanobiotechnology. Europe has a rather high market share in nanobiotechnology (though still below the one of North America and rapidly decreasing) while Europe could improve its position in nanomaterials. Europe's market share in nanoelectronics, nanoanalytics and nanooptics is constantly low.

Within Europe, most countries show a focus on nanomaterials (particularly Germany and the smaller EU countries) while France and Italy are specialised in nanobiotechnology and the Netherlands in nanoelectronics and nanomagnetics.

***Links to disciplines, sectors and other KETs***

Nanotechnology is a cross-disciplinary field of research that affects a multitude of industries. At the science side, main links go to chemistry, physics and -increasingly- biology, but also engineering sciences have been making important contributions to the development of this KET. In contrast to other KETs, public research plays a very prominent role in patenting, accounting for about 30 per cent of all nanotechnology patents. In recent years, patenting by public research has increased more rapidly than in the business sector. Sector links of nanotechnology are broad as well.

Nanotechnology patents are technologically linked to electronics (especially semiconductors), the chemical industry, manufacturing of instruments, pharmaceuticals, machinery and vehicles, and manufacture of metals. In East Asia, most nanotechnology patent applicants from the business enterprise sector belong to the electronics industry while public research is less important. In North America, universities and other research institutions are the most important group of nanotechnology applicants. Within the business sector, the electronics industry is leading. In Europe, the chemical industry plays an equally important role as the electronics industry does, though the largest group of nanotechnology applicants are public research institutions. In North America, nanotechnology and biotechnology start-ups contribute significantly to nanotechnology patenting, while in Europe and East Asia this segment is of minor importance.

Nanotechnology is closely linked to other KETs, particularly to advanced materials, microelectronics and industrial biotechnology. Several subfields are also part of other KETs, such as nanomaterials (advanced materials), nanoelectronics and nanomagnetics (microelectronics), nanobiotechnology (industrial biotechnology) and nanooptics (photonics). Nanodevices can play an increasingly important role in advanced manufacturing technologies. These close links imply that nanotechnology development is highly relevant to other KETs, which calls for joint initiatives.

***Market prospects and growth impacts***

All existing market forecasts for nanotechnology and the various submarkets suggest a strong increase in sales in the next decade. Market potentials vary considerably, however, reflecting different definitions of the nanotechnology market. The most optimistic and broadly defined forecasts expect global sales in 2015 to 2020 of more than one trillion US-$, making the nanotechnology industry to one of the key industrial sectors in terms of sales. So far, many of the forecasts have proved to be too optimistic, however. But there is no doubt that demand for nanotechnology products will increase clearly above the total market expansion.

Above average growth of nanotechnology products originates from two sources. On the one hand, nanotechnology is substituting other technologies, e.g. in the field of materials or microelectronics. On the other hand, nanotechnology has a strong potential to open up new markets not explored yet (particularly through product innovations), thus serving needs not met by conventional products yet.

***Success factors, market and system failures***

Nanotechnology is a young, research-driven field of technology which is still in its infant stage. Most commercial applications of nanotechnology are at their concept stages and will have yet to be developed. Consequently, many activities of today's nanotechnology industry still focus on R&D and exploring the commercial prospects of new research findings. Public research institutions and research-based start-ups play a prominent role in developing the new nanotechnology industry. Under this environment, future growth of this industry depends on a multitude of factors.

The perhaps most important success factor is funding. Financing nanotechnology R&D and commercialisation in young firms is challenging since huge amounts of capital is needed while technological and market risks are high and future returns not yet known. Public funding as well as a viable venture capital industry is critical to overcome financial barriers.

Another critical factor is to successfully link technological opportunities with user demand. Many product developments in nanotechnology tend to be research-driven, i.e. focusing on exploring the potentials of new research results. However, users typically do not adopt new technology solely based on their technical superiority but rather on a price-cost advantage over established technologies, taking into account issues such as safety, compatibility to other products and existing production processes, and acceptance by their own clients (including adjustment costs to adopt nanotechnology products).

As for any newly emerging technology, potential impacts of nanotechnology on health, safety and the environment have been discussed widely. Commercialising nanotechnology products broadly will require acceptance by users and all other parties that may be concerned by nanotechnology product. Assessing and minimising (e.g. through regulation and information) perceived risk potentials are important activities here. Certainty about regulatory issues is also critical for nanotechnology producers to decide about investment and directions of future research.

Nanotechnology is currently promoted by many governments. Most governments set up national nanotechnology programmes or strategies (see OECD, 2009c). Most of these programmes focus on strengthening the national research base for nanotechnology and link (national) actors from industry and science to advance commercialisation of nanotechnology products. While regional or national clustering has certainly its merits and can be an important driver for advance in nanotechnology, a too strong national focus may understate the value of international co-operation in a field of technology that is characterised by global research networks and global markets.

Many nanotechnology firms complain about scarcity in skilled personnel (see Palmberg et al., 2009: 74ff). As a cross section technology that combines findings from various scientific disciplines and develops technologies that can be applied across many different industries, skill demands are particularly high. Since education typically focuses on imparting knowledge from specific and established scientific or business fields, people who integrate skills from different disciplines and industries are rare, as are people who have the skills to form a productive team of experts from different backgrounds.

***Policy options***

Advancing the commercialisation of nanotechnology in Europe requires a variety of activities by industry, public research and policy. As for any newly emerging field of technology, linking industry and science and smoothly transferring scientific findings into commercial applications is perhaps the single most important element. Scientific research is still the most important knowledge source in this KET, and it is most likely that the industry's development in the next decade will critically depend on the ability of firms to identify and evaluate new research findings, transfer them into business models and develop new products and processes that leverage the potentials of nanotechnology while at the same time fit to the needs of customers in terms of performance and costs. Doing this requires a close interaction between firms and public research, including joint R&D activities. Cluster initiatives have proved to facilitate this exchange significantly.

Closely related to better linking industry and science is the emergence of a viable community of start-up firms. In newly emerging fields of technology, many of these start-ups originate from public research. Typically, they concentrate on very specific nanotechnology applications and explore the business prospects of new research results. In order to establish a dynamic sector of nanotechnology companies, venture capital funding as well as public support to R&D conducted by these firms is essential. Compared to other fields of technology such as biotechnology, the community of nanotechnology start-ups is still small, particularly in Europe. One reason is certainly the reluctance of the private venture capital business in recent years to provide large amounts of risk capital for these firms. While biotechnology start-ups could profit from a generous venture capital industry in the 1990s, the situation has changed. Today private venture capital companies very carefully evaluate the business prospects of young firms and most often provide only limited funding, focussing on close-to-market-introduction projects. This situation is disadvantageous for nanotechnology since a large number of potential applications are still in the research and concept stage, with high uncertainty over the technological feasibility, the time of market introduction and the sales volumes that may be generated. In order to advance the commercialisation of nanotechnology, huge investment in R&D, pilot plants and marketing are required. Today, only large companies can shoulder the needed long-term financial commitment, resulting in a low share of start-ups in global nanotechnology business.

In this situation, policy will have to compensate for this “market failure” in the financial market which results from a certain risk aversion and a rather short-term time horizon of the venture capital business. A promising starting point for public policy in Europe can be start-ups form public research. On the one hand, public research institutions hold a strong position in nanotechnology patenting, indicating a wealth of knowledge relevant to commercialisation. This potential has to be used more effectively. First, financial support for spin-offs from public research can help to enlarge the community of nanotechnology start-ups. Secondly, programmes to actively commercialise public research patents though out-licensing is another promising option. Thirdly, nanotechnology research programmes at public research should be designed in a way that combines basic research with more application-oriented development, involving partners from the business enterprises sector. Competence centres and R&D co-operation programmes have proved to be helpful in this respect.

Further policy actions should relate to providing a stable regulatory environment, particularly with respect to likely safety, health and environment impacts of nanotechnology. Informing the general public about the prospects and potential dangers of nanotechnology and how one can deal with these is important to achieve a broad acceptance of nanotechnology. Public programmes for risk assessment and risk control can reduce uncertainty about likely future impacts of nanotechnology and thus stimulate investment and demand.

Since R&D in nanotechnology involves very long time horizons, stable networks among actors from industry, science and government are needed. Cluster initiatives can help to establish and maintain such networks.

# 4 MICRO- AND NANOELECTRONICS

## 4.1 Definition and State of Technology

The technology field of micro- and nanoelectronics refers to semiconductor components as well as highly miniaturised electronic subsystems and their integration in larger products and systems. The term nanoelectronics is rather broadly defined, which means that it can be applied to all areas of electronics where fine structures on the level of nanometres are used. In this sense, today's microelectronics could also be referred to as a kind of nanoelectronics as the control electrodes of modern chips are usually only a few layers of atoms thick. In a narrow sense, nanoelectronics can be limited to a technique based on silicon, which is still one of the most important semiconductor materials, and to a structural width – the smallest dimension which can be achieved with lithography, the patterning method for integrated circuits – of less than 100 nanometres. Nanoelectronics often refer to transistor devices that are so small that inter-atomic interactions and quantum mechanical properties need to be studied extensively (BMBF, 2002a).

By the year 2010, microelectronics has already crossed the verge of nanoelectronics in the above sense with structural widths for chips of the latest generation of only 32 nanometres. Only five years ago, a number of 55 million transistors placed on an area of 1 $cm^2$ was classified as more than excellent in the chip industry. Contemporary processors have a three to ten times higher number of transistors on the same area (Fraunhofer CNT, 2008). The benefits of miniaturisation are clear. On the one hand costs for chip manufacturing can be reduced. On the other hand, smaller chips are much faster because the propagation delay on a chip is dependent on its size. Technical progress is expected to result in a further reduction of structural widths (BMBF, 2005).

Nevertheless, there are considerable technological barriers in the transition from micro- to nanoelectronics, and this transition cannot be expected to happen almost automatically. Decreasing structural widths lead to leakage currents and quantum effects. The latter refer to the properties and behaviour of single atoms or molecules which are the key to modern quantum physics. To cope with these, new concepts and materials need to be integrated into the manufacturing process such that the enduring trend of the industry (increasing performance at decreasing costs) can be continued. In order to achieve success and continued growth of the industry, a cost reduction of about 30 percent per year is required, while functionality needs to double every two years. This development, referred to as "Moore's

Law", has already been anticipated by Gordon Moore at the beginning of the 1960s (Fraunhofer CNT, 2008).

Over the last 20 years, an end to this trend has often been propagated. But technical progress has constantly resolved the upcoming obstacles and has even overcome physical limits that had previously been thought of as insurmountable. However, "conventional" concepts will presumably be fully exploited in the future, which raises a need for new concepts. An example for this might by extreme ultraviolet lithography which is a next-generation lithography using a special wavelength. For the next decade, further miniaturisation can be expected up to 23 nanometres. This corresponds to a width of only 100 silicon atoms. Optical lithography will then have reached a physical limit. At the same time, necessary changes in plant engineering will presumably not be sufficient to support further miniaturisation. Instead, new developments will be required which creates considerable investment requirements for the manufacturers (Fraunhofer CNT, 2008).

In the following we will use the term "microelectronics" for simplification, though this term will always refer to both micro- and nanoelectronics.

## 4.2 Technological Competitiveness, Industry Links and Market Potentials

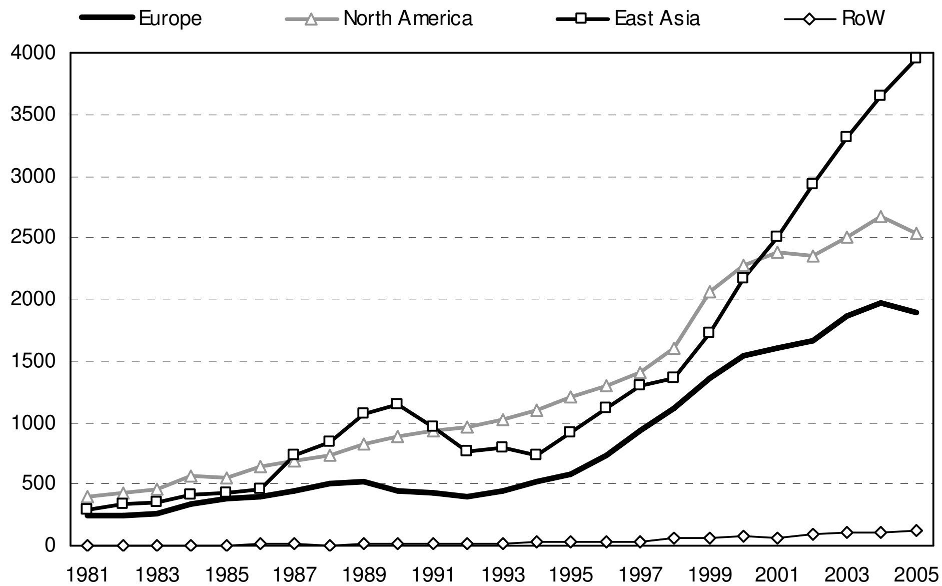
### 4.2.1. Technological Competitiveness

In the following, technological competitiveness of Europe is analysed in comparison to that of North America (USA, Canada, Mexico) and East Asia (Japan, China incl. Hong Kong, Korea, Taiwan, Singapore). In order to account for "home office" effects in patenting (i.e. the propensity for applicants from a particular region to use predominantly that regional patent office for applications), patent applications from the EPO (incl. PCT), USPTO, JPO, as well as triadic patent applications are analysed.

***Market Shares***

Figure 4-1 shows the number of microelectronics patents applied for at the EPO or through PCT by region of the applicant. In the period from 1981 to 2005 around 100,000 patents were applied for. The majority of applicants comes from East Asia (more than 40,000), closely followed by North America (almost 36,000) and Europe (23,000). Patenting activities by East Asian applicants are steadily increasing at an almost constant rate since 1994 while the number of patents from North America and Europe did not grow much after the year 2000.

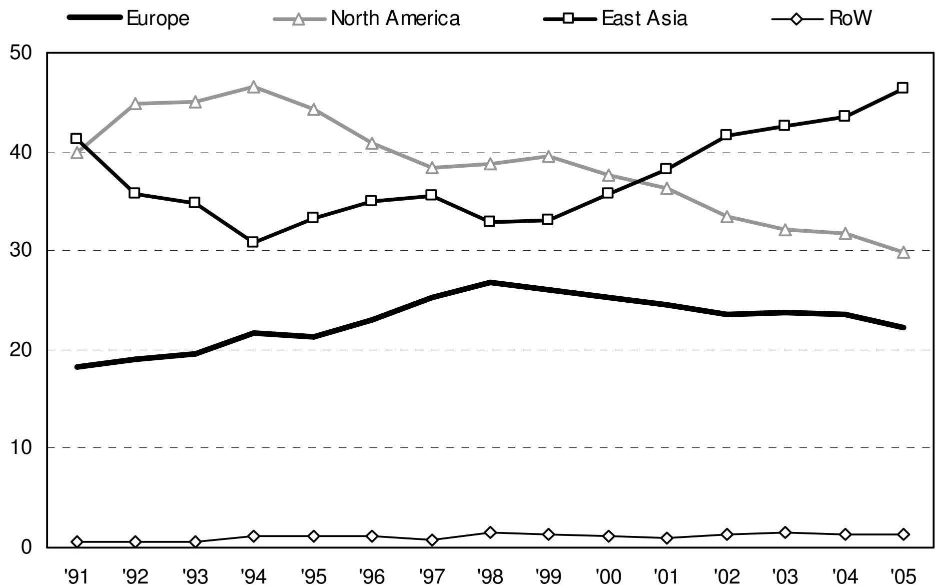
**Figure 4-1: Number of microelectronics patents (EPO/PCT) 1981-2005, by region of applicant**




Source: EPO: Patstat, ZEW calculations.

In 2005, European applicants had a share of 22 percent in total microelectronics patent applications at the EPO/PCT, compared to 30 percent for North American applicants and 46 percent for East Asian applicants (see Figure 4-2). Over the past 15 years, market shares of European applicants have remained relatively constant while North American applicants lost shares in favour of East Asia.

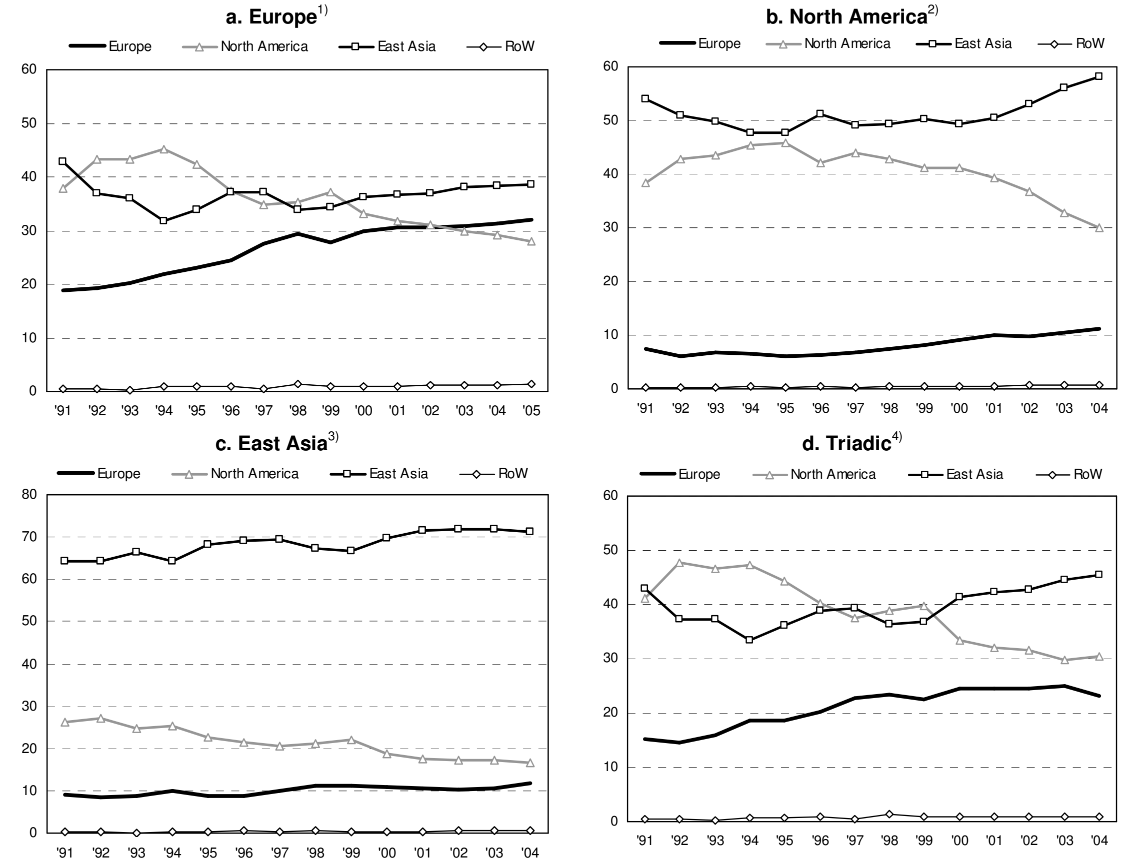
**Figure 4-2: Market shares of microelectronics patents (EPO/PCT) 1991-2005, by regions (percent)**




Source: EPO: Patstat, ZEW calculations.

Figure 4-3 shows the shares in microelectronics patents for national patent applications at the EPO, USPTO and JPO as well as for triadic patents. At the European market for microelectronic technology, European applicants slightly gained market shares over the past 15 years. In 2005, their share in the total number of EPO patent applications was 32 percent, being now second behind East Asian (39 percent) and North American (28 percent). Among USPTO patents, East Asian applicants are also dominating with a market share of 58 percent, followed by North American applicants (30 percent) and European applicants with only 11 percent. Europe's position is likewise weak when patent applications in microelectronics at the JPO are considered. East Asian applicants lead with 71 percent, followed by North American applicants (17 percent) and European applicants (12 percent). However, European applicants were able to increase their shares both at the USPTO and the JPO since the mid 1990s to some extent. When looking at triadic patents, it turns out that Europe's position has improved up to a market share of 25 percent in 2003. North American applicants report sharply falling shares down to 30 percent in 2004 while East Asian applicants were able to gain shares in the global output of triadic patents in microelectronics, reaching 45 percent in 2004.

**Figure 4-3: Market shares in microelectronics patents 1991-2005 for national applications and triadic patents (percent)**




*1) EPO applications*

*2) USPTO applications*

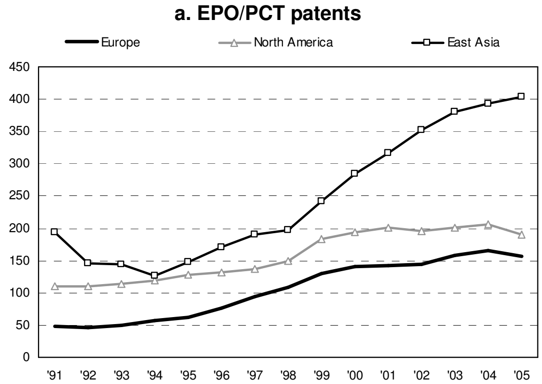
*3) JPO applications*

*4) Patents for which 1), 2) and 3) applies (including PCT applications transferred to national patent offices from all three regions).*

*Source: EPO: Patstat, ZEW calculations.*

Patent intensities can be calculated in order to determine the relative importance of microelectronics patents for a region. They relate the number of patents per year by applicants from a certain region to the GDP of that region. Both graphs in Figure 4-4 show that East Asian applicants clearly exhibit highest patent intensities while North American and European applications have considerably lower patent intensities.

**Figure 4-4: Microelectronics patent intensity 1991-2005 for EPO/PCT and triadic patents (number of patents per 1 trillion of GDP at constant PPP-$)**




*Source: EPO: Patstat, OECD: MSTI 02/2009. ZEW calculations.*

### *Patenting by Subfields*

Based on the IPC classification, microelectronics can be broadly separated into six subclasses which will be analysed in the following (IPC classes in parantheses):

Semiconductors in general (H01L 21, H01L 23, H01L 27, H01J)

Computing (all microelectronics patents with co-assignment to IPC classes G06, G11, G12)

Measurement (all microelectronics patents with co-assignment to IPC classes G01, G05, G07, G08, A61B)

X-ray (all microelectronics patents with co-assignment to IPC classes G02, G03, G09, G21)

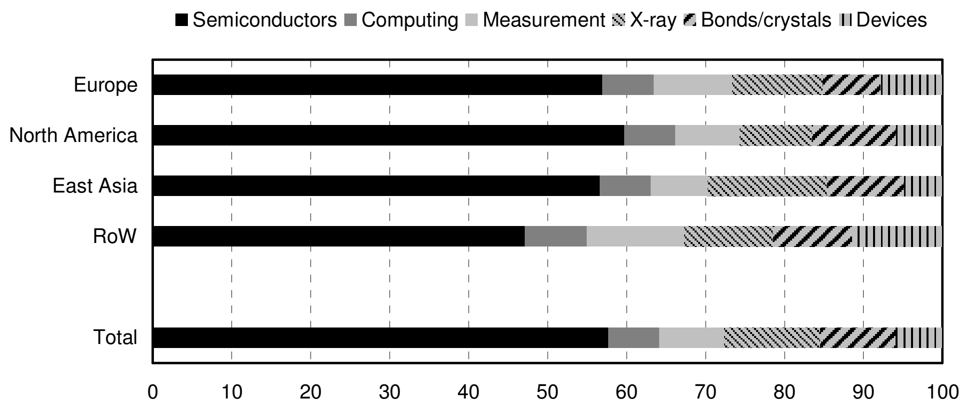
Bonds, electrolytes, crystals (all microelectronics patents with co-assignment to IPC classes C23, C30, C40, C01C)

Devices (all microelectronics patents with co-assignment to IPC classes B01, B05, F)

The largest subfield by far is semiconductors, accounting for more than half of all microelectronics patents (Figure 4-5). All three main regions show similar shares for this subfield. The remaining subfields account for about 10 percent each.

East Asia reports well above average shares for x-ray while Europe's share is relatively highest in measurement. North American applicants are particularly strong in bonds and crystals.

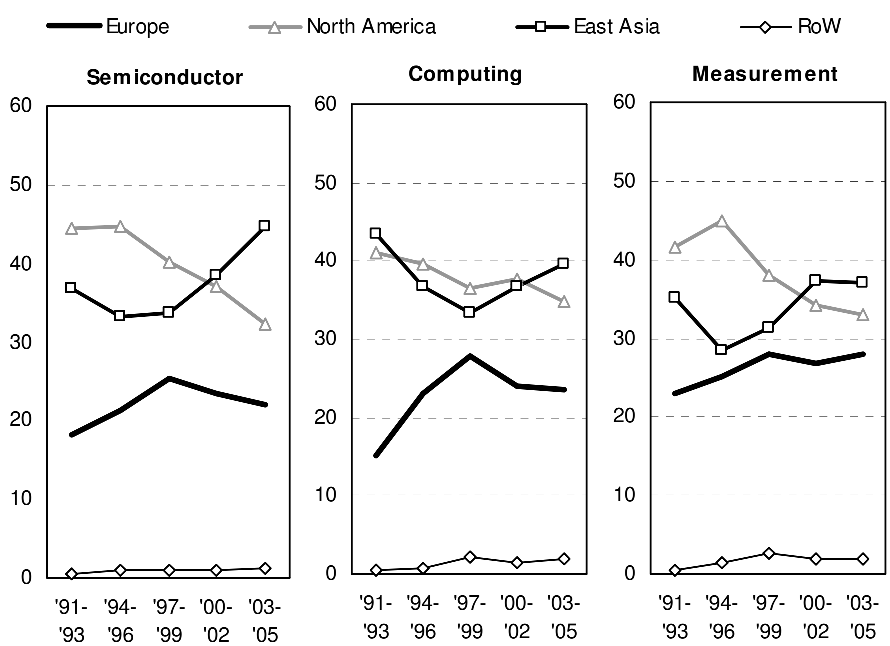
**Figure 4-5: Composition of microelectronics patents (EPO/PCT) by subfields (percent)**

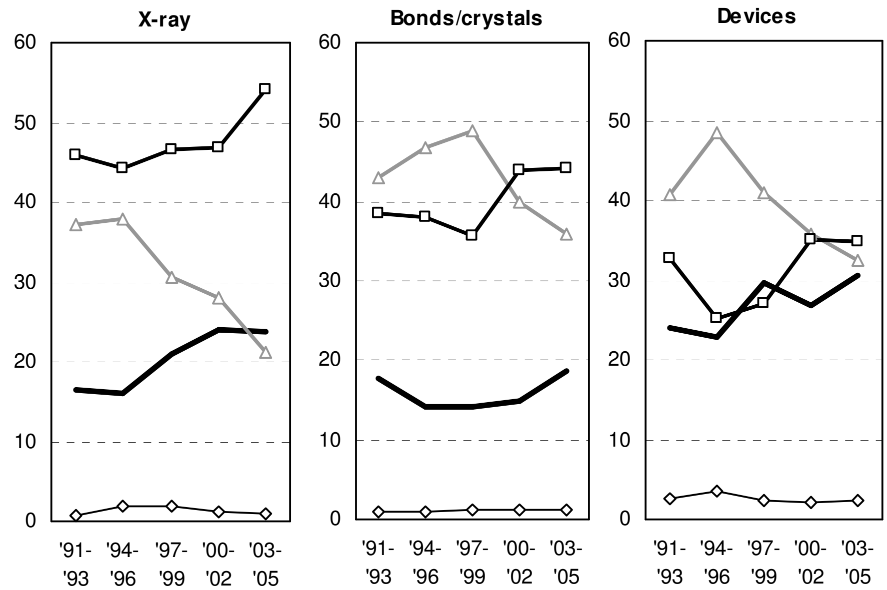



*Source: EPO: Patstat. ZEW calculations.*

When looking at the development of market shares across subfields over time (Figure 4-6), it turns out that European applicants have improved their position predominantly in the fields of measurement, x-ray and devices while the position remained rather static in the fields of semiconductors and bonds/crystals. Interestingly, North American applicants have lost market share in all subfields over time while East Asian applicants have generally gained over time.

**Figure 4-6: Market shares for EPO/PCT microelectronics patents by subfields 1991-2005 (percent)**

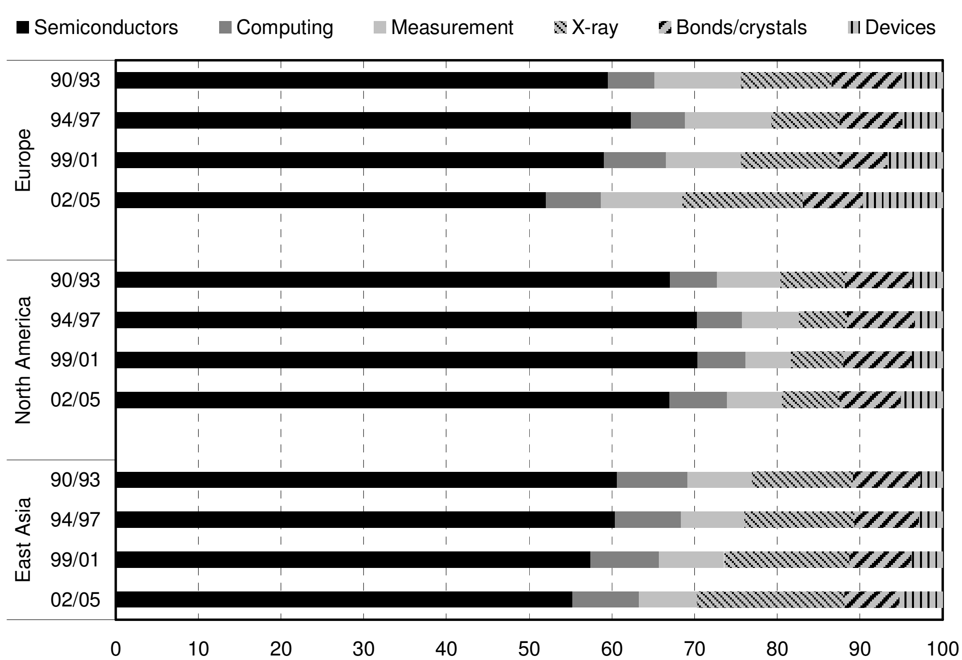





Source: EPO: Patstat, ZEW calculations.

Patent application in microelectronics by European applicants is more focused on measurement and devices than the one of North American and East Asian applicants. In East Asia, the specialisation on semiconductors has been continuously decreasing while x-ray increased. In North America, shares of specialisation remained relatively stable (Figure 4-7).

**Figure 4-7: Composition of microelectronics patents (applications at home patent offices), by region, subfield and period (percent)**

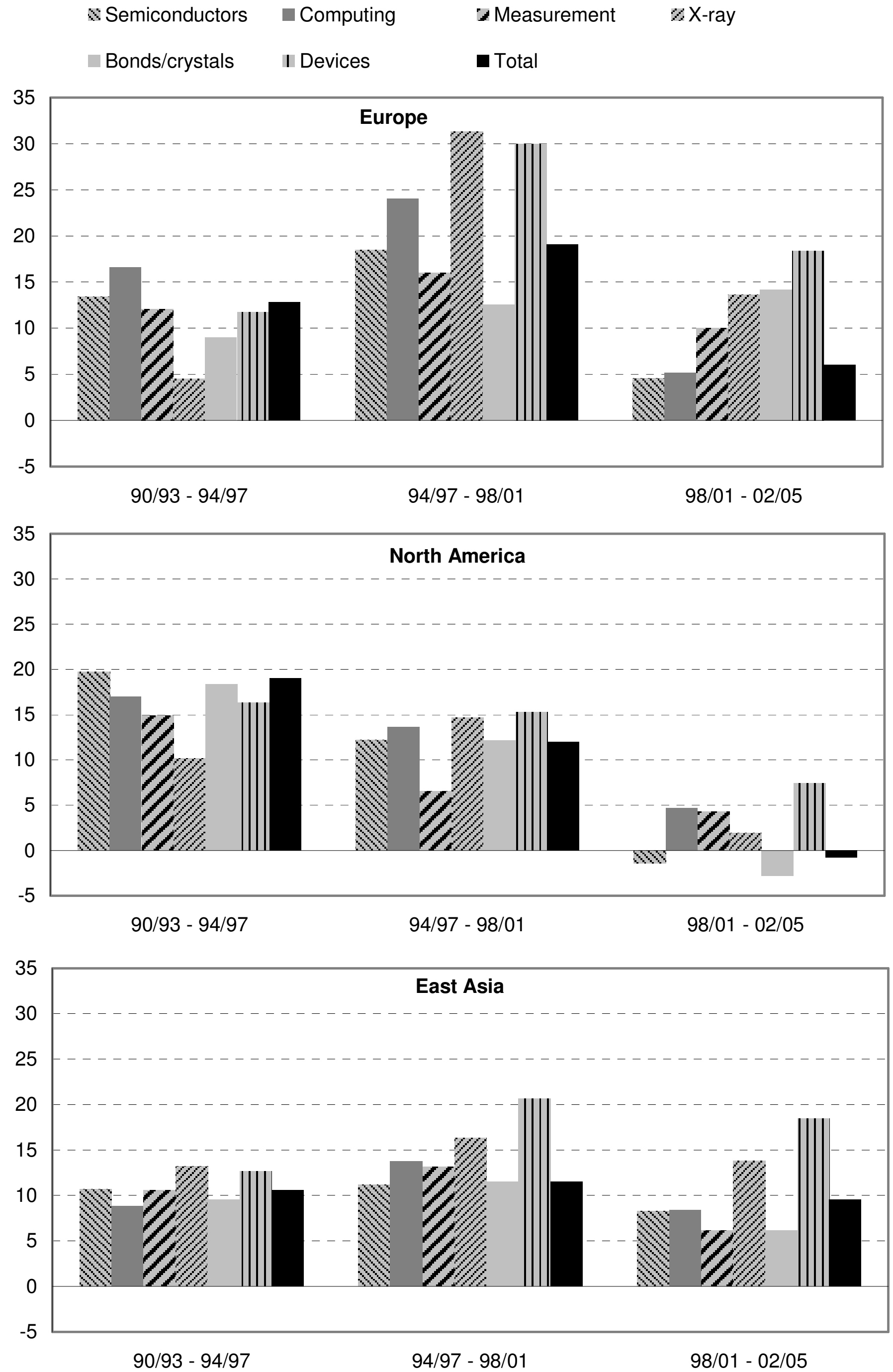



*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*

*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

Dynamics in microelectronics patent applications at the regional home offices significantly differ by subfield and region. In the most recent period (1998/01 to 2002/05), Europe increased the number of annual patents in microelectronics by around 6 percent which closely follows growth East Asia of around 9 percent (Figure 4-8). In contrast to this, the rate of change in North America has even been slightly negative. In all three regions, growth has been highest in the subfield of devices, followed by x-ray and bonds/crystals.

**Figure 4-8: Average annual rate of change in the number of microelectronics patents (applications at home patent offices), by region, subfield and period (percent)**



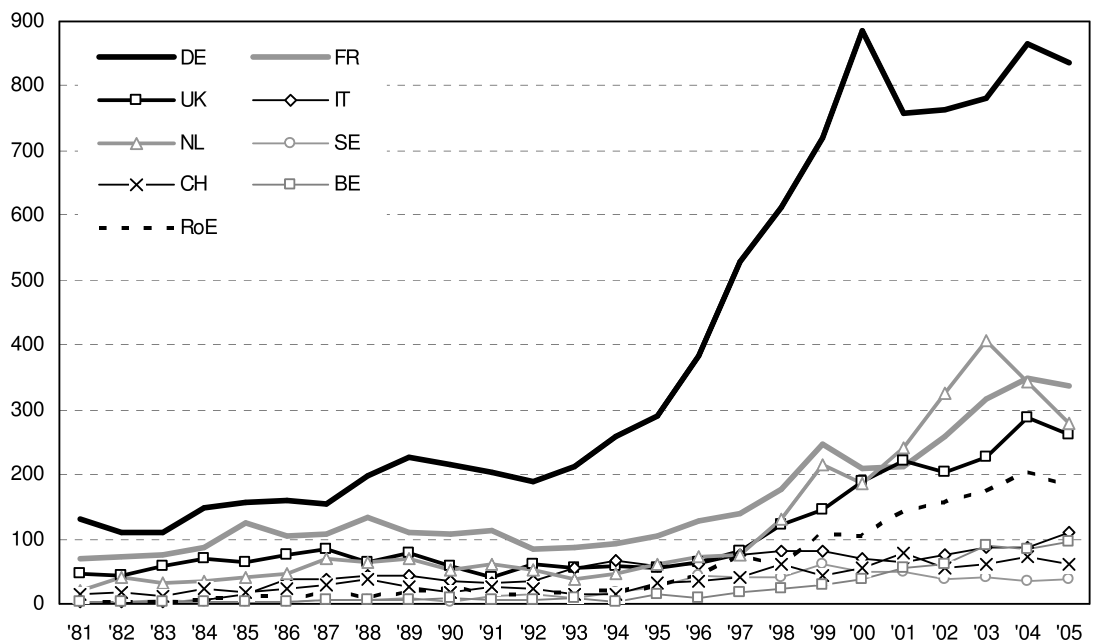

*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*

*Source: EPO: Patstat, ZEW calculations.*

***Patenting at the country level in Europe***

Shedding light on the microelectronics patenting within Europe, applicants from Germany represent the largest group of microelectronics patents (Figure 4-9). From 1981 to 2005, 41 percent of all microelectronics patents at the EPO from European applicants stem from German inventors, followed by France (16 percent), the Netherlands (12 percent) and the United Kingdom (11 percent). There has been a particularly fast growth of German patent applications from 1993 to 2000 after which, however, patent output did not grow anymore. Applications by applicants from other European countries further grew in the 2000s, particularly in France, the UK and the Netherlands.

**Figure 4-9: Number of microelectronics patent applications (EPO and PCT) 1981-2005 by European applicants, by country**

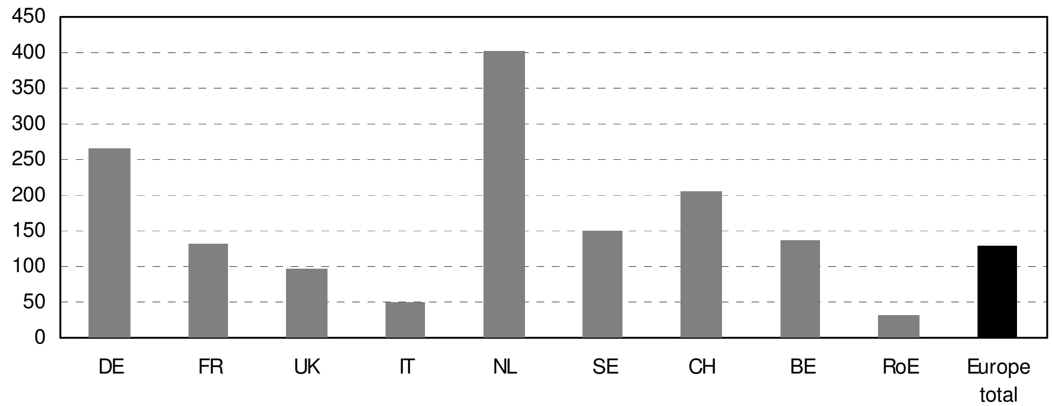



*Eight European countries with the largest number of microelectronics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

Source: EPO: Patstat, ZEW calculations.

The economic significance of microelectronics patenting differs substantially by country (Figure 4-10). Microelectronics patent intensity -that is the ratio of the number of microelectronics patents to GDP- is highest in the Netherlands and clearly above the European average in Switzerland and Germany. Sweden produces somewhat more microelectronics patents per GDP than the European average whereas France and Belgium report average patent intensities. UK, Italy and the total of all other European countries show low microelectronics patent intensities.

**Figure 4-10: Patent intensity in microelectronics 1991-2005 of European countries (EPO/PCT patents)**



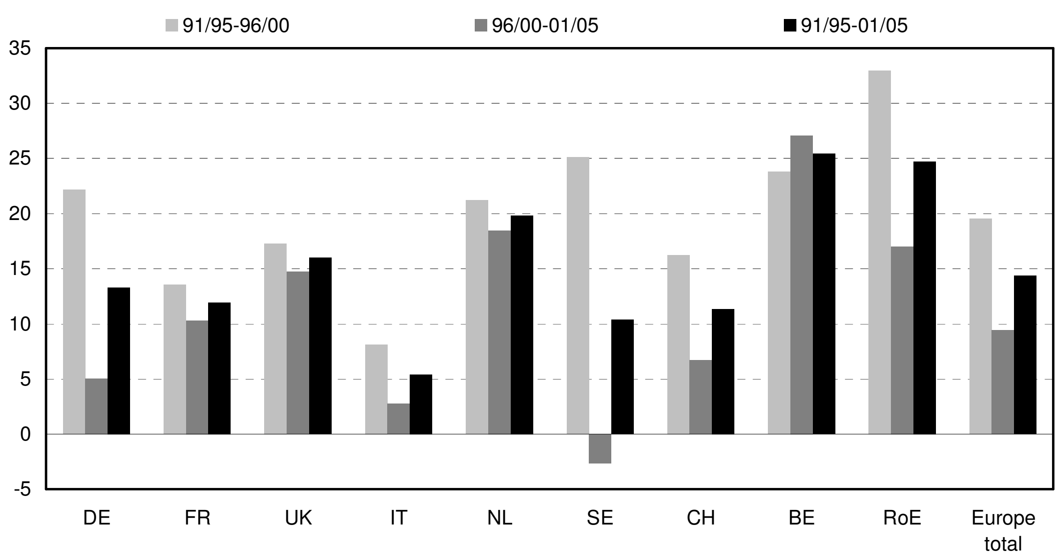

*Patent intensity: number of EPO/PCT patents applied between 1991 and 2005 per trillion GDP at constant PPP-$ in the same period.*

*Eight European countries with the largest number of microelectronics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Growth rates in microelectronics patenting also differ considerably among European countries. Out of the eight countries that produce the largest number of microelectronics patents, Belgium, the Netherlands and Italy could increase their patent output between the first half of the 1990s (1991-95) and the first half of the 2000s (2001-05) above the European average at compound annual rates between 20 and 25 percent (Figure 4-12). A very high growth rate was also experienced by the group of European countries not qualifying for the eight largest patent producers in microelectronics.

**Figure 4-11: Change in the number of microelectronics patents between 1991/95 to 1996/00 and 1996/00 to 2001/05, by country (EPO/PCT patents; compound annual growth rate in percent)**



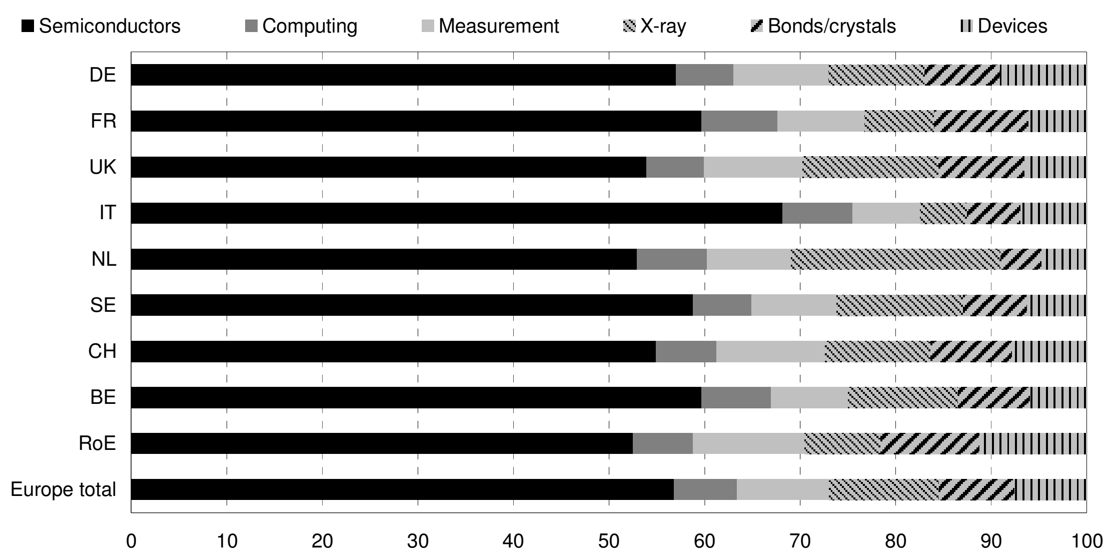

*Eight European countries with the largest number of microelectronics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Microelectronics patenting increased slightly above the average European rate in UK whereas Germany, France, Switzerland and Sweden report growth rates somewhat below the European average. In almost all countries, growth rates were higher in the 1990s (i.e. between 1991/95 and 1996/00) than in the recent period (1996/00 to 2001/05). Belgium is the only country among the eight largest microelectronics patents producers that could increase its output in the latter period at a higher rate.

The composition of microelectronics patent applications by subfields differs only slightly by country of inventor (see Figure 4-12). Patents from Italy show a very high share in semiconductors while this share is below average for the Netherlands. The Netzerlands show a higher share in X-ray patenting. All other countries exhibit shares around the European average.

**Figure 4-12: Composition of microelectronics patents in Europe, by subfield and country (percent)**

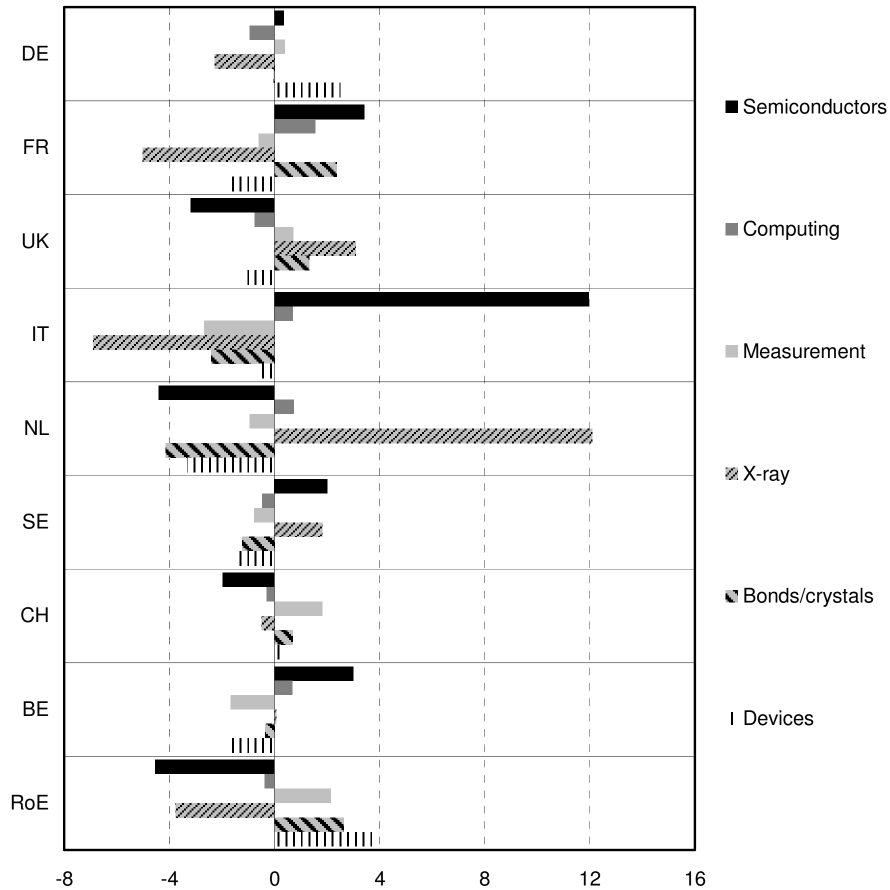



*Eight European countries with the largest number of microelectronics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Figure 4-13 provides a more detailed picture of country-specific specialisation by subfield within microelectronics. It emerges that Italy is largely specialised on semiconductors while the Netherlands exhibit a strong focus on x-ray which is where Italy is least specialised in. Moreover, a specialisation of Germany on microelectronic devices becomes apparent while patenting by Frech inventors is specialised on semiconductors, bonds/crystals and computing applications, whereas UK inventors are specialised on x-ray.

**Figure 4-13: Specialisation patterns of microelectronics patenting in Europe, by subfield and country of inventor (percent)**




*Difference between the share of a subfield in a country's total microelectronics patents and the respective share for Europe total (excluding the country under consideration).*

*Eight European countries with the largest number of microelectronics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

European countries show different trends in microelectronics patenting by subfield (Table 4-1). When comparing the growth in the number of patents applied by subfield for the 1990s (i.e. between the number of patents over the 1991-95 and the 1996-2000 periods) and the early 2000s (i.e. between 1996-00 and 2001-05), one can see high growth rates for x-ray and devices in both periods while patenting in semiconductors clearly slowed down. Belgium, the UK and the Netherlands could sustain high growth rates in semiconductors during the early 2000s, however. France increased its patent output in the microelectronic devices in the 2000s substantially while Italy reports high growth rates for x-ray and devices. Belgium and the Netherlands show high growth rates in the 2000s in all subfileds of microelectronics whereas Germany's recent growth rates in microelectronics patenting are rather low, except for devices and x-ray. The "rest of Europe" increased microelectronics patent output at a high pace in all subfields during in the 1990s but growth rates fell somewhat in the early 2000s.

**Table 4-1: Change in the number of microelectronics patents between 1991/95 to 1996/00 and 1996/00 to 2001/05 by subfield and country (EPO/PCT patents, compound annual growth rate in percent)**

| | DE | | FR | | UK | | IT | | NL | | SE | | CH | | BE | | RoE | | Europe total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Semiconductors | 23 | 4 | 16 | 8 | 17 | 14 | 7 | -1 | 21 | 18 | 26 | -4 | 17 | 6 | 26 | 27 | 34 | 16 | 20 | 8 |
| Computing | 33 | 2 | 10 | 12 | 22 | 10 | 1 | 4 | 22 | 23 | 43 | 23 | 19 | 11 | 18 | 35 | 42 | 23 | 23 | 10 |
| Measurement | 14 | 9 | 5 | 12 | 15 | 11 | 14 | 5 | 36 | 20 | 23 | 3 | 8 | 15 | 14 | 25 | 33 | 14 | 15 | 12 |
| X-ray | 16 | 15 | 7 | 17 | 20 | 14 | 10 | 34 | 32 | 31 | 20 | 16 | 15 | -1 | 14 | 25 | 33 | 23 | 19 | 20 |
| Bonds/crystals | 17 | 8 | 12 | 16 | 25 | 15 | 14 | 19 | 8 | 17 | 8 | 18 | 7 | 15 | 18 | 20 | 29 | 15 | 16 | 13 |
| Devices | 28 | 18 | 5 | 32 | 35 | 23 | 25 | 35 | 29 | 27 | 25 | 2 | 19 | 12 | 50 | 36 | 39 | 18 | 26 | 21 |
| Microelectronics tot. | 22 | 5 | 14 | 10 | 17 | 15 | 8 | 3 | 21 | 18 | 25 | -3 | 16 | 7 | 24 | 27 | 33 | 17 | 20 | 9 |

*a: compound annual growth rate of patent applications between 1991/95 to 1996/00*
*b: compound annual growth rate of patent applications between 1996/00 to 2001/05*

*Eight European countries with the largest number of microelectronics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

## 4.2.2. Links to Sectors and Fields of Technologies

### *Technological links to sectors*

When microelectronics patents are linked to industrial sectors based on the IPC classes to which a patent was assigned (so-called "technological sector links"), we find a rather focused sector relevance of microelectronics (Table 4-2). 58 percent of all microelectronics patents are linked to the electronics sector, followed by machinery and instruments (12 percent each). The remaining sectors are only of minor importance. There is an even stronger link between microelectronics patents and the electronics sector for North American patent applicants while the affiliation with the instruments sector is somewhat lower.

**Table 4-2: Technological sector affiliation of microelectronics patents (EPO/PCT), by region (average of 1981-2007 applications, percent)**

| | Europe | North America | East Asia | **Microelectronics total** |
|---|---|---|---|---|
| Food | 0 | 0 | 0 | **0** |
| Textiles | 0 | 0 | 0 | **0** |
| Wood/Paper | 1 | 0 | 0 | **0** |
| Chemicals | 5 | 5 | 5 | **6** |
| Pharmaceuticals | 1 | 0 | 0 | **1** |
| Rubber/Plastics | 1 | 1 | 1 | **1** |
| Glass/Ceramics/Concrete | 2 | 2 | 2 | **3** |
| Metals | 5 | 4 | 4 | **5** |
| Machinery | 9 | 11 | 11 | **12** |
| Electronics | 60 | 67 | 61 | **58** |
| Instruments | 13 | 9 | 14 | **12** |
| Vehicles | 3 | 1 | 1 | **2** |
| Total | 100 | 100 | 100 | **100** |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

The importance of patenting in microelectronics for sectors can also be analysed with respect to the subfields of microelectronics. It turns out that –again– electronics industry is the most important sector across all subfields. About half of the microelectronics patents can be technologically attributed to this industry (Table 4-3). It is followed by instruments as well as machinery with 12 percent of the patents each.

**Table 4-3: Technological sector affiliation of microelectronics patent applications (EPO/PCT), by subfield (average of 1981-2007 applications, percent)**

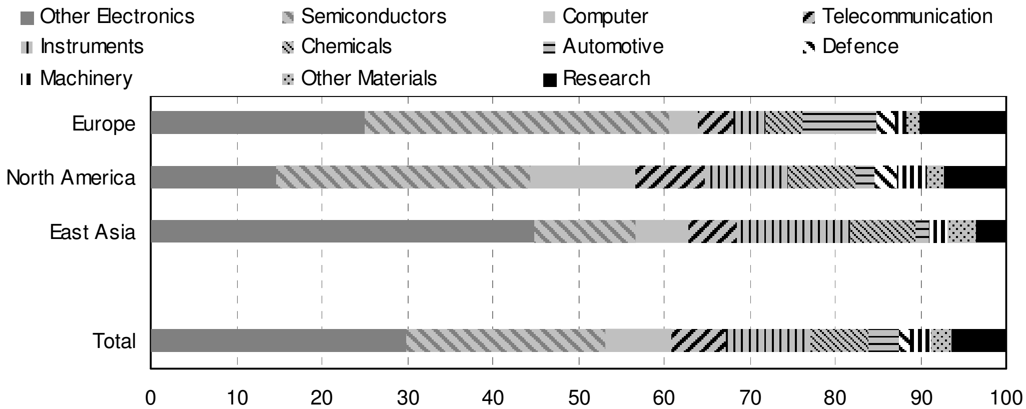
| Sector | Semicon-ductors | Compu-ting | Measure-ment | X-ray | Bonds/ crystals | Devices | Total |
|---|---|---|---|---|---|---|---|
| Food | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Textiles | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wood/Paper | 0 | 2 | 0 | 0 | 0 | 1 | 0 |
| Chemicals | 6 | 2 | 3 | 7 | 13 | 10 | 6 |
| Pharma | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| Rubber/Plastics | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Glass/Ceramics | 2 | 1 | 1 | 2 | 4 | 4 | 3 |
| Metals | 5 | 2 | 3 | 2 | 15 | 8 | 5 |
| Machinery | 12 | 5 | 5 | 8 | 24 | 22 | 12 |
| Electronics | **60** | **73** | **47** | **49** | **37** | **41** | **58** |
| Instruments | 12 | 12 | 34 | 30 | 4 | 7 | 12 |
| Vehicles | 1 | 2 | 5 | 1 | 1 | 4 | 2 |

Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.

### *Sector affiliation of applicants*

Moreover, it is possible to analyse the applicants of microelectronics patents and their industry affiliation. Adopting a rather high level of aggregation, these industry sectors are semiconductors, computer, telecommunication, instruments, chemicals, automotive, defence, machinery, other materials, research, and other electronics. Figure 4-14 shows the sector shares in the production of microelectronic patents at the EPO and through PCT. It has to be kept in mind that these figures do not refer to absolute numbers of patents that were generated in the respective sectors. Instead, Figure 4-14 rather gives insights on the industrial structure in the three regions with respect to microelectronics.

**Figure 4-14: Sector affiliation of microelectronics patent applicants (EPO/PCT), by region (average of 1981-2007 applications, percent)**

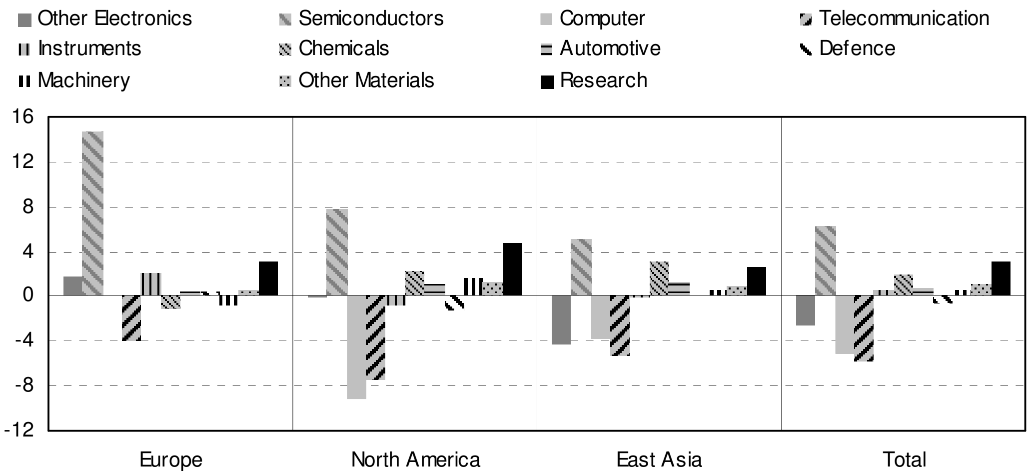



*Source: EPO: Patstat, ZEW calculations.*

Interesting differences between the three world regions under study emerge. In East Asia, most microelectronics patents are applied for by electronics firms while this share is considerably lower in Europe and North America where specialised semiconductor firms dominate. Europe also has a focus on the automotive sector which has a higher share in total European microelectronics patents than the other two regions. Moreover, East Asian firms from the instruments sector produce a relatively higher number of patents than firms from these sectors in Europe and North America. Another interesting finding is that microelectronics patenting in Europe is to a higher extent a result of public research efforts. This finding might serve as an indication of an excellent public research infrastructure in Europe. The public research share is lowest in East Asia.

Comparing the sector affiliation of microelectronics patent applications before and after the end of 2001 – which splits the total sample of microelectronics patents in two subsamples of similar size – reveals a shift of microelectronics patenting toward specialised semiconductor firms. This trend is particularly pronounced in Europe and reflects the strategy of the largest European electronic companies -Siemens and Philips- to spinoff their microelectronics businesses in separate companies (Infineon and Epcos as Siemens spinoffs, ASML and NXP as Philips spinoffs). In all three regions, public research gained market shares in microelectronics patenting. In Europe, automotive manufacturers become increasingly engaged in this field of technology. In North America and East Asia, the chemical and materials industries increased their share in total microelectronic patenting. Decreasing shares are reported for the electronics industry (i.e. integrated electronic companies) in Europe and Japan, for telecommunication companies in all three regions, and for computer manufacturers in North America and East Asia.

**Figure 4-15: Change in the sector affiliation of microelectronics patent applicants before and after the end of 2001 (EPO/PCT), by region (percentage points)**




*Source: EPO: Patstat. ZEW calculations.*

Microelectronic patenting is typically concentrated among a few applicants, mostly from the business and enterprise sector. Table 4-4 shows the list of top-ten patent applicants in the three regions.

**Table 4-4: 25 main patent applicants in microelectronics by region (EPO/PCT patents, 2000-2007 applications)**

| **Europe** | | | | | **North America** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | Name | Country | Sector | No. of patents | Rank | Name | Country | Sector | No. of patents |
| 1 | Infineon | DE | semiconductor | 1525 | 1 | Applied Materials | US | semiconductor | 1051 |
| 2 | STMicroelectronics | IT | semiconductor | 724 | 2 | IBM | US | computer | 645 |
| 3 | ASML | NL | semiconductor | 568 | 3 | Intel | US | semiconductor | 615 |
| 4 | Philips | NL | electronics | 506 | 4 | Freescale Semicond. | US | semiconductor | 540 |
| 5 | Comm. à l'energie atom. | FR | government | 450 | 5 | AMD | US | semiconductor | 531 |
| 6 | Robert Bosch | DE | automotive | 442 | 6 | Micron Technology | US | electronics | 519 |
| 7 | Siemens | DE | electronics | 441 | 7 | Texas Instruments | US | instruments | 473 |
| 8 | OSRAM Opto Semicond. | DE | semiconductor | 248 | 8 | LAM Research Corporation | US | research | 461 |
| 9 | Carl Zeiss SMT | DE | instruments | 237 | 9 | Eastman Kodak | US | instruments | 423 |
| 10 | NXP | NL | semiconductor | 193 | 10 | Hewlett-Packard | US | computer | 395 |
| 11 | S.O.I. Tec | FR | semiconductor | 153 | 11 | Motorola | US | telecommunication | 326 |
| 12 | IMEC | BE | research | 150 | 12 | Honeywell International | US | machinery | 324 |
| 13 | Fraunhofer-Gesellschaft | DE | research | 133 | 13 | Du Pont | US | chemicals | 269 |
| 14 | Continental Automotive | DE | automotive | 115 | 14 | 3M | US | chemicals | 266 |
| 15 | THOMSON-CSF | FR | defence | 105 | 15 | CREE | US | electronics | 247 |
| 16 | CNRS | FR | research | 95 | 16 | Advanced Technology M. | US | materials | 227 |
| 17 | L'Air Liquide | FR | chemicals | 83 | 17 | University of California | US | research | 203 |
| 18 | SEMIKRON Elektronik | DE | electronics | 79 | 18 | ATMEL | US | automotive | 190 |
| 19 | Schott AG | DE | materials | 71 | 19 | Delphi Technologies | US | automotive | 173 |
| 20 | Saint-Gobain Glass | FR | materials | 70 | 20 | General Electric | US | electronics | 170 |
| 21 | X-FAB Semic. Foundries | DE | semiconductor | 66 | 21 | ASM America | US | semiconductor | 168 |
| 22 | ALCATEL | FR | telecommunication | 62 | 22 | SanDisk | US | machinery | 167 |
| 23 | Merck Patent GmbH | DE | chemicals | 60 | 23 | Air Products and Chemic. | US | chemicals | 136 |
| 24 | Cambridge Display Tech. | GB | electronics | 59 | 24 | Dow Corning | US | chemicals | 134 |
| 25 | EPCOS | DE | semiconductor | 58 | 25 | Axcelis Technologies | US | semiconductor | 126 |

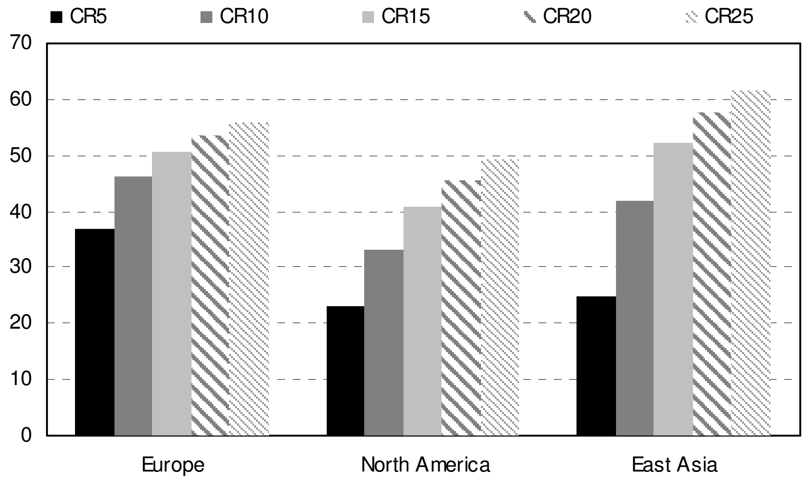
| **East Asia** | | | | |
|---|---|---|---|---|
| Rank | Name | Country | Sector | No. of patents |
| 1 | Tokyo Electron | JP | electronics | 1498 |
| 2 | Matsushita Electric Indust. | JP | electronics | 1392 |
| 3 | Samsung Electronics | KR | electronics | 1077 |
| 4 | Fujitsu | JP | computer | 903 |
| 5 | Nikon | JP | instruments | 736 |
| 6 | NEC | JP | telecommunication | 675 |
| 7 | Canon | JP | instruments | 659 |
| 8 | Sharp | JP | electronics | 646 |
| 9 | Hitachi | JP | electronics | 620 |
| 10 | Sony | JP | electronics | 605 |
| 11 | Semicond. Energy Lab. | JP | semiconductor | 554 |
| 12 | Fujifilm | JP | chemicals | 471 |
| 13 | Toshiba | JP | electronics | 437 |
| 14 | Sumitomo Electric | JP | electronics | 430 |
| 15 | Seiko Epson | JP | instruments | 407 |
| 16 | Tokyo Ohka Kogyo | JP | semiconductor | 305 |
| 17 | Shin-Etsu Handotai | JP | semiconductor | 271 |
| 18 | JSR | JP | electronics | 270 |
| 19 | SANYO Electric | JP | electronics | 269 |
| 20 | Shin-Etsu Chemical | JP | chemicals | 256 |
| 21 | LG Electronics | KR | electronics | 235 |
| 22 | Nitto Denko | JP | electronics | 230 |
| 23 | Ebara | JP | machinery | 215 |
| 24 | Rohm | JP | semiconductor | 209 |
| 25 | Showa Denko | JP | research | 206 |

Source: EPO: Patstat. ZEW calculations.

Infineon from Germany, followed by STMicroelectronics from Italy and ASML from the Netherlands, lead the list in Europe. Philips and the Commissariat à l'energie atomique follow. The top patenting firm in North America is Applied Materials. In East Asia, Tokyo Electron leads the list, followed closely by Matsushita Electric Industries.

The concentration of patent applications on a few applicants can be quantified by using concentration measures. Figure 4-16 shows the concentration of patenting activity in microelectronics on the basis of five concentration measures indicating the share of patents for which the 5 percent (CR5), 10 percent (CR10), 15 percent (CR15), 20 percent (CR20), and 25 percent (CR25) most patenting active firms account for.

**Figure 4-16: Concentration of patenting activity in microelectronics (EPO/PCT patents, 2000-2007 applications)**



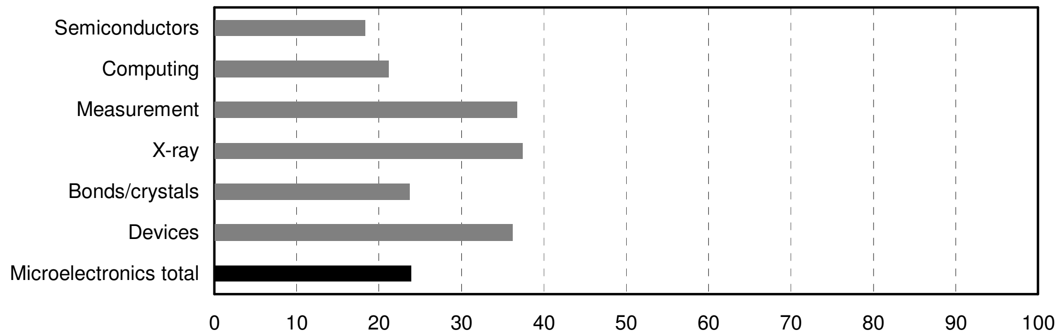

*Source: EPO: Patstat. ZEW calculations.*

Regarding CR5, it turns out that concentration is highest in Europe (37 percent), followed by East Asia (25 percent) and North America (23 percent). However, East Asia shows a higher number of firms with substantial patenting activity than Europe, leading to an overall higher concentration when CR25 is applied. Concentration in North America is generally lower.

***Links to other KETs***

Related to the issue of sector links is the degree to which microelectronics patents are linked to other KETs. One way to assess likely direct technological relations is to determine the share of microelectronics patents that are also assigned to other KETs (because some IPC classes assigned to a microelectronics patent are classified under other KETs). The degree of overlap of microelectronics patents with other KET patents by subfields is shown in Figure 3-18. Almost a quarter of all microelectronics patents has been assigned to other KETs too. High share of overlaps can be found for devices, measurement and x-ray (36 to 37 percent of all patents) while overlaps to other KETs are lower for bonds/crystals, computing and semiconductors.

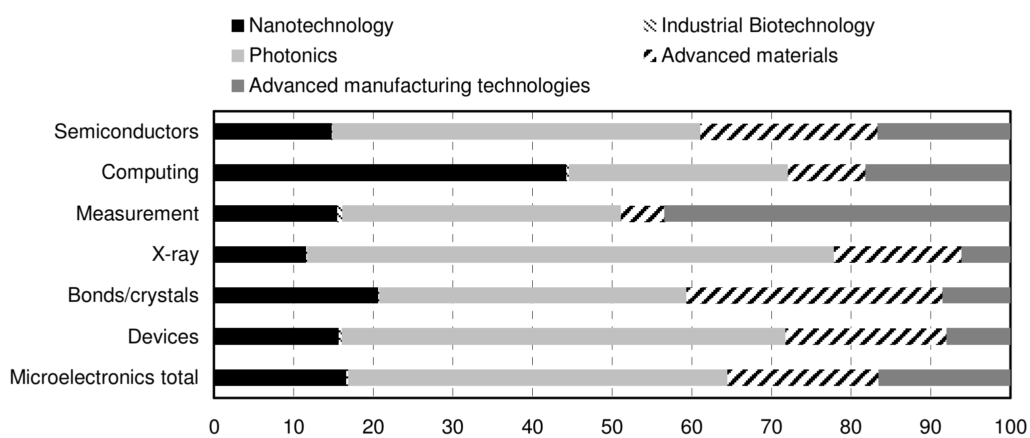
**Figure 4-17: Share of microelectronics patents linked to other KETs by subfield (EPO/PCT patents 1981-2007, percent)**




*Source: EPO: Patstat. ZEW calculations.*

For those microelectronics patents that are linked to other KETs, one can see that many of these patents overlap with the field of photonics (particularly x-ray, devices, semiconductors and measurement), indicating the increasing importance of photonics for technological advance in microelectronics (Figure 4-18). Microelectronics patenting is also linked to nanotechnology, advanced materials and advanced manufacturing technologies. The subfield of computing is strongly linked to nanotechnology while measurement has strong ties to advanced manufacturing technologies. Patents in the subfield of bonds and crystals often overlap with advanced materials. There is no overlap between microelectronics and industrial biotechnology.

**Figure 4-18: Links of microelectronics patents to other KETs by subfields (EPO/PCT patents 1981-2007, only patents with links to other KETs, percent)**




*Source: EPO: Patstat. ZEW calculations.*

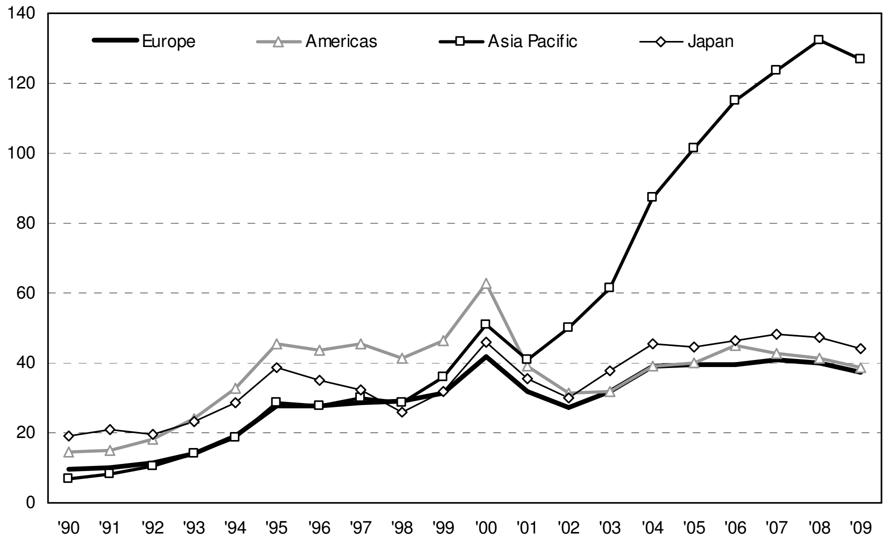
### 4.2.3. Market Potentials

The market potential of microelectronics becomes predominantly manifest in the semiconductor industry. Semiconductors are an intermediate input for a variety of sectors but they are particularly important for information and communication technology (ICT) equipment and embedded systems. In this respect, semiconductor production and shipments can be characterised as leading indicators of ICT product market trends.

Semiconductor production is a highly cyclical industry. During economic downturns production drops sharply but when the economy recovers, semiconductor production does so as well. Nevertheless, long-term growth prospects are very positive, given the general societal trend towards digital appliances, media, and mobile communication which is supported by strong consumer demand. Moreover, this trend is expected to be fuelled by higher semiconductor content per installed system, leading to a “digital upgrading” of the economic and social infrastructure. In this respect, semiconductor sales worldwide in current prices have increased by 10 percent annually since 1990. Between 1990 and 2000 the world market for semiconductors quadrupled from $50 billion to more than $200 billion, which was however followed by a collapse of the market in 2001 to less than $140 billion. Since then, sales have recovered and reached the original growth pattern. In 2008, the OECD reports a moderate growth of the semiconductor industry, the most recent data available, of 2.2 percent to $260 billion in current prices (OECD, 2008). With that market size, semiconductors amount to around one fourth of the total worldwide electronics industry which is estimated at €800 billion (BMBF, 2005). Earlier projections had, however, anticipated a total semiconductor market size of $280 billion. Owing to the recent economic downturn, sales had declined by 5.9 percent in 2009.

Regarding the market size in different world regions, Asia dominates with 68 percent of worldwide sales (2007) whereas Europe and North and South America each account for around 16 percent. Market growth in Asia except Japan has been more than 13 percent annually between 2000 and 2007 while Japan grew slightly and Europe and the Americas declined (OECD, 2008). Figure 4-19 shows the worldwide semiconductor market by region in the period from 1990 to 2009.

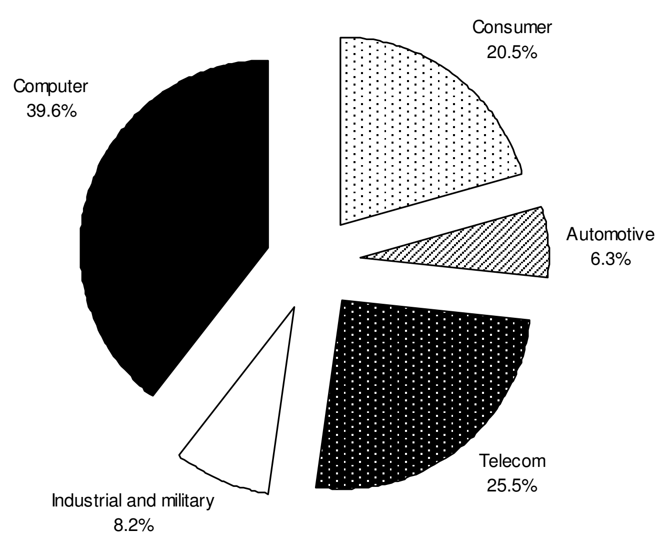
**Figure 4-19: Global semiconductor market 1990-2009, by region (billion US-$, current prices)**




*Figures for 2008 are preliminary and for 2009 are forecast.*
*Source: OECD, partly estimated, based on World Semiconductor Trade Statistics (WSTS).*

Regarding the final use of semiconductors, patterns have changed over the last years, reflecting shifts in final consumption and technological advances. While the final use in consumer electronics and all other products has increased in relation to the total final use, the use in computers has relatively decreased. Nevertheless, Figure 4-20 shows that with a share of almost 40 percent of total sales (2007), computers still dominate the final use for semiconductors, followed by the telecom market segment with around 25 percent.

**Figure 4-20: Worldwide semiconductor sales 2007, by market segment (percent)**




*Source: OECD, based on Semiconductor Industry Association (SIA).*

Semiconductor components also rapidly diffuse into other sectors like automotive or medical instruments. Europe is a particularly important market for semiconductors in automotive with a share of sales of 19 percent in 2008 compared with 8 percent worldwide (European Commission, 2009). Furthermore, microelectronic components are essential in civil and military aerospace in which Europe sustains a dominant position.

The prospects for the semiconductor industry can be differentiated into a short-, medium- and long-term horizon. Regarding the short-term perspectives, the financial markets and economic crisis has severely impacted business and consumer confidence worldwide. In the past, the semiconductor market has closely followed the development of GDP growth. As a consequence, less favourable conditions can be expected for the short-term development of microelectronics. In contrast to this, the medium-term global performance of the industry is seems as much more promising. In a survey of industry executives, KPMG predicts increasing sales of 6 to 10 percent over the next three years (KPMG, 2009). Wireless consumer electronics and computing together with a focus on green technology are identified as the most rapidly growing market segments. The expected growth rate is confirmed by the World Semiconductor Trade Statistics, projecting a market size of $270 billion in 2011 and a similar growth for the following three years (WSTS, 2009). Long-term growth projections are rare owing to the cyclical nature of the industry. However, there are indications of a long-term annual growth of 8 to 10 percent (WSTS, 2009). These long-term growth prospects, however, critically depend on a successful solution of the technical problems associated with the increased miniaturisation of semiconductors. Table 4-5 summarises available estimates and forecasts on the market potential in microelectronics and selected subfields.

**Table 4-5: Estimates and forecasts for the size of the global microelectronics market and selected subfields (billion US-$)**

| Subfield | Source | 2005/06 | 2007/08 | 2010/11 | 2012/13 | ~2015 | ~2020 | Cagr* |
|---|---|---|---|---|---|---|---|---|
| **Semiconductors** | | | | | | | | |
| Total | OECD (2008) | | 260 | | | | | 8.8 |
| Total | KPMG (2009) | | | | | | | 6-10 |
| Total | WSTS (2009) | 227 | 248 | 270 | | | | 3-7 |
| Analog/mixed signal devices | BCC (2005) | 31.7 | | 67.6 | | | | 13.5 |
| Advanced electronic packaging | BCC (2006) | 39.5 | | 57.6 | | | | 7.8 |
| Memory products (DRAM, NAND flash, etc.) | BCC (2010) | | 27 | | | 41 | | 7.2 |
| Sputtering targets and sputtered films | BCC (2007) | | 2.8 | | 5.9 | | | 16.1 |
| Thin-layer deposition | BCC (2007) | | 9.6 | | 16.7 | | | 9.6 |
| Thermal mgmt. technologies | BCC (2007) | | 6.2 | | 11.1 | | | 10.2 |
| Displays | BCC (2008) | | 0.1 | | | 0.2 | | 6.5 |
| Microelectro-mechanic systems (MEMS) | BCC (2008) | | 7.2 | | | 13.2 | | 10.6 |
| Atomic layer deposition | BCC (2008) | | 0.3 | | | 1.0 | | 10.6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ASIC | BCC (2009) | | | 18.5 | | 22.3 | 3.8 |
| **Bonds, electrolytes, crystals** | | | | | | | |
| Microfluids technology | BCC (2005) | 2.9 | | 6.2 | | | 13.5 |
| Chemicals/materials | BCC (2006) | 22.7 | | 34.8 | | | 8.9 |
| Dielectrics/substrates | BCC (2009) | | 14.5 | 13.5 | | 18.3 | 6.2 |
| **Total market** | | | | | | | |
| Electronics | BMBF (2005) | 800 | | | | | |
| Electronics | BCC (2007) | | 2,000 | | 3,200 | | 12.6 |

** Compound annual growth rate in nominal terms (percent).*

*Source: Compilation by ZEW based on the sources quoted.*

## 4.3 Success Factors, Barriers and Challenges: Cluster Analysis

Clustering can be viewed from three angles: production locations, research activity and investments indicating future (production) location. In terms of production output Asia is the largest geographical agglomeration with China accounting for 27 percent of production in 2007, South East Asia and Australia for 15 percent, Japan for 13 percent, North America for 20 percent and Europe for 21 percent (Innova, 2008). This trend towards clustering of production in Asia is likely to continue with share of worldwide investment in microelectronics in Europe declining. In 2007, 10 percent of global investments of €28 billionin microelectronics were in Europe, compared to 48 percent in Asia. In 2009, China led the world last year in new semiconductor factory construction, with six semiconductor fabrication plants (further referred to as fabs), followed by Taiwan with five, and Korea, Japan, the European Union, the USA and Southeast Asia, all with one a piece (McCormack, 2010). Global semiconductor production is hence dominated by China in Asia, while European production is comparable in level to America and Japan (OECD, 2009).

However, in terms of semiconductor design (R&D) the global distribution looks much more favorable for Europe. In 2006[43], Europe's share in global semiconductor design was 35 percent compared to 22 percent of production. This specialisation is even more apparent in automotive (46 percent design and 30 percent production), industrial (43 percent design and 30 percent production) and telecommunications (40 percent design and 35 percent production) (Innova, 2008). This specialisation is also documented in the literature by so-called fabless semiconductor firms, which only design and market semiconductor components, primarily in advanced economies. At the same time, they rely on specialised manufacturers, so called semiconductor foundries, to make the products in locations with low labour costs, such as Asian countries (Mowery, et al, 2007).

[43] The most recent R&D data of the OECD Technology Outlook 2008 does not go beyond 2006.

This strength in design is also reflected in a number of European clusters with particular semiconductor competencies which are recognised world-wide. These clusters address all application fields and have access to the most advanced technologies globally. Examples of recognised European clusters in the field are the Grenoble cluster in France, the Eindhoven cluster in the Netherlands, the Dresden cluster in Germany and the Leuven cluster in Belgium.

For this analysis we have chosen to compare one European cluster with one international counterpart. With the Grenoble cluster being one of the worlds best known regions for micro- and nanoelectronics, we chose to compare this cluster with the Ontario region (Canada), which exists since the 1970s and is a leader on microelectronics application markets.

Comparing cluster however is not without pitfalls. Microelectronics cluster are heterogeneous in their activities. For example the difference in business models focusing on continued miniaturisation versus a diversification of new functionalities makes a comparison along number of employees or levels of investment little meaningful. However, one shared commonality across clusters is the excellence of their applied research (Collet, 2007). This will be hence the prime focus of our comparison including how policy can support to achieve this ‘global excellence’.

### 4.3.1. Micro- and Nanoelectronics Europe: The Grenoble cluster

***Introduction***

The Grenoble cluster has one of the highest concentrations of scientists and high-tech companies in the world and its activity is targeting many industrial sectors, ranging from industrial process automation to consumer electronics, via energy consumption optimisation, to the world of connectivity and mobility (Nanomicro, 2010). What is particularly recognised about the cluster is its market driven focus and coordinated effort at all administrative levels (Innova, 2008). In the field of micro- and nanoelectronics 3,000 people are employed by research and 21,700 by business, while 1,200 graduates leave higher education per year. In comparison, the closely related sector of IT and software employs 14,000 people with 2,200 graduates annually (Innova, 2008).

The micro- and nanoelectronic field as one activity in the Grenoble cluster is also related to a broad field of applications[44], focusing on the communications segment while in the last years shifting more and more to industrial applications. Design activities in the cluster are very high compared to production, representing half of the output (Innova, 2008).

[44] Communications 38 percent, cards 20 percent, military and aeronautics (20 percent), automotive (20 percent) to home applications (2 percent).

Some 500 companies work in the field of micro- and nanoelectronics, including the leader ST Microelectronics, Freescale (Motorola) and NXP, but also several start-ups like Soitec, designing and producing silicon on insulators being a successful flagship. Research in the area is led by ST Microelectronics and Soitec, and the national research organisation CEA (Commissariat à l'énergie atomique). The LETI, a CEA centre focused on electronics and IT, hosts some 1,500 researchers.[45] In 2006, LETI has created a collaborative research environment called Minatec bringing together researchers from its centre with partners from industry and university located on the central campus. 18 joint laboratories have been setup with manufacturers since.[46] The cluster can hence be characterised as a global centre of excellence in its field with a very interdisciplinary and collaborative research environment. Furthermore, the Grenoble cluster also benefits from a strong research environment in the wider region and the Rhône-Alpes region enjoys easy access to major industrial hubs in northern and southern Europe (Innova, 2008).

***Short history of the Grenoble cluster***

The high-tech cluster around Grenoble dates back to the activity of the French nuclear research organisation CEA, founded in 1945. Since its existence it has been addressing major scientific challenges in various fields, including nuclear energy, but also micro- and nanotechnology, astrophysics, medical imaging, toxicology, biotechnologies, etc. The decreasing French defence budget after the cold war period resulted in an increased focus towards private sector applications. The micro- and nanoelectronics activities have benefitted from substantial investment and partnership programmes between industrial firms and publicly funded laboratories in the semiconductor industry in France since the early 1990s. This has fostered a network of expertise in France, centred on major players and laboratories such as ST Microelectronics, LETI, etc. with Grenoble as one of the major geographical centres (Innova, 2008). This has made Grenoble one of Europe's leading centres for microelectronics.[47] Cluster development can be characterised by several important events in the last two decades. In 1992, STMicroelectronics, Léti-CEA and France Telecom R&D joined forces for research in submicronic technologies, with STMicroelectronics handling production. This resulted in leveraging public and private R&D but also production knowledge to improve innovative output. Secondly, with semiconductor fabrication facilities becoming more and more expensive[48], Freescale (Motorola) NXP Semiconductors and STMicroelectronics set-up a joint facility called Crolles 2 in 2002. Lastly, in 2006 the CEA-

[45] http://www-leti.cea.fr/en/Discover-Leti/About-us
[46] http://www-leti.cea.fr/en/Discover-Leti/About-us/History
[47] http://www.minalogic.com/en/environnement-grenoble.htm
[48] The cost of a state of the art semiconductor production fab is continuously increasing over time. Estimates vary between $3 and $8 billion making such investment for very few companies possible to finance. But also costs for designing system-on-chips are increasing ranging between $20 to $50 million (Scott, 2007)

Leti research centre and the Grenoble Institute of Technology set up a new centre innovation in micro- and nanotechnologies (Minatec) bringing together partners from industry, universities and research in a collaborative, open innovation environment. This impressively shows the historic development of the cluster not only showing a high concentration of actors in the field of micro- and nanotechnology but also fostering intensive collaboration between industry, research and public authorities.

***System failures and system drivers for growth***

*Infrastructure*

As outlined in the previous section the cluster goes back to research infrastructure of CEA after World War II. The cluster infrastructure has hence a strong evolutionary component. Next to the wider research infrastructure outlined in the introduction, the Grenoble cluster benefits from a very well organised and integrated infrastructure combining four core elements: 1) several leading research laboratories (including CEA-Leti, INRIA, CNRS, and Verimag), 2) a number of prestigious universities and engineering schools including the Grenoble Institute of Technology, 3) unique scientific facilities including the Minatec research campus and the Synchrotron facility, and 4) a strong eco-system of innovative firms. Leading firms in the micro- and nanoelectronics field from large to small, including STMicroelectronics, NXP Semiconductors, Freescale, France Telecom, Schneider Electric, Bull, Soitec, Atmel, Trixell, Sofradir, Sofileta , Ulis, Silicomp, and Teamlog are combined with highly innovative start-ups. All these actors together represent a diverse scientific community of 38,500 people (Minalogic, 2010). Lastly, the local government plays an important role coordinating activities and promoting the cluster to attract firms but also generate financial support from French and European authorities.

*Institutions*

*Rules and regulations:* microelectronics, in contrast with bio- or nanotechnology, is not a radically new technology with potential health risks in need for regulation. Also the nanoelectronics field does not seem to pose new health risks with production contained in highly controlled environments and output comprising solid electronic components. However, recycling of electronic goods is increasingly regulated with electronics waste representing an increasing share of total waste and miniaturisation making recycling more difficult. Regulation has not affected the formation of the Grenoble cluster.

*Norms and values:* affect the cluster initiative at several levels. On the one hand a global trend in research towards centres of excellence can be observed. Grenoble as one of the European centres of excellence in the field of microelectronics has the scale and expertise to attract global research activities of firms and financial support from national and European authorities.

On the other hand also at the cluster level, norms and values of members seem to make a difference. Grenoble is an example of coordinated efforts. Firms collaborate with universities and research centres institutionally in the form of Minatec but also informally. Furthermore, regional authorities, branch organisations, together with universities and research centres join efforts promoting the cluster using the same ‘pitch’ in developing and organizing support for the cluster. Secondly, advised by industry and through continuous benchmarking efforts, CEA is actively setting strategies that combine the increasing capabilities, fostering new ones and converging them with future trends (Innova, 2008). These activities characterise a cluster culture that plays an important role in the success over the last decades.

*Public policy:* plays a critical role in enforcing the underlying research infrastructure trough public investments. Since the beginning of the 1990s, the semiconductor industry in France has benefited from significant investments and partnership programmes between industrial companies and public laboratories. CEA-Leti being often the leader behind new initiatives and activities in the cluster is a public research centre. The Minatec innovation pole being one of the examples of new LETI initiatives, with investments of around €193 million was for example financed half by local authorities. And also the Minalogic partnership brining together research partners from industry, university and public research is hence partly publicly funded. (Innova, 2008) Next to that the cluster also benefits from national funds in support of nanoelectronics. France subsidises the alliance between STMicroelectronics NV, IBM Corp. and the CEA, commonly referred to as ‘Crolles 3’. Total investments are expected to be around €3.6 billion, with national and local government funding exceeding €500 million. The rationale of these subsidies is to create the conditions for an exceptional ecosystem and keep the micro and nanotechnology industry in Grenoble-Isre at the top of the global ranking.[49]

*Interactions*

Interactions play a critical role in cluster success. Interactions play at two levels: 1) between actors in the cluster, and 2) between the cluster and the world.

Two organisations play a critical role for interactions in the cluster: Minalogic and Minatec. Minalogic is the ‘pole de competititve’ being part of the national cluster strategy. Minalogic consists of a management board with representatives from across public and private actors from the cluster region with high influence also in their ‘own’ organisation. This ensures that

[49] http://www.eetasia.com/ART_8800534241_480200_NT_120af4d9.HTM

ideas and decisions of the cluster board can readily be executed. Minalogic's role is to bring together major corporations, small and mid-sized businesses with public organisations and government agencies and to identify new activities for the cluster to develop (Gibney and Murie, 2008). Minatec on the other hand is a research campus focused on micro and nanotechnologies at the heart of the Grenoble cluster that aims to create spillovers between public and private research actors bundling efforts through co-location. The campus is home to 2,400 researchers, 1,200 students, and 600 technology transfer. Minatec campus staff (9) identifies new synergies, organises meetings for residents, develops communication tools, and promotes the campus and cluster internationally.[50] Next to the cluster motors of interaction outlined above, firms also extensively collaborate informally and bilaterally. One example of such bilateral collaboration is t the globally-recognised Crolles 2 Alliance.

The high visibility and status of the cluster also generates high levels of interaction with the outside world. Each year some 6,000 students and 400 academics and researchers from abroad study or work in Grenoble-Isère. At the same time many of the Grenoble scientists and engineers can be seen around the globe (Innova, 2008).

*Capabilities*

Capabilities of actors can be best described by strong, collaborative technological capabilities. The strength lies in the interaction of (public) research actors (CEA-LETI, etc.) interacting very goal oriented with a number of leading firms (ST Microelectronics, Freescale, NXP etc.). This creates an innovative environment that attracts scientists and firms globally to come and work at the Grenoble cluster. Furthermore, with more than 50 percent design output the cluster is very much focused on a high value added segment (specific chips for specific clients that cannot be applied to different products) that allows to financing the costly infrastructure and environment.

***Market failures and drivers for growth***

*Market structure*

The cluster is research focused and strongly supported by public research actors. The public research organisation CEA-LETI also plays an important role to identify future activity areas. The cluster is very open to new players, aiming to attract firms globally to locate at Grenoble. There are many large international firms with research activities located at the cluster. Furthermore, there are many SMEs and increasingly more start-ups founded at the cluster.

[50] http://www.minatec.com/en

*Market demand*

The Grenoble cluster is very market focused in its activities and has identified a market niche. Its activities are focused on design output, with Asia having a competitive advantage in microelectronics production and focuses on specific chips for specific clients, which will be produced by (Asian) foundries. This is in contrast to other clusters in Europe such as Dresden, Germany, that have large manufacturing capabilities, which compete directly with Asian activities.

***Conclusion***

Compared to other clusters that are built on an industrial heritage going back to the 19$^{th}$ century, the cluster is relatively young being founded after World War II with the founding of the French national research centre CEA. Especially in the first decades this was the key actor at the cluster. However, with military spending decreasing strongly with the end of the Cold War the cluster had to restructure taking a much more market oriented focus towards commercializing research. Particularly in the last two decades the cluster has developed very dynamically being frequently named as a success example in Europe. Key events have been the joint industry initiative Crolles, currently in its third stage (Crolles 3), and the Minatec campus where public research, university researchers and industry researchers work jointly together creating sufficient scale to work at world leading level.

One of the key strengths of the Grenoble cluster is its strong research base. Several leading research laboratories and prestigious universities provide a rich pool of leading knowledge and high skill labour supply that innovative firms thrive on. CEA-LETI through its Minatec initiative takes a special role of a anchor organisation at the cluster that at other cluster a large MNE plays (e.g. Philips at the Eindhoven cluster). Next to the scientific base the cluster is very well organised and coordinated. This means that scale is created by aligning the actions of the different actors and the coordination board comprises representatives from all important actors that can directly put ideas into action. This strong coordination also means that the cluster is very effective at lobbying for resources at local, national and European level allowing it to attract world leading firms also using financial incentives.

*Public funding*

Public funding of basic research activities and infrastructure are a key element for the eco-system of the Grenoble cluster. The cluster also has very strong coordination power being able to lobby effectively for national and European resources.

*Tax incentives*

Tax incentives are not known to play a role for the cluster development. However, public authorities have subsidised the joint initiative of called Crolles.

*Public procurement and lead markets*

Public procurement and lead markets have essentially played no role for the Grenoble cluster. Many high-tech firms are located at the Grenoble cluster for the research environment. While the cluster is very 'demand' driven customers are not directly co-located. Instead Grenoble concentrates on one aspect of the value chain, namely micro- and nanoelectronics design, with customers of end-products globally dispersed across several industries. While work in the past was focused on 'demand pull' activities such as improved mobile phone functionality, the decisions for these functions were external to the cluster. Today, "idea labs" at the cluster aim to develop solutions for the products of tomorrow (Innova, 2008).

### 4.3.2. Micro- and Nanoelectronics Canada: The Ontario region

The Ontario province is located in east-central Canada, comprising the largest population of any Canadian province and being the second largest after Quebec in territory. It is bordering with the Quebec province in the East, also making up part of the photonics corridor as outlined in the Photonics chapter. There is a strong link between microelectronics and photonics.

The Ontario province comprises several ICT clusters, with different specialisations. These are the Greater Toronto Area, Ottawa and Kitchener/Waterloo. While Toronto is the largest agglomeration, it is also the most diverse. The Ottawa cluster on the other hand is much more specialised in telecommunications equipment, microelectronics, photonics and software (Wolfe, 2002). Consequently, the Ottawa cluster will be focused upon in this analysis.

The Ottawa microelectronics cluster includes semiconductor and electronic component design, computer hardware design, and manufacturing and applications for defence and private industry. There were over 100 microelectronics companies, including over 40 fables semiconductor companies in 2003. The semiconductor activities are more diversified and resistant to slowdown compared to computer hardware (Ottawa, 2003). Large firms that play an important role for the cluster include MDS Nordion, Mitel Networks, Mosaid, Nortel Networks (R&D), Hewlett-Packard (Canada) Ltd., Alcatel Canada, Cisco, and semiconductor firms such as Freescale Semiconductor Canada, Tundra Semiconductor, and Chipworks Inc. (OCRI, 2006).[51]

The Ottawa cluster is supported by two key national actors in semiconductors: 1) the Strategic Microelectronics Council (SMC) part of the Information Technology Association of Canada, and 2) the Canadian Microelectronics Corporation (CMC). Located in Ottawa, the SMC is a

[51] http://www.ottawaregion.com/Business_in_Ottawa/Industry_Overview/semiconductor.php

not-for-profit national industry association that works to articulate a national strategy for the cluster. The CMC, also a not-for-profit organisation, is dedicated to facilitating strategic alliances between the semiconductor industry and Canadian universities and educational institutions helping to ensure the production of well-trained graduates (OCRI, 2006).

### *Short history of micro- and nanoelectronics in the Ontario region*

The Ontario region has a long tradition in microelectronics with the first firm, Microsystems International Ltd. (MIL), founded in Ottawa in 1969 as a joint venture between Nortel Networks and the Federal Government to attract highly qualified experts, notably from the United Kingdom. In the 1970s and 1980s a vibrant cluster emerged around the quickly developing market for telecommunications equipment driven by a number of spin-offs from large firms in the region. At this time also the first firms in the Toronto and southern Ontario clusters emerged, fuelled by public investments and research capabilities of the University of Toronto.

By the 1990s, Ontario was a significant player in the global silicon chip business, with several world-leading centres of excellence in the industry. However, with the burst of the dotcom bubble the industry had to diversify beyond telecommunications equipment. In spite of this nascent diversification the global downturn in demand for telecommunications equipment around 2001 and the closure of Nortel’s semiconductor factory in Ottawa dramatically stalled the growth of Ontario’s microelectronics industry. The aftermath of these developments lingers until today. Together with the relatively small size and weakness compared to other microelectronics cluster around the world, this led to efforts to *revitalise* the microelectronics industry in the region. It is proposed to develop four centres of excellence for microelectronics in 1) health care technology, 2) automotive, 3) broadband and 4) multi-media applications (Scott, 2007).

Nevertheless, Ontario remains an important microelectronics region with many international firms still located there, and 65 percent of survey respondents stating that the presence of the cluster is the reason for them to be located there (Scott, 2007). One of the recent famous success examples are Research in Motion and its Blackberry products located at the Waterloo cluster.

### *System failures and system drivers for growth*

*Infrastructure*

The Ontario province has a strong research infrastructure with a number of leading public research institutes, universities but also research centres of large corporations. These are the Communications Research Centre (CRC), which is the federal government’s leading communications research facility (for details see introduction). The National Research Council (NRC) Institute for Information Technology located in Ottawa and Atlantic Canada. Its mission is, in contrast to the CRC, to support industry through collaborative R&D programmes. At the Ottawa cluster the microelectronics sector further benefits from the NRC institute for microstructural sciences that through its research enables future hardware development. Lastly, in 1995 the NRC founded the Regional Innovation Centre in Ottawa to link NRC resources with industry, academic research and government. Part of its activity is to assist NRC scientist with commercialising ideas through spin-offs. (Wolfe, 2002). The Ottawa cluster further benefits from a number of universities, including the University of Ottawa, Carleton University, Algonquin College, and Université du Québec en Outaouaistd (Ontario, 2009).

This public research infrastructure is complemented by a number research centres of large multinationals that also act as anchor firms in the cluster providing an attractive eco-system for SME. Three firms are particularly relevant in this context: 1) Nortel Networks, 2) Alcatel (formerly Netbridge Networks), and 3) Mitel that spun-off its semiconductor activities (now Zarlink semiconductors) (Wolfe, 2002). These anchor firms play a crucial role as they contribute to the home grown success of the microelectronics cluster of Ottawa that attracts research activities of international firms again re-enforcing the quality of the cluster. In their view the strong anchor firms, combined with a strong local pool of talent, and high growth rates have made it very attractive for MNEs and venture capitalists to invest in Ontario (e.g. Cisco, Nokia) (Wolfe, 2002).

There are two notable institutional factors that have affected the evolution of the Ontario microelectronics cluster: 1) the highly skilled labour pool and commercial talent, 2) a strong cluster policy supported by federal and regional funds, aiming to coordinate efforts between industry, academia and government.

*High skilled labour pool and commercial talent*

Generally, Canada has a highly skilled workforce and several world leading microelectronics researchers have contributed to the success of the cluster’s evolution (CMC, 2009). Also regional organisations praise Canada’s industrial culture as concentrating on commercializing new technologies for the global market. (FAITC, 2009). However, some also point to problems in the high skilled labour supply in the late 1990s contributing to the problems the cluster has and issues with the local culture. Scott (2007) points to concerns of local actors that there is a general lack of desire to excel in Ontario’s microelectronics industry by both public and private players. Also experienced research and business people that have founded companies in the early years of the cluster are retiring and leaving the industry. (Scott, 2007)

*What is the role of public policy?*

Cluster policy plays an important role for the Ontario cluster, with 65 percent of firms participating in a survey stating that they are located in Ontario owing to the existence of the cluster (Scott, 2007). Also the birth of the cluster was a direct result of policy intervention with a public private joint venture founding the first microelectronics firm in Canada, Microsystems International Ltd, in 1969. The role of public policy focuses on three main components: 1) supporting a sound public research base 2) attracting corporate research activities, and 3) facilitating the commercialisation of research by linking different type of actors (Wolfe, 2002). Since the burst of the dotcom bubble public policy focuses on revitalizing microelectronic activities in the region. Funding research and collaboration plays a key role on this.

*Financing of Research*

The Canadian government claims that it leads the OECD as the largest active funder in science and technology research and development. Canada also operates a R&D tax-credit programme under which foreign companies can access 35 percent tax credit by creating a Canadian-controlled private corporation and can access 25 percent tax credit by building a Canadian subsidiary that carries out qualifying SR&ED activities in Canada (FAITIC, 2009). This is complemented with provincial tax programmes, in the case of Ontario's R&D super allowance amounting in 2002 to $100 million in tax credits. (Wolfe, 2002). In practice this results in companies investing $49 net for $100 R&D output.

In addition to tax credits, a number of direct federal and provincial funding initiatives strengthen the microelectronics sector. These largely take the form of supporting networks and (collaborative) research programmes. Examples of these are the Ontario S&T programme supporting R&D, a number of centres of excellence both federally and provincially funded, including important actors such as the Canadian Institute for Telecommunications Research, Micronet but also linking excellent university research with industry. In addition Ontario province operates a Research and Development Challenge Fund (ORDCF), the Ontario Innovation Trust, the Ontario Research Performance Fund next to a number of technology specific initiatives (Wolfe, 2002).

*Venture capital*

While availability of capital for start-ups is an issue in Canada generally, the Ottawa microelectronics cluster does particularly well. According to Ontario (2009) two-thirds of U.S. venture capital investment in Canada goes to Ottawa tech firms. This is also supported with examples from Wolfe (2002) who describes the takeover of Skystone System by Cisco as a breakthrough for the Ottawa cluster with many local firms grown before sold to multinationals.

One particularly important actor in the context of venture capital is the Ontario Centre of Excellence for Communications that has spun off about 25 companies in the period 2002-2007. The Centre co-invests in R&D and commercialisation for leading-edge technologies, and helps move the results to market through existing companies or spin-off enterprises. It is hence not confined to microelectronics and also plays a role in developing new activities. One example is Distil Ineractive, that was a fledgling start-up initially supported with an investment of $50,000 to create a partnership with researchers at the University of Ottawa. After promising results Distil was further supported with $250,000 through the Accelerator Investment Program. This helped Distil to attract a $700,000 investment from GrowthWorks Canadian Fund. Distil Interactive has received follow up funding of $2.2 million by GrowthWorks in 2007 employing 25 people. The Centre is funded through the Ministry of Research and Innovation. Staff expertise and experience have produced a consistent track record of successful commercialisations and built strong partnerships with the research community, investors, and industry (Ontario, 2007).

However, despite the comparatively good access to venture capital there are other barriers for start-ups perceived. Scott (2007) reports that the loss of the LSIP programme in Ontario left a large in early stage funding and that cash-refunds from the SR&ED tax credit system are paid with delay creating cash-flow issues particularly relevant to start-ups. Also the focus of the tax credit system on early stage research, not including later stages of 'development', are seen as a desirable extension by local start-ups (Scott, 2007)

*Intellectual Property Rights*

One of the issues related to public funding of technology developments is that Intellectual Property (IP) is shared or owned outright by the university or government agency involved in the project. According to some local actors this potentially inhibits corporate growth since the companies involved cannot directly commercially exploit the IP. This issues is currently addressed by the Ontario Ministry of Research and Innovation (Scott, 2007).

*Interactions*

Compared to other clusters there seems to be no dedicated microelectronics cluster organisation or network for the Ontario region, nor the Ottawa cluster. Instead the two earlier outlined organisations SCM and CMC, both located in Ottawa are dedicated to the development of the microelectronics sector more broadly in Canada, although located in Ottawa.

Interaction at the cluster level comprises two aspects: 1) interaction between cluster actors, and 2) interactions with actors of related economic activities. Several initiatives support collaborative research efforts between industry and academia and firms (as outlined in the financial support section). However, it was noted in the past that interaction at the provincial level (Ontario) is hindered by the large geographical spread, necessarily limiting interaction to the senior level between organisations (Scott, 2007). Interactions at working level hence take place within the three Ontario microelectronics clusters Ottawa, Toronto, and Waterloo. Secondly, the microelectronics sector in the Ottawa sector has strong interaction with the telecommunications equipment, software, and emerging photonics sector.

*Capabilities*

Compared to other global microelectronics clusters the Ottawa cluster shows a strong concentration on R&D activities. Its strength is based on the national Communications Research Centre (CRC), two other NRC institutes and a number of universities. These often collaborate with local firms, having produced many key innovations in the field. This is complemented by strong capabilities of firms, both in research and marketing. Nortel alone accounts for almost 20 percent of all industrial R&D expenditures in Canada and hires one third of all Masters and Ph.D. graduates in electrical engineering and computer science from Canadian universities. This concentration is even more visible in the telecommunications sector, with 90 percent of Canada's R&D in industrial telecommunications conducted in the region (Wolfe, 2002). However, what is also emphasised is the drive in the region to commercialise and to take a global focus. A number of successful niche companies have been set-up by (university) researchers in the past indicating a conducive climate to commercialisation.

***Market failures and drivers for growth***

Anchor firms, which are large firms surrounded by many smaller firms (e.g. suppliers), have played a key role in the cluster's evolution. They represent an important source of demand for many smaller firms. The first anchor firm being Nortel Networks, but in the meantime these are complemented by (research) facilities of a number of large multinationals (Cisco, Alcatel etc.). The cluster is very open to attract outsiders with preferential tax credits to attract foreign firms.

But Ontario is also the most populous province in Canada and also the largest consumer of ICT products in Canada. This can be attributed to the high number of corporate headquarters located in the province, more specifically in Ontario's three high-tech clusters, (Toronto, Ottawa and Waterloo). In addition to this strong home market, microelectronics is a global industry sector. Access to the US market is facilitated through geographic proximity as well as the NAFTA free trade agreement, a common language and cultural and business similarities (DoC, 2007). Next to the US Canadian microelectronics firms primarily invest in China, India and Europe (Scott, 2007).

Lastly, public procurement is identified as a means to promote economic development, innovation and investment in the microelectronics sector by the Ontario government (Ontario, 2007).

***Conclusion***

The Ontario, and particular Ottawa, cluster are a relatively old microelectronics cluster dating back to the late 1960s. It is located in the most populous province of Canada with many firm headquarters representing a lead customer base. It is located close the US markets and part of a larger microelectronics / photonics corridor across Ontario and Quebec. Industry benefits from a strong research infrastructure including national research institutes and a number of Universities. The Ottawa cluster has a strong specialisation in telecommunications equipment, which led to a state of crisis after the dotcom bubble resulted in the closing of a number of production plants. Consequently, the cluster is in a state of re-vitalisation identifying new opportunities, aiming to found new centre's of excellence in: 1) health care technology, 2) automotive, 3) broadband and 4) multi-media applications

*System and market failures and drivers*

There are two key components for the evolution of the microelectronics cluster in Ontario going beyond the specific aspects highlighted below. This is a sound research base comprising key national research institutes and universities producing high level knowledge. However, they also provide stable employment for highly skilled people in the field that can take the risk to start own commercial ventures. Secondly, the culture of the people in the region with their commercial focus is an important component having contributed to the evolution of the cluster.

*Public funding*

Canada claims to be the largest R&D spender in the OECD. This is invested in a strong research base including specific research institutes as well as universities. Furthermore, national as well as provincial funds are targeted at specific technology development initiatives, funding for industry-university collaborations as well as supporting start-up companies. However, no dedicated cluster organisation seems to exist or receive funding. In that sense public funding is essential for the research base of the cluster as well as fostering collaboration between cluster actors.

*Tax incentives*

Tax incentives play a very important role to attract international firms to locate their research facilities in the region. The tax credits are to a large extent nationally and not restricted to a specific cluster but are complemented in the case of Ontario with provincial tax credits.

However, tax credits alone are not sufficient to attract firms. High quality labour supply, a commercial environment and a well functioning cluster are at least as important.

*Public procurement and lead markets*

No role of public procurement was identified. However, in the plans for re-vitalisation of the microelectronics industry public procurement is named as a tool for development.

### 4.3.3. Conclusion on microelectronics cluster benchmark between France and Canada

*Strengths and weaknesses*

One of the key strengths of the Grenoble cluster is its strong research base comprising several leading research laboratories and prestigious universities providing a strong high skill labour pool. Its key asset in this respect is the Minatec campus where public researchers, university researchers and industry researchers work jointly together. A central role for development of the cluster plays CEA-LETI through its Minatec initiative taking the role of anchor organisation. Furthermore, a cluster board with representatives from all important actors that can directly put ideas into action ensures that plans can be put into practice effectively. This strong coordination also means that the cluster is very effective at lobbying for resources at local, national and European level allowing it to attract world leading firms also using financial incentives.

Particular strengths of the Ontario microelectronics region are a strong research infrastructure comprising key national research institutes and universities, an entrepreneurial culture, a slightly skilled and stable labour pool, a local lead customer base with many corporate headquarters located in the province, and its close location to the large US market. A particular weakness of the region after the dot-com bubble is the strong specialisation in telecommunications equipment requiring ongoing revitalisation efforts.

*Public policy, funding and tax incentives*

Both the Ontario and Grenoble cluster have been supported in their development with public funds both from national and regional actors. The infrastructure is supported in both cases by strong public efforts to coordinate cluster development and by providing public funding to stimulate R&D, collaboration and start-ups. In contrast to the Grenoble cluster there seems to be no strong cluster identity developed in Ontario. However, this can be explained with a much larger geographical spread and a number of sub-clusters.

Differences in policy emphasis:

Whereas there cluster development in Grenoble is very research led, in Ontario microelectronics activities started with the founding of a public-private joint venture, now known as the microelectronics firm Nortel.

Furthermore, the local government in Grenoble took the lead in cluster development, while in Ontario it was driven by a number of spin-offs from large firms in the region.

Also, the development of the Grenoble cluster is pre-dominantly led by regional actors, whereas most microelectronics initiatives in Canada are nationally oriented (SCM, CMC). However, most of the Canadian national activities are based on Ontario with strong regional impact.

A large difference lies in the exceptional tax incentives and other incentives the Canadian government provides for companies to locate their research activities in Canada. The tax incentives significantly alter the cost structure for firms. Every $100 investment in R&D, comes at a net cost of $49 because of several national and regional tax incentives. This makes the area particularly attractive for R&D activities of large foreign corporations that have the scale and capability to benefit from such incentives.

*Lead markets: The role of lead actors / anchor firms*

Both clusters have strong anchor organisations that have played an important role in the development of the cluster. In case of Grenoble, the national nuclear agency CEA occupies this role, while in the case of Ontario it is the company Nortel. These lead actors provide

A very strong science base that in contrast to universities is very application oriented;

A critical scale of employment having positive effects for the local labour markets by attracting and retaining highly skilled labour;

Significant numbers of and spin-offs creating a dynamic business environment;

International linkages and visibility strengthening the competitive position of the cluster globally and acting as an international magnet for high skilled talent.

From these clusters we see how important lead organisations for cluster development can be. They play an essential role in helping a cluster to develop. Where a number of smaller companies will find it hard to reach critical mass and international visibility, the larger companies can provide exactly that. But cluster success relies on the combination of strengths of large and small firms forming a unique eco-system, where small firms are essential for creative ideas and exploring new grounds, which can be exploited with the experience and resources of larger firms.

The Ontario cluster is the only cluster where we have found explicit attention to the role of public procurement to stimulate microelectronics development. However, this is only stated as an intention in context of the cluster regeneration. The extent to which this is implemented is not known. As in the case of other KETs it is difficult to imagine how an effective public procurement strategy in the case of microelectronics might look like as many applications target market segments with industrial customers (B2B).

**Table 4-6: Summary of findings from microelectronics cluster comparison**

| Cluster | **Microelectronics Grenoble - France** | **Microelectronics Ottowa Canada** |
|---|---|---|
| History | After World War II nuclear research agency laid basis for cluster development.<br>Long history of support of research and R&D collaboration (since 1990)<br>Two cluster platforms: Minatech and Minalogic. Both are very active in promoting collaboration, R&D, marketing and internationalisation | First dedicated microelectronics firm founded in 1969. Strong growth with telecommunications equipment boom in 70s/80s<br>Large lasting crisis following dotcom burst → need for regeneration of cluster<br>Two national platforms: SMC: Strategic microelectronics council (focus on industry and strategy), CMC: Canadian microelectronics corporation (focus on alliances and PPP)<br>No dedicated local cluster platform |
| Size | ~500 firms; 38,500 people | ~100 firms |
| Classification | Mature | Post-mature / regeneration |
| Infra-structure | The cluster claims to have the highest concentration of scientists and high-tech companies in the world: research laboratories, universities/ engineering schools<br>Collaborative research environment stimulated by Minatech (industry-research-public triangle)<br>Cluster also has an important joint semiconductor fabrication plant (Crolles2 & 3) | Strong knowledge infrastructure comprising public and private research facilities and universities/ engineering schools.<br>Many R&D facilities of large microelectronic firms. |
| Institutions | *Rules and regulations*<br>R&R have a minor role, only recycling laws in electronics play a role, miniaturisation makes recycling more complex<br>*Norms and values / culture*<br>The cluster has a very strong cluster culture<br>Well established cluster identity attracting new entrants because of reputation<br>Open culture stimulation exploration and new ideas | *Rules and regulations*<br>R&R have a minor role, only recycling laws in electronics play a role, miniaturisation makes recycling more complex<br>*Norms and values / culture*<br>Strong commercially focused culture<br>No strong cluster identity, but generally open culture.<br>If IPR rests with research organisations this is perceived as sometimes blocking path to commercialisation by companies |
| Public policy / funding / taxation | Generous funding of research and collaboration since 1990's, both from regional and national actors.<br>Very focused cluster vision and strategy implemented by key local actors bringing together industry, research and government actors.<br>Also the European Union plays an important role through their Framework Programmes and cluster initiatives. | Strong national investments in science and research.<br>Support for research collaboration and commercialisation of research<br>Canada has most favourable R&D tax scheme of Western economies ($49 costs for $100 ´R&D investment)<br>Network and collaborative research support<br>2/3 of US VC goes to Ottawa cluster<br>Many spin-off of large research centres and large firms |
| Interactions | Collaboration stimulated by Minalogic | Industry-science collaboration targeted |

| | | |
|---|---|---|
| | (identifying and orchestrating new commercial challenges/collaborations) and Minatec (identifies and organises new research opportunities)<br>Strong international exchange culture of researchers and students | through general programmes (not technology specific).<br>No significant role of collaborative ties mentioned in cluster development<br>Ontario is a large province with several industry clusters making collaborations between clusters difficult. |
| Capabilities | Strong scientific basis<br>Highly skilled labour force<br>Strong focus on collaboration between top-research and leading corporations<br>Strong focus on design (>50 percent of output) | Strong scientific basis<br>Highly skilled labour force<br>Generation of successful entrepreneurs is about to retire leaving a gap |
| Market demand | Research activities very application oriented through central coordination of identification of market opportunities (Minalogic)<br>Focus on semiconductor design activities, to avoid direct competition with Asia (production focus).<br>Global production networks with global demand. | In the past strong focus on telecommunications equipment. Cluster regeneration plans aim to focus on health care, automotive, broadband and multi-media<br>Good access US market<br>Ontario government aims to stimulate innovation and growth in microelectronics through public procurement. |
| Market structure | Large companies take active role in cluster development and leverage public R&D.<br>Also many smaller firms and start-ups, providing good balance between large and small firms.<br>Cluster open to new entrants | Large companies in cluster such as Hewlett-Packard and Cisco. Nortel crucial role as anchor firm!<br>Anchor firms create critical mass and attract new MNEs and venture capital<br>Strong concentration of large MNEs e.g. Nortel hires 1/3 of all masters and PhDs in electrical engineering nationally |
| Cluster features | Large and internationally recognised, mature cluster.<br>Continuous government support for research and collaboration, as well as production activities.<br>Good mix of large and small firms<br>Many spin-offs of large companies and research institutes | Heterogeneous cluster: with different microelectronics industries, e.g. telecommunications equipment, software, etc.<br>R&D tax credits important role in cluster strategy.<br>Regeneration of cluster activity on-going.<br>Only cluster to mention role of public procurement (intention of government). |

*Source: TNO compilation.*

### 4.3.4. Factors influencing the future development of microelectronics

***Factors influencing the future market potential of microelectronics***

The previous chapters have outlined that microelectronics are a key intermediate input for a large variety of sectors. These sectors, for example the information and communication technology sector, are generally characterised by increased technological sophistication which immediately impacts the market for micro- and nanoelectronics. In this respect, the future market development critically depends on the market development in the sectors for which microelectronics are a key input.

Microelectronics is a continuously evolving field of technology, typified by "Moore's Law" which suggests a continuous growth of chip capacity and performance and at the same time further miniaturisation of the components. Although these steps of improvement can be characterised as incremental, it is unlikely that microelectronics face a threat of substitution by another technology. At the same time, technology adoption can even be expected to increase in the future because increasing performance of microelectronic components enables the products and processes in which microelectronics form an essential part to become more user-friendly.

Because of miniaturisation, new generations of semiconductors typically require considerable investments into the semiconductor fabrication plants (fabs). While this would typically drive the fixed costs of production, it has become standard industry logic that semiconductors are basically considered as commodity goods with rather low profit margins. As a consequence, semiconductor manufacturers are typically reluctant to invest into new plants which resulted in a concentration of manufacturing sites in a few places worldwide.

***The role of public support***

Given that production costs particularly in semiconductors are substantial, there are several opportunities for public support to ameliorate the conditions for microelectronics research, development and manufacturing in Europe. The potential shall be demonstrated against the example of Taiwan's support for the microelectronics industry from which two components are further analyzed (ITRI, 2010).

Since the 1980s, Taiwan's government established several high-tech industrial parks, one of which the Hsinchu Science-based Industrial Park (HSIP), that was established in north-western Taiwan to create an environment conducive to high-tech research and development, production, work, life, and entertainment, and which attracts high-tech professionals and technologies. The park is surrounded by a number of renowned science and engineering research institutes, such as the Industrial Technology Research Institute (ITRI), National Tsing Hua University and National Chiao Tung University providing ample human resources for the firms located in the park. Both the park's location and the rapid growth of its companies and products have made it the Silicon Valley of Asia. There are more than 300 high-tech companies located in a 605 hectare business area and employing more than 100,000 people. Total sales amounted to roughly $30 billion with steep growth rates. The park has made Taiwan a world leader in fields of microelectronics like integrated circuit (IC) manufacturing and key information industry components.

ITRI is the largest non-profit research organisation in Taiwan, with a total workforce of around 6,000 and a budget of more than $500 million. It is primarily responsible for developing industrial technologies and helping private enterprises enhance their competitiveness with a focus on the field of IC. ITRI led Taiwan's developing IC industry, providing both technology and human resources. The top two IC foundries in the world, Taiwan Semiconductor Manufacturing Company and United Microelectronics Company, originated in ITRI. The institute receives about half of its funding from the government and half from industrial sources. As a result, ITRI engaged heavily in knowledge and technology transfer activities. More than 30,000 firms received services from ITRI.

To sum up, microelectronics is a technology that critically relies on the interaction between academia and industry. Co-location of firms and academic institutions therefore seems to be a promising route to follow, for example in the form of a dedicated science park. Moreover, because of high costs, especially in manufacturing, (partly) government funded academic institutions can facilitate industry development by bringing down the costs while at the same time providing access to qualified human capital and technologies.

***Contribution of microelectronics to social wealth***

The contributions of microelectronics to social wealth are manifold. First of all, modern environmental technologies would be unthinkable without the use of sophisticated microelectronics components that enable the efficient deployment of such technologies. Microelectronics can make existing technological installations, for example in the energy production sector, more efficient in that they allow a more precise steering and management of processes. The same effects can be envisioned in other areas, for example the health care and medical instruments sectors. Microelectronics may not only lead to significant technological advances in the diagnostics and therapeutics but also streamline the process from the patient's perspective and as a result increase the quality of life. Although medical progress typically tends to come at increased cost, microelectronics may in principle also be used for increasing efficiency in the medical sector which should eventually bring down the associated costs. An example for this is an electronical patient management system that prevents costly double-diagnostics. This is all the more important given the tight financial pressure that today's health systems face.

***Importance of sustaining production capabilities***

Production capabilities allow for an application of newly developed technologies and as a result facilitate experimental learning that can be assumed to be valuable in future technology development efforts. Because of the commoditisation trend in microelectronics and particularly in semiconductors, new developments need to be quickly scaled up in order to allow for a cost efficient production. This implies a need for close interaction between R&D

and production. In this respect, sustaining production capabilities can be regarded as important.

## 4.4 Conclusions and Policy Implications

***State of technology***

Micro- and nanoelectronics refer to semiconductor components as well as highly miniaturised electronic subsystems and their integration in larger products and systems. By 2010, microelectronics has already crossed the verge of nanoelectronics. Technical progress is expected to result in a further reduction of structural widths. In order to achieve success and continued growth of the industry, a cost reduction of about 30 percent per year is required, while functionality needs to double every two years. This development has been described as “Moore’s Law” in the 1960s. Because conventional semiconductor manufacturing concepts will encounter technical limits, further miniaturisation will require considerable investments into plant technology.

***Europe’s technological position***

The development of micro- and nanoelectronics is clearly concentrated on the three global regions Europe, North America and East Asia. In this respect, East Asian patent applicants dominate with a market share of more than 45 percent in recent years. Europe contributes slightly more than 20 percent to total micro- and nanoelectronics patenting. In terms of patents per GDP, Europe has a significantly lower micro- and nanoelectronics patenting intensity than East Asia, but a similar intensity to North America. East Asia has been able to continuously improve its position in terms of patenting while Europe’s market share has remained rather stable over the past ten years.

The largest subfield in micro- and nanoelectronics is semiconductors, followed by x-ray and bonds/crystals. When looking at the development of market shares across subfields over time, it turns out that European applicants have improved their position predominantly in the fields of measurement, x-ray and devices while the position remained rather static in the fields of semiconductors and bonds/crystals. North American applicants have lost market share in all subfields while East Asian applicants have generally gained over time.

The composition of micro- and nanoelectronics patent applications by subfields differs only slightly by country of applicant. Applicants from Italy show a very high share in semiconductors while this share is below average for the Netherlands. All other countries exhibit shares around the European average.

### *Links to disciplines and sectors*

Micro- and nanoelectronics can be characterised as a cross-cutting technology that not only affects the electronics industry but a multitude of other industries. Besides electronics, important micro- and nanoelectronics patent applicants are from the chemicals, machinery and instruments industry. Public research plays an important role particularly in Europe, where 10 percent of all micro- and nanoelectronics patents are generated by public research, compared to an average of around 7 percent worldwide.

Comparing the sector affiliation of micro- and nanoelectronics patent applications before and after the end of 2001 – which splits the total sample of nanotechnology patents in two subsamples of similar size – reveals a shift of micro- and nanoelectronics patenting toward specialised semiconductor firms. This trend is particularly pronounced in Europe and reflects the strategy of the largest European electronic companies -Siemens and Philips- to spinoff their microelectronics businesses in separate companies (Infineon and Epcos as Siemens spinoffs, ASML and NXP as Philips spinoffs). In all three regions, public research gained market shares in micro- and nanoelectronics patenting. In Europe, automotive manufacturers become increasingly engaged in this field of technology. In North America and East Asia, the chemical and materials industries increased their share in total microelectronic patenting. Decreasing shares are reported for the electronics industry (i.e. integrated electronic companies) in Europe and Japan, for telecommunication companies in all three regions, and for computer manufacturers in North America and East Asia.

In Europe, patenting activities are highly concentrated among a few firms compared to North America and East Asia. However, East Asia shows a higher number of firms with substantial patenting activity than Europe, leading to an overall higher concentration when a larger number for firms are considered. Concentration in North America is generally lower.

### *Market prospects and growth impacts*

The market potential of micro-and nanoelectronics becomes predominantly manifest in the semiconductor industry. Semiconductors are an intermediate input for a variety of sectors but they are particularly important for information and communication technology (ICT) equipment and embedded systems. Semiconductor production is a highly cyclical industry. During economic downturns production drops sharply but when the economy recovers, semiconductor production does so as well. Nevertheless, long-term growth prospects are positive, given the general societal trend towards digital appliances, media, and mobile communication which is supported by strong consumer demand. Moreover, this trend is expected to be fuelled by a higher semiconductor content per installed system, leading to a "digital upgrading" of the economic and social infrastructure. In fact, evidence from the patent analysis suggests robust growth for semiconductors.

In this respect, semiconductor sales worldwide in current prices have increased by 10 percent annually since 1990. Between 1990 and 2000 the world market for semiconductors quadrupled from $50 billion to more than $200 billion. For 2008, a market size of $260 billion is estimated. Long-term growth is expected to show an annual growth rate of 8 to 10 percent. However, the patent analysis has also made clear that recent changes in microelectronics patenting hint at higher growth dynamics in subfields like devices, x-ray and measurement which only partially overlap with semiconductors.

There are a couple of factors underlying the forecasts, i.e. factors that determine whether the growth potentials can actually be realised. As conventional techniques in the optical lithography will reach their physical limits with increasing miniaturisation, new concepts will be required that have not yet been developed. Semiconductors have, despite their high-technology content, almost reached commodity status which further requires that technical solutions to present physical limits be cost-efficient without raising high investment needs for the manufacturers. At the same time, benefits from increasing miniaturisation need to warrant an added value for consumers in order for the industry to recoup costs.

***Policy options***

Micro- and nanoelectronics are important for policy because of their potential to add value in a multitude of applications. Europe will therefore only be able to keep and expand its market position if it succeeds in attracting research, development and manufacturing capabilities in micro- and nanoelectronics to take place in Europe. Micro- and nanoelectronics allow a broad spectrum of firms to benefit from the value chain, given that electronic components and systems have important applications in a multitude of fields. Results from the patent analyses however indicate that concentration of patenting activities in Europe is considerable. In other words, only a few firms account for a large share of patents. In contrast to this, East Asia benefits from a higher number of firms that generate strong technological competences. As a consequence, chances for Europe to sustain system leadership in a number of fields – like mobile and stationary telecommunication systems, automotive electronics, smart cards, environmental technologies, and automation – are lower.

As technical progress in micro- and nanoelectronics is eventually based on further miniaturisation which allows for an increased complexity of design, higher speed and a reduction of electric power consumed, it thus seems essential to promote Europe’s industry and science such that further research efforts are possible. In order to sustain system leadership that is driven by the fruits of increased miniaturisation, policy should be concerned with both the promotion of high-end technology development as well as the required breadth. Another major policy field is to promote design capabilities that serve as the decisive connection between available technology and application-specific system requirements. After all, basic research is required to obtain and secure the basis for all future applications of micro- and nanoelectronics. Scientific research can still be regarded as the most important knowledge source in this KET, and therefore the industry's future development will critically depend on the ability of firms to identify and evaluate new research findings, transfer them into business models and develop new products and processes that leverage the potentials of micro- and nanoelectronics while at the same time fit to the needs of customers in terms of performance and costs. Doing this requires a close interaction between firms and public research, including joint R&D activities. Cluster initiatives have proved to facilitate this exchange significantly. They can be assumed to facilitate the transfer of knowledge and technology into commercial applications, and they also serve as a instrument to attract a "critical mass" of qualified people willing to do research and development in micro- and nanoelectronics.

A critical factor in the promotion of micro- and nanoelectronics is the highly cyclical nature of the industry. It is therefore all the more important to secure continuous research and development efforts even in times of economic downturn in order to stay fully operational and innovative when the economy catches up again. Policy should therefore be concerned with the smoothing of growth cycles as far as research and development activities are concerned. Funding instruments of collaborative research with public science should thus in particular be readily available when industry has to cut down R&D expenses during a downturn.

Further policy actions should relate to providing a stable regulatory environment, particularly with respect to likely safety, health and environment impacts of micro- and nanoelectronics.

# 5 INDUSTRIAL BIOTECHNOLOGY

## 5.1 Definition and State of Technology

Biotechnology comprises applications of science and technology that use living organisms – or parts, products and models thereof – to produce knowledge, goods and services (OECD). Depending on the area of application subgroups are defined. The industrial biotechnology – also called white biotechnology – refers to industrial applications and uses micro-organisms like moulds, yeasts or bacteria as well as enzymes in industrial processes to produce biochemicals, biomaterials and biofuels. Today, already a large number of products are being manufactured using biotechnological processes; for instance, in the production of chemicals, plastics, biofuels, detergents, vitamins, enzymes and in the finishing of textiles, leather and paper (BMBF, 2008).

Biotechnological processes compete with other production methods, in particular with chemical synthesis, and are chosen rather than chemical processes if it is economically or ecologically beneficial. Industrial biotechnology tends to consume fewer resources and to be more environmentally friendly since renewable raw materials such as vegetable oils and starch are used. Biotechnological processes tend to produce less harmful by-products and produce higher yields. This also reduces the dependence on fossil resources. However, biotechnological processes are not always less energy-intensive but instead consume sometimes considerably more energy. The level of the active agent is for example typically much lower in the output from biotechnological processes compared with the output of chemical processes. Nevertheless, industrial biotechnology provides the opportunity to improve the quality of existing products and to develop completely new products which cannot be produced by traditional synthetic methods and processes (OECD, 2009a; OECD, 2009b, OECD 2010).

Industrial biotechnology is not a new discipline. Using nature's toolbox for industrial products has a long tradition. Brewing beer was one of the first applications and already used in Mesopotamia 6000 BC. The production of wine, cheese and leavened bread has also been based on living micro-organisms from the beginning on. Although the molecular process behind it was not explained until Pasteur's work in the 19th century. Nowadays methods of molecular biology are used in a targeted manner which was only made possible through knowledge gained from genome research and microbiology. Examples are the discovery of enzymes as biocatalysts or of bacteria for producing medical substances (BMBF, 2008). Enzyme products for the manufacture of detergents, food, textiles, chemical and pharmaceutical industry are well established on the market although only about 130 different enzymes of the thousands of known enzymes are used industrially (BMBF, 2008; OECD, 2009a; OECD, 2010).

Industrial biotechnology related activities such as the development of new enzymes, new bio materials or biotechnological production processes are not only conducted by dedicated biotechnology firms but also by the chemical industry. Most chemical firm uses biotechnology processes.

Biotechnology is a fast developing technology. Current and emerging research comprise the improvement of enzyme's characteristics like its substrate specificity, activity and stability and the creation of new tailormade and high performance enzymes through genetic manipulation, protein engineering, directed evolution and by advanced selection techniques – the area of synthetic biology is just emerging; the development of microbial cells as whole cell catalyst in an industrial process for a specific product in the area of systems biology; improvements in reactor design to reduce the genetic variability of the production cell population in order to have continuous product pipeline; creation of biotechnological platform intermediates based on the use of renewable carbon sources; integrating biotechnological and chemical technologies and reducing the number of process steps. Becoming more cost-competitive through the increase of output efficiency is thereby an important goal. Emerging fields of application with the largest potential are the production of bio-based polymers – to replace petrochemical plastics, of biofuels such as bioethanol and biodiesel and of fine chemicals for the pharmaceutical and agro industry (OECD 2009a, OECD 2009b, OECD 2010).

An important driver for the industrial biotechnology sector will be the stronger use of renewable raw materials and efficient bioprocesses to achieve a sustainable development. This shift is partly driven by governmental regulation and partly by consumer demand as consumers increasingly request a smaller environmental footprint. But biotechnology must compete with alternative production technologies. Along with the rising use of renewable feedstock for the biofuel and bio raw material production a discussion about land-use for food or fuel and about increasing food prices has arisen. Therefore, optimising feedstock such as modifying crops to increase their content of oils and starches is a target for plant breeders. Alternatives such as switching to the use of meagre land and grow undemanding non-food plants or to the increasing use of algae as feedstock are discussed.

Sales of products produced by biotechnological processes accounted for €99 billion in 2007 (McKinsey, 2009). Although biotechnology is well established in the chemical industry it is still a niche there and overall it is in its infancy (OECD 2009b). Estimations for 2007 for the global annual sales volume of chemical products produced by industrial biotechnology vary between €48 billion (Festel Capital, 2009) and €65 billion (McKinsey, 2009). The lower of the two estimate is equivalent to about 3.5 percent of the worldwide chemical sales (without pharmaceutical products but including active pharmaceutical ingredients; Festel Capital, 2009). Depending on the application the adoption of biotechnology varies significantly. In basic chemicals – which accounts for 59 percent of chemical sales, only 1.5 percent are based on biotechnology. In active pharmaceutical ingredients the share of biotechnology sales equals 18.7 percent (Festel Capital, 2009). Biotechnology-based polymers are the most important biomaterials and are produced in substantial quantities – estimations range from 300,000 metric tonnes to nearly 600,000 metric tonnes – but represent less than 1 percent in polymer production (EC 2007, OECD 2009a). In pulp and paper biotechnological applications reach 10 percent, in detergents 30 percent and in some food production processes (e.g. fruit juice) up to 100 percent (EC 2007).

## 5.2 Technological Competitiveness, Industry Links and Market Potentials

### 5.2.1. Technological Competitiveness

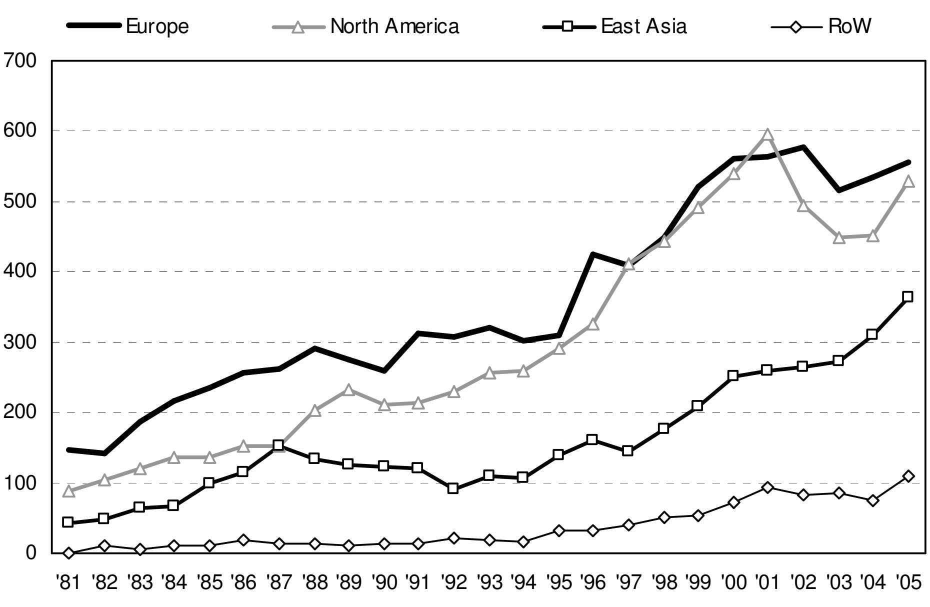
Analysing technological competitiveness in industrial biotechnology based on patent data using patent classification systems is challenging. It is even more difficult to identify whether the inventions belong to industrial biotechnology subfields given above. Only patents related to enzymes and biochemicals are possible to identify. Since enzymes or biochemicals serve as a basis for the subfields biomaterials and biofuels but their application area is not given or even not yet known, it is not possible to determine whether the enzymes or biochemicals are linked to biomaterials and biofuels.

While patent classification allows to identifying advances in biochemicals (e.g. new enzymes or enzym-using processes, new protein-based compositions), it is often unknown whether it will be applied in industrial, medical or agricultural processes. Therefore, the assignment of patents to the different types of biotechnology is also difficult. If patents have IPC classes which point to medical or agricultural applications they are dropped. In addition, firms from the pharmaceutical, diagnostic and crops sector are identified and their patents are left out, too. This restriction reduces the number of patents by 19 percent. Since dedicated biotechnology firms are not assignable to a certain application area, patents without an identified application area and from dedicated biotechnology firms that are active in the field of medical or agricultural biotechnology might be still in the sample. This caveat also applies for patents without an assigned application from research institutions.

### *Market shares*

Europe's performance in producing industrial biotechnology patents is compared to that of applicants from North America (USA, Canada, Mexico) and East Asia (Japan, China incl. Hong Kong, Korea, Taiwan, Singapore). Measured in terms of patents applied at EPO or based on PCT (EPO/PCT patents), the number of industrial biotechnology patents applied per year increased steadily to almost 1,500 patent applications in 2001 and decreased in the following two years (Figure 5-1). In 2004 the number of applications started to increase, again. Over the entire period from 1981 to 2005, about 21,000 industrial biotechnology EPO/PCT patents were applied. The three main regions show a similar application pattern at the EPO/PCT over the period, except for the temporary decrease after 2001. The downturn applies only for European and North American applicants. European applicants apply for the most patents, followed by North American and East Asian applicants. Applicants from other regions than Europe, North America and East Asia are of little significance, though the number of patents from the rest of the world has also increased. Their market share is still below 10 percent.

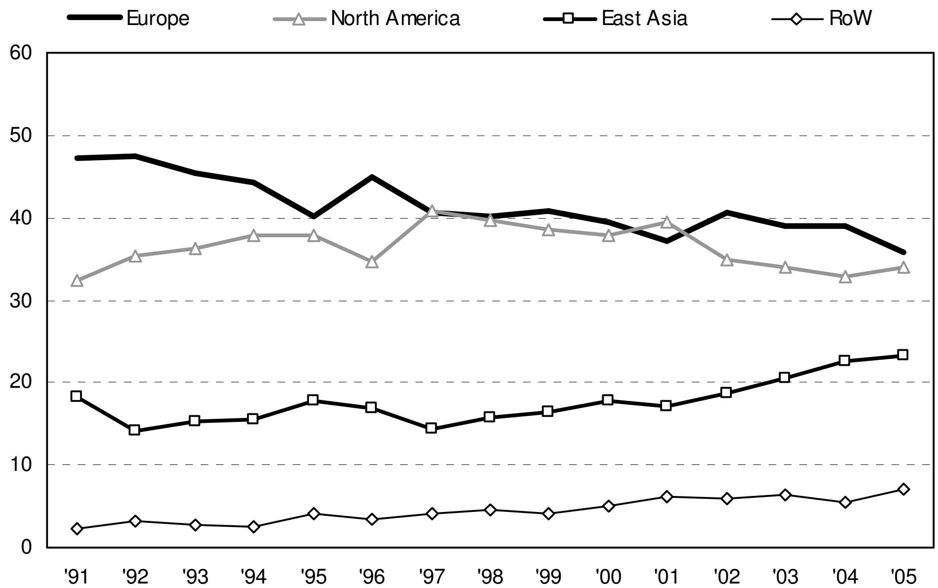
**Figure 5-1: Number of industrial biotechnology patents (EPO/PCT patents) 1981-2005, by region of applicant**




*Source: EPO: Patstat, ZEW calculations.*

European applicants show the highest market share of EPO/PCT patent applications in 13 years of the 15-year-period from 1991 to 2005 (Figure 5-2). Only in 1997 and 2001 North American applicants had the highest share. In 2005, the shares of patent applications from European and North American applicants have narrowed, again. The share of East applicants has been steadily increasing since 1997. European applicants had a share of 36 percent in total industrial biotechnology patent applications at the EPO/PCT in 2005, compared to 34 percent for North American applicants and 23 percent for East Asian applicants.

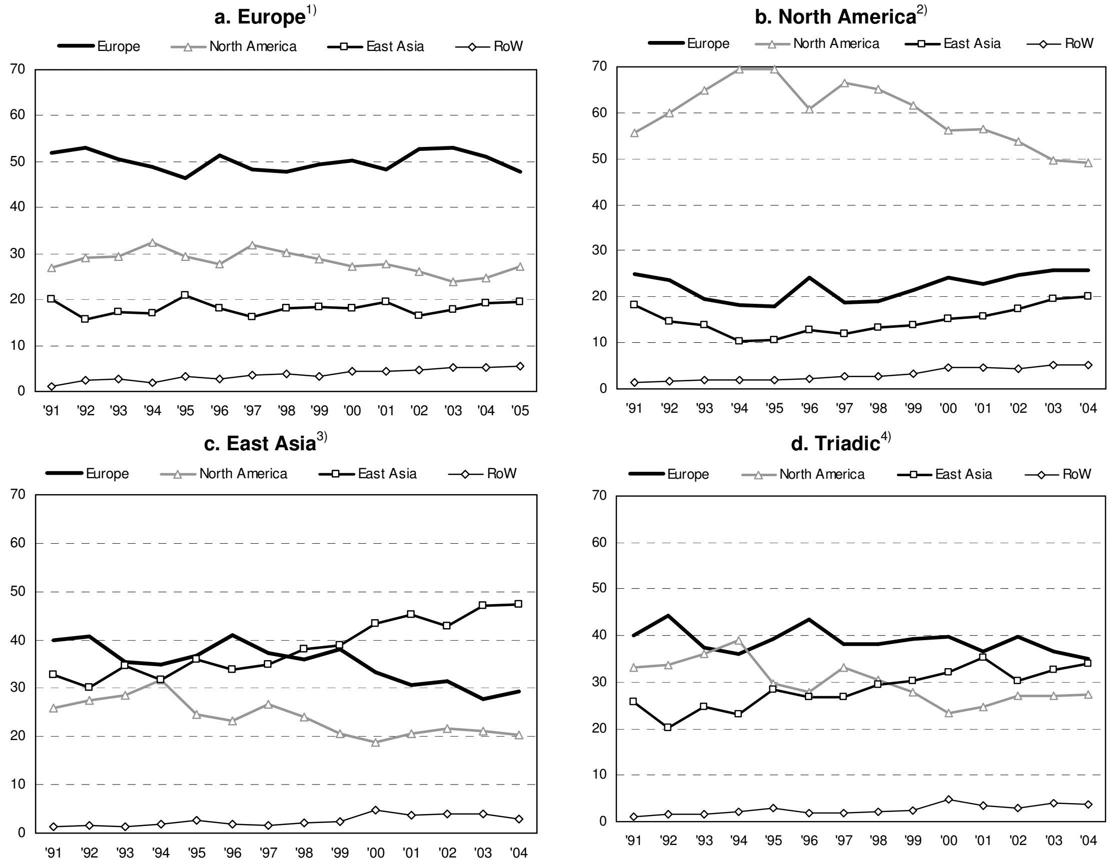
**Figure 5-2: Market shares of industrial biotechnology patents (EPO/PCT) 1991-2005 (percent)**




*Source: EPO: Patstat, ZEW calculations.*

In order to account for "home office" effects in patenting (i.e. the propensity for applicants from a particular region to use predominantly that regional patent office for applications), patent applications in industrial biotechnology at USPTO and JPO are analysed as well. The shares of patent applications at EPO, USPTO and JPO are shown in Figure 5-3. While at the EPO applicants from Europe dominate (51 percent), at the USPTO applicants from North America clearly dominate although their dominance has diminished since 1995. In 2004 North American applicants are ahead at the USPTO (49 percent), followed by European applicants (26 percent). At the JPO East Asian applicants show the highest share in 2004 (47 percent), while European applicants contribute 30 percent to the total. North American applicants account only for 209 percent. When looking at triadic patents, the shares of European, North American and East Asian patent applicants are close with 35 percent, 34 percent and 27 percent, respectively.

**Figure 5-3: Market shares in industrial biotechnology patents 1991-2005 for national applications and triadic patents (percent)**




*1) EPO applications*

*2) USPTO applications*

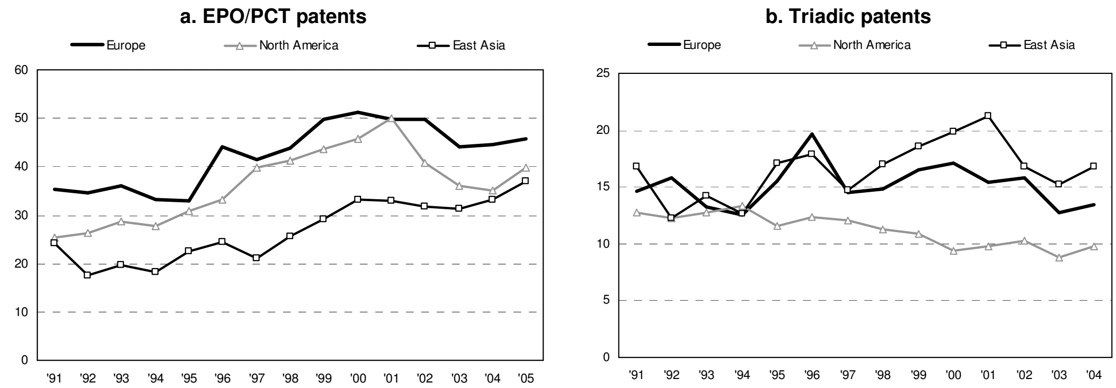
*3) JPO applications*

*4) Patents for which 1), 2) and 3) applies.*

*Source: EPO: Patstat, ZEW calculations.*

In order to determine the relative importance of industrial biotechnology patents for a region, patent intensities are calculated. The patent intensity is defined as the number of patents per year form applicants of a certain region to the GDP of that region. This type of specialisation indicator shows that Europe still produces the highest number of industrial biotechnology patents per GDP at EPO/PCT (Figure 5-4). Patent intensities grew for Europe and North America until around the year 2000 and tend to decline since then while East Asia is increasing its patent intensity unitl the mid 2000s. Considering triadic patents, East Asia exhibits the highest intensity, followed by Europe and North America. No clear updwards trend can be seen for triadic patents in industrial biotechnology.

**Figure 5-4: Industrial biotechnology patent intensity 1991-2005 for EPO/PCT and triadic patents (number of patents per 1 trillion of GDP at constant PPP-$)**




*Source: EPO: Patstat, OECD: MSTI 02/2009. ZEW calculations.*

### *Patenting by subfields*

Enzyme-related patents account for the vast majority of identified industrial biotechnology patents. Therefore, enzyme-related patents are further divided into three classes. Established biochemicals constitute a fourth subfield. These four subfields of industrial biotechnology are identified through a set of IPC classes (IPC classes given in parentheses):

Enzymes (C12N)

Fermentation processes (C12P)

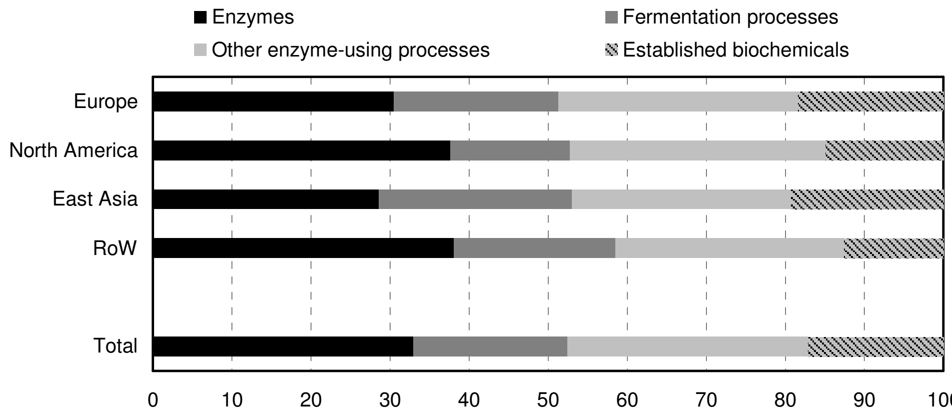
Other enzyme-related processes (C02F 3/34, C12M, C12Q, C12S)

Established biochemicals except enzymes, e.g. organic acids, amino acids, vitamins, proteins except enzymes (C07C 29/00, C07D 475/00, C07H 21/00, C07K 2/00, C08B 3/00, C08B 7/00, C08H 1/00, C08L 89/00, C09D 11/04, C09D 189/02, C09J 189/00, G01N 27/327)

Since several IPC classes can be assigned to each patent, one patent can belong to several subclasses and are double-counted in these cases.

The two largest subfields within industrial biotechnology are enzymes (33 percent) and other enzyme processes which comprise organic acids, amino acids, vitamins, proteins except enzymes (30 percent; Figure 5-5). All three main regions show a similar composition. While in North America and the Rest of the World patents on enzymes are relatively more important; in Europe and East Asia fermentation and other established biochemicals are more pronounced.

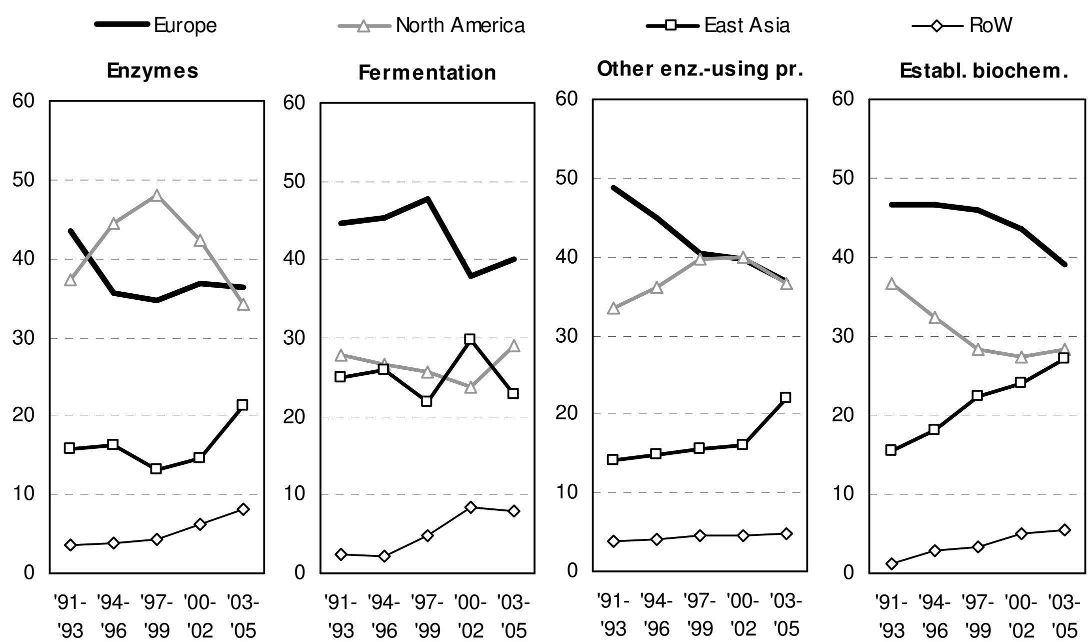
**Figure 5-5: Composition of industrial biotechnology patents (EPO/PCT) by subfields (percent)**




*Source: EPO: Patstat, ZEW calculations.*

The regional distribution of patent applications at the EPO/PCT for the four subfields shows the same rankings of the three regions. Europe leads in all four subfields followed by North America and East Asia, though the lead is very small for enzymes and other enzyme-using processes (see Figure 5-6). In these two subfields East Asia has caught up in recent years.

**Figure 5-6: Market shares for industrial biotechnology patents (EPO/PCT) 1991-2005, by subfields (percent)**



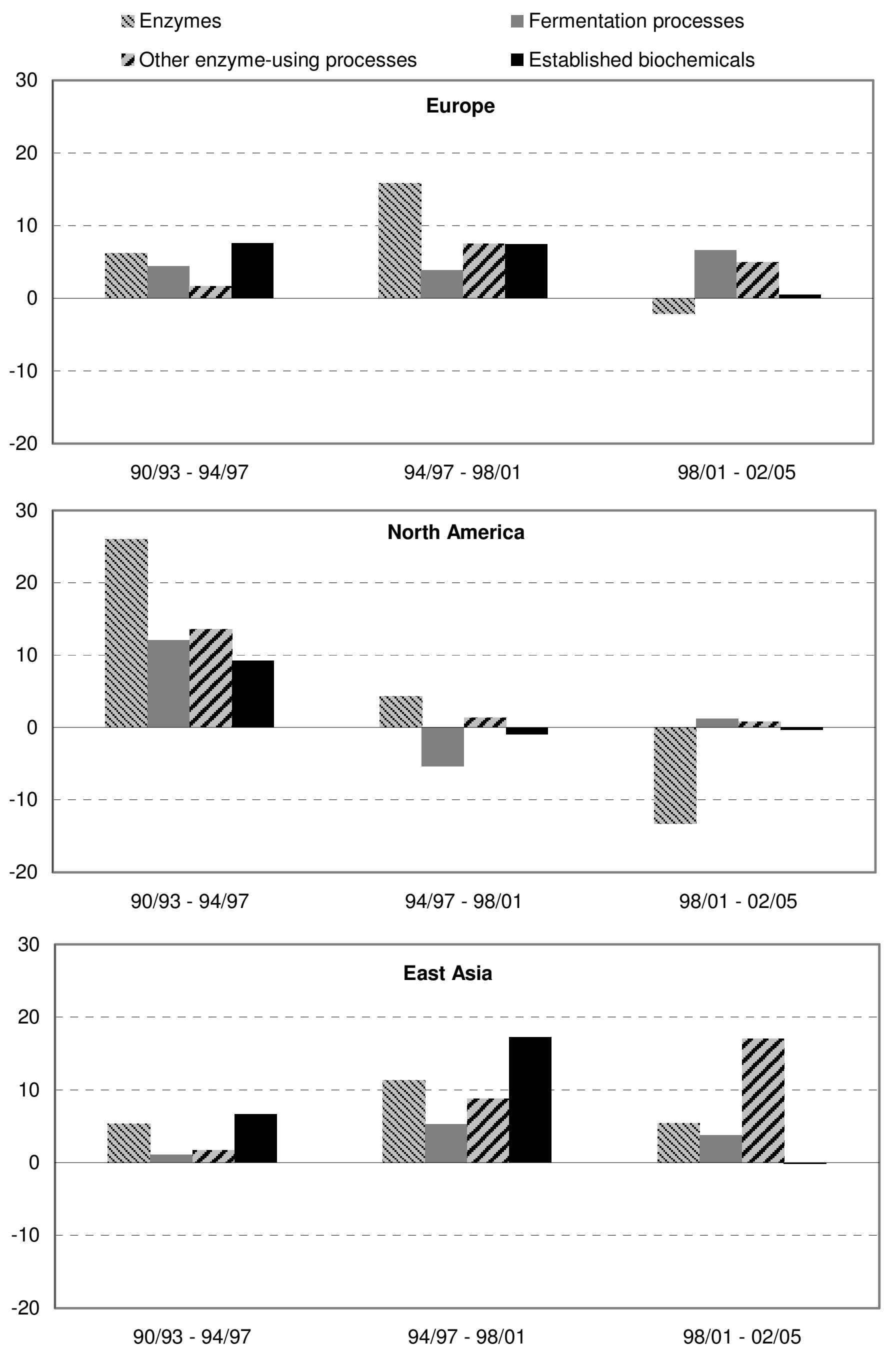

*Source: EPO: Patstat, ZEW calculations.*

Technological dynamics by subfields based on EPO/PCT patents may be biased from varying attractiveness of the European market. For instance, a rise in demand for certain applications of industrial biotechnology in Europe may stimulate patenting by North American and East

Asian applicants at EPO, thus raising the number of EPO/PCT patents by applicants from these regions. A decreased attractiveness of the European market may result in the opposite effect. In order to avoid such biases from the market environment, we evaluate technological dynamics by looking at patent applications by European, North American and East Asian applicants at their respective “home patent office” (EPO, USPTO and JPO, respectively).

Dynamics in industrial biotechnology patent applications at the regional home offices varies over time (see Figure 5-7). Europe and East Asia were able to increase their patent activities in most subfields in the three periods. Europe reports high growth in enzymes in the lat 1990s, following an even stronger increase of patent outpout in North America in this subfield in the early 1990s. North America shows increasing patenting activities in industrial biotechnology only in the first period. In the 2000s, industrial biotechnology patenting in North America was stagnating or even declining (in the field of enzymes). East Asia experienced a strong increase in industrial biotechnology patenting in the late 1990s and could maintain high growth rates in otehr enzyme-using processes in the early 2000s. In all three regions, patenting in established biochemicals did not grow in the 2000s.

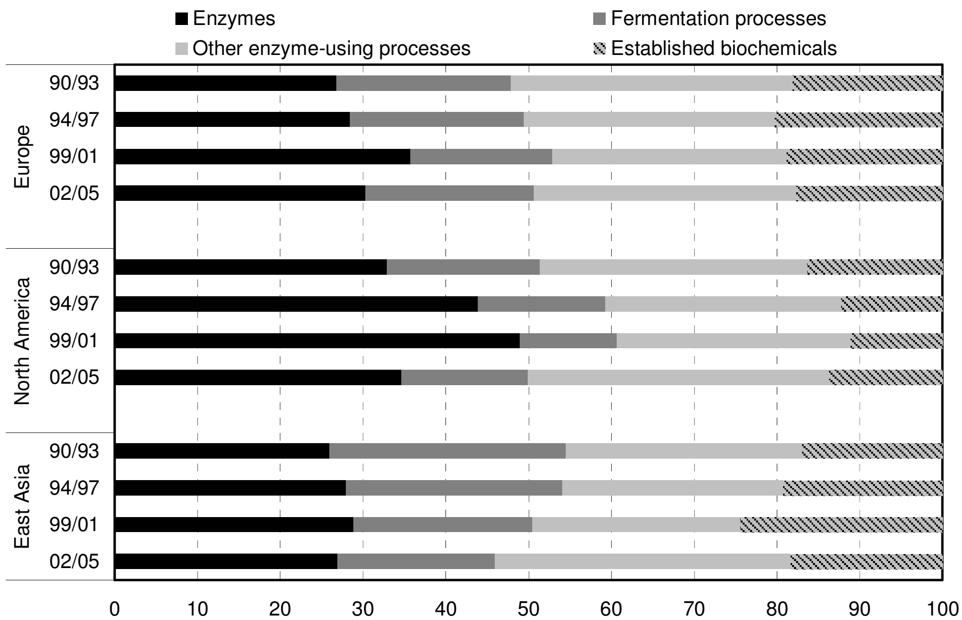
**Figure 5-7: Average annual rate of change in the number of industrial biotechnology patents (applications at home patent offices), by region, subfield and period (percent)**




*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

The composition of industrial biotechnology patents by subfields is rather stable over time (see Figure 5-8). However, patent applications related to enzymes have gained some importance in North America until around 2000, but lost shares in total industrial biotechnology patenting afterwards. In East Asia, patenting in the field of fermentation processes lost in importance while patents related to other enzyme-using processes gained shares.

**Figure 5-8: Composition of industrial biotechnology patents (applications at home patent offices), by region, subfield and period (percent)**

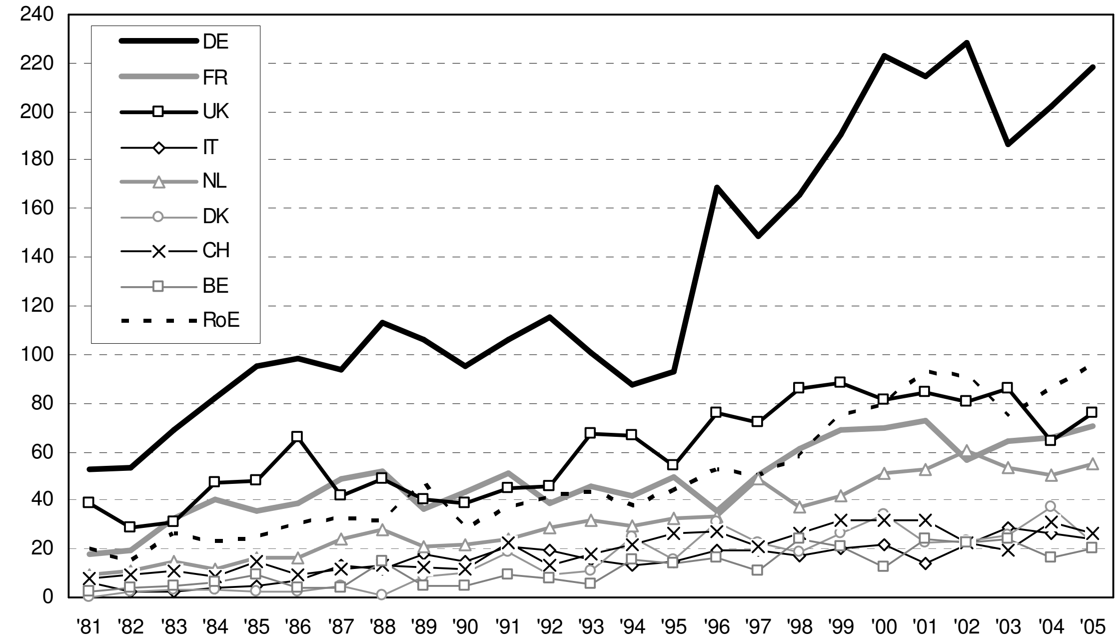



*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

### *Patenting at the country level in Europe*

Within Europe, applicants from Germany represent the largest group of producers of industrial biotechnology patents. From 1981 to 2005, one third of all industrial biotechnology patents at the EPO/PCT stem from German applicants, followed by the United Kingdom (16 percent), France (13 percent), and the Netherlands (8 percent) (see Figure 5-9). Among the smaller European economices, Denmark is an important location for generating industrial biotechnology patents. There has been a particularly fast growth of German patent applications from 1994 to 2000 after which, however, there was a significant decline to the level of 1996 in 2002.

**Figure 5-9: Industrial biotechnology patents (EPO/PCT) in Europe 1981-2005, by country**

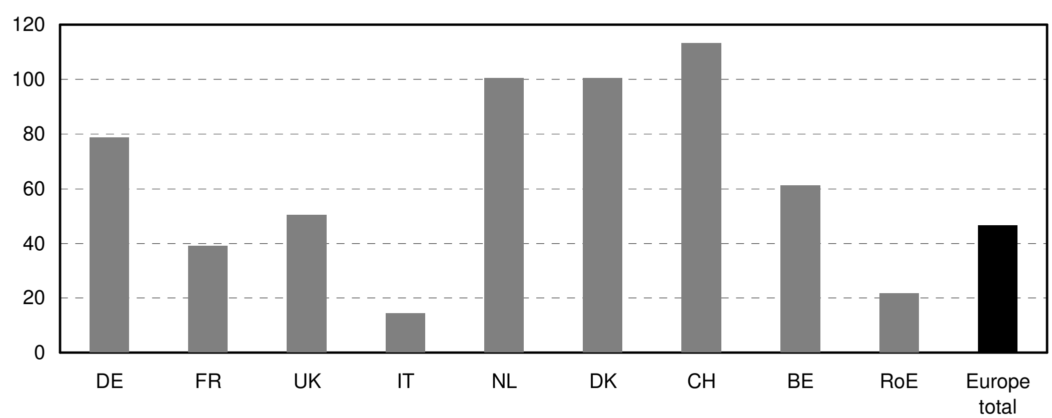



*Eight European countries with the largest number of industrial biotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The economic significance of industrial biotechnology patenting differs substantially by country (Figure 5-10). Patent intensity -that is the ratio of the number of industrial biotechnology patents to GDP- is highest in Switzerland, the Netherlands and Denmark and clearly above the European average Germany. Belgium produces somewhat more industrial biotechnology patents per GDP than the European average whereas the UK reports average patent intensities. Patent intensity in industrial biotechnology is slightly below the European average in France and very low in Italy and the total of all other European countries.

**Figure 5-10: Patent intensity in industrial biotechnology 1991-2005 of European countries (EPO/PCT patents)**



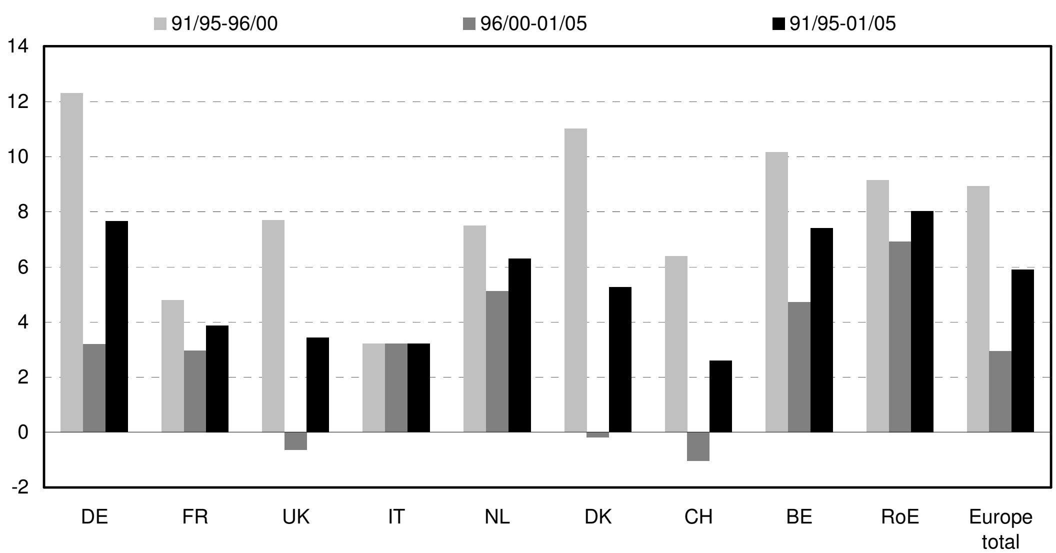

*Patent intensity: number of EPO/PCT patents applied between 1991 and 2005 per trillion GDP at constant PPP-$ in the same period.*

*Eight European countries with the largest number of industrial biotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The differences in the absolute number of industrial biotechnology patents and in patent intensities have to be kept in mind when looking at patenting dynamics since countries with low patent activities can more easily generate high growth rates. Among the eight countries that produce the largest number of industrial biotechnology patents, Belgium and Germany could increase their patent output at an annual growth rate of almost 8 percent between the first half of the 1990s (1991-95) and the first half of the 2000s (2001-05) (Figure 5-11). An even higher growth rate was experienced by the group of European countries not qualifying for the eight largest industrial biotechnology patent producers. Industrial biotechnology patenting increased at about the average European rate in the Netherlands and Denmark. In France, the UK, Italy and Switzerland patenting grew slower compared to the European average.

**Figure 5-11: Change in the number of industrial biotechnology patents between 1991/95 to 1996/00 and 1996/00 to 2001/05, by country (EPO/PCT patents; compound annual growth rate in percent)**



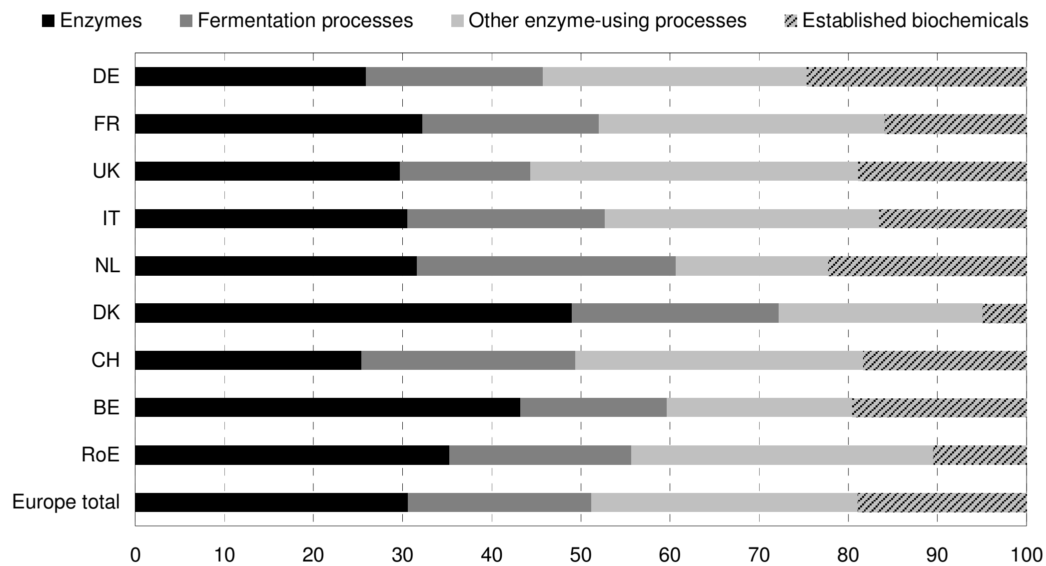

*Eight European countries with the largest number of industrial biotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

In most countries, growth rates were significantly higher in the 1990s (1991/95 to 1996/00) than in the more recent period (1996/00 to 2001/05), indicating a slow down in the production of new technological knowledge in this KET. Italy is the only country that was able to sustain a similar though low growth rate in both periods. In the UK and Switzerland, industrial biotechnology patenting declined in the early 2000s. High average annual growth rates in the recent period are reported by the rest of Europe (7 percent), the Netzerlands (5 percent) and Belgium (4 percent).

The composition of industrial biotechnology patent applications by subfields and country of applicant is depicted in Figure 5-12. The distribution of patent applications by subfield does not vary to a large extent between the countries of applicants. Exceptions are the strong focus on enzyme patents in Denmark which is due to the location of the world largest producer of enzymes (Novozymes) there. Owing to its large chemical industry, Germany is more specialised in established biochemicals.

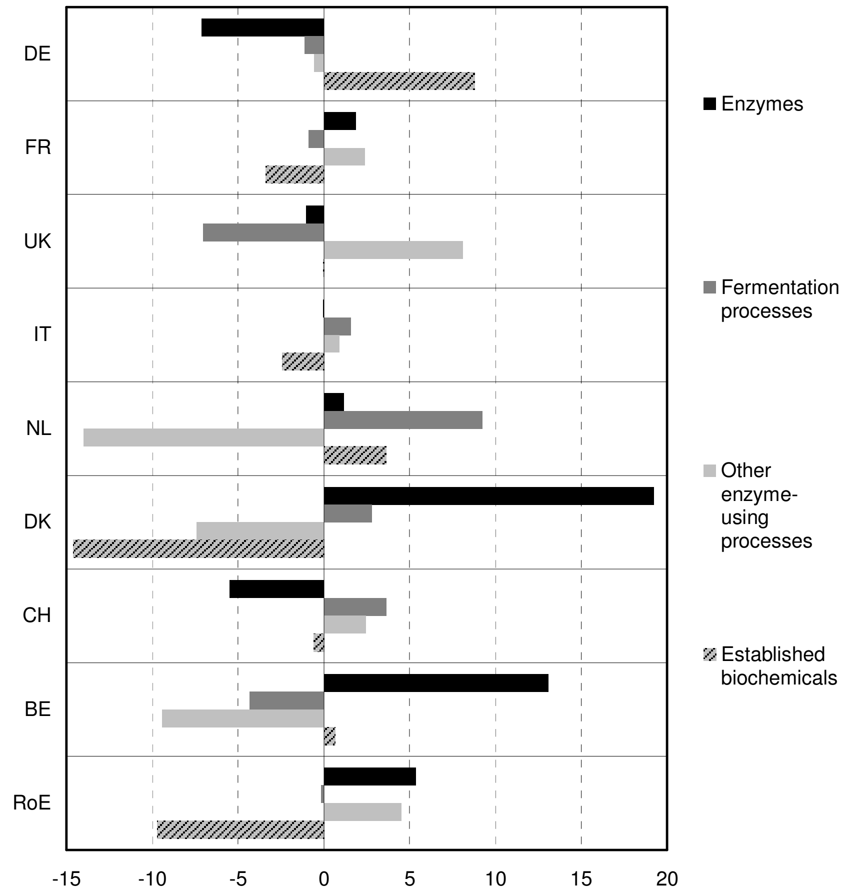
**Figure 5-12: Composition of industrial biotechnology patents in Europe, by subfield and country (percent)**




*Eight European countries with the largest number of industrial biotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*
*Source: EPO: Patstat, ZEW calculations.*

Figure 5-13 provides a more detailed picture of country-specific specialisation by subfield within industrial biotechnology. The specialisation pattern of Germany is clearly focused on established biochemicals and underspecialised in enzymes. Enzymes are the clear strength of Denmark and Belgium. The Netherlands are specialised on fermentation process and underspecialised in other enzyme-using processes. The UK shows exactly the opposite pattern of specialisation while France's and Italy's composition of industrial biotechnology patents by subfields is very similar to the Eutropean one.

**Figure 5-13: Specialisation patterns of industrial biotechnology patenting in Europe, by subfield and country of inventor (percent)**




*Difference between the share of a subfield in a country's total industrial biotechnology patents and the respective share for Europe total (excluding the country under consideration).*

*Eight European countries with the largest number of industrial biotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

European countries show different trends in industrial biotechnology patenting (Table 5-1). Comparing the growth in the number of patents applied by subfield for the 1990s (i.e. between the number of patents over the 1991-95 and the 1996-2000 periods) and the early 2000s (i.e. between 1996-00 and 2001-05) shows that all subfields except other enzyme-using processes report higher growth rates for the 1990s than for the early 2000s. In the field of enzymes, patent output increased at a very high rate during the 1990s but almost stagnated in since about the year 2000. In some countries (UK, Denmark, Switzerland) patent output in the field of enzymes even declined. In the field of fermentation processes, Germany could sustain a high growth rate in both periods. Belgium, the Netherlands and Denmark report high growth in the 1990s, but lower rates in the more recent period. In the field of othe enzyme-using processes, France, the Netherlands and the "rest of Europe" could increase patent output in the early 2000s compared to the 1990s while the UK and Belgium experienced a decreasing patent output in the early 2000s. Trends in established biochemicals are dispers. Germany reports high growth in the 1990s, but a decline in the early 2000s while the UK, the Netherlands and Belgium were able to increase annual growth in patent output.

**Table 5-1: Change in the number of industrial biotechnology patents between 1991/95 to 1996/00 and 1996/00 to 2001/05 by subfield and country (EPO/PCT patents, compound annual growth rate in percent)**

| | DE | | FR | | UK | | IT | | NL | | DK | | CH | | BE | | RoE | | Europe total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Enzymes | 14 | 6 | 12 | 3 | 14 | -3 | 13 | 0 | 9 | 1 | 9 | -3 | 8 | -2 | 10 | 1 | 18 | 6 | 13 | 2 |
| Fermentation proc. | 11 | 9 | -2 | -4 | -1 | 1 | 7 | 6 | 11 | 0 | 12 | 7 | 4 | -8 | 25 | 6 | -8 | 1 | 6 | 4 |
| Oth. enzyme-us. pr. | 9 | 7 | 1 | 8 | 6 | -2 | 3 | 1 | 4 | 13 | 9 | 6 | 11 | 5 | 6 | -1 | 3 | 9 | 6 | 6 |
| Establ. biochemicals | 11 | -4 | 6 | 4 | 6 | 8 | -8 | -1 | 9 | 12 | 49 | 0 | 5 | -6 | 6 | 14 | 13 | 10 | 9 | 2 |
| Industr. biotechn. tot. | 12 | 3 | 5 | 3 | 8 | -1 | 3 | 3 | 7 | 5 | 11 | 0 | 6 | -1 | 10 | 5 | 9 | 7 | 9 | 3 |

*a: compound annual growth rate of patent applications between 1991/95 to 1996/00*
*b: compound annual growth rate of patent applications between 1996/00 to 2001/05*
*"∞": not available due to zero value in base period.*

*Eight European countries with the largest number of industrial biotechnology patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

### 5.2.2. Links to Sectors and Fields of Technologies

#### *Technological links to sectors*

When linking patents to industrial sector based on the IPC classes a patent was assigned to, just 3 sectors -chemicals, pharmaceuticals, instruments- account for 85 percent of all industrial biotechnology patents. Technological links to sectors are thus strongly focused, and most industrial sectors have no direct technological links to industrial biotechnology. 45 percent of all industrial biotechnology patents are linked to pharmaceuticals, 23 percent to the chemical industry, 17 percent to the manufacture of instruments (optical, medical, measurement, steering instruments). 5 percent of industrial biotechnology patents are technologically linked to the manufacturing of machinery and equipment, 4 percent to the food industry and 2 percent to electronics (Table 5-2). Industrial biotechnology patenting in Europe tends to be stronger linked to chemicals and less to pharmaceuticals while for North America, the opposite is true.

**Table 5-2: Technological sector affiliation of industrial biotechnology patents (EPO/PCT), by region (average of 1981-2007 applications, percent)**

| | Europe | North America | East Asia | **Industrial biotechnology total** |
|---|---|---|---|---|
| Food | 5 | 2 | 4 | **4** |
| Textiles | 1 | 0 | 0 | **1** |
| Wood/Paper | 1 | 1 | 1 | **1** |
| Chemicals | 26 | 20 | 25 | **23** |
| Pharmaceuticals | 41 | 51 | 41 | **45** |
| Rubber/Plastics | 1 | 1 | 1 | **1** |
| Glass/Ceramics/Concrete | 1 | 1 | 1 | **1** |
| Metals | 1 | 1 | 1 | **1** |
| Machinery | 6 | 5 | 5 | **5** |
| Electronics | 1 | 2 | 3 | **2** |
| Instruments | 16 | 17 | 18 | **17** |
| Vehicles | 0 | 0 | 0 | **0** |
| Total | 100 | 100 | 100 | **100** |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

The importance of pharmaceuticals might be overestimated since patents in the area of enzymes are difficult to being assigned to the different types of biotechnology (red, green and white). Enzymes used for the red (medical) biotechnology may still be in the sample of analysis. This can be seen from the fact that most iIndustril biotechnology patents related to enzymes (enzymes, fermentation processes and other enzyme-using processes) are more closely linked to the pharmaceutical industry than to the chemical industry (Table 5-3). Patents connected to the subfield of established biochemicals are naturally closely linked to the chemical sector. Patents in the field of other enzyme-using processes often relate to the instruments industry, pointing to the fact that technological advance in this area has to master both chemical and process technology challenges.

**Table 5-3: Technological sector affiliation of industrial biotechnology patent applications (EPO/PCT), by subfield (average of 1981-2007 applications, percent)**

| | Enzymes | Fermentation processes | Other enzyme-using processes | Established biochemicals | **Industrial biotech total** |
|---|---|---|---|---|---|
| Food | 6 | 8 | 1 | 1 | **4** |
| Textiles | 1 | 0 | 0 | 1 | **1** |
| Wood/Paper | 1 | 1 | 1 | 1 | **1** |
| Chemicals | 11 | 21 | 14 | **57** | **23** |
| Pharmaceuticals | **66** | **59** | 34 | 18 | **45** |
| Rubber/Plastics | 0 | 0 | 1 | 1 | **1** |
| Glass/Ceramics | 1 | 0 | 1 | 1 | **1** |
| Metals | 0 | 0 | 1 | 1 | **1** |
| Machinery | 3 | 4 | 7 | 7 | **5** |
| Electronics | 1 | 1 | 3 | 2 | **2** |
| Instruments | 10 | 5 | **37** | 9 | **17** |
| Vehicles | 0 | 0 | 0 | 0 | **0** |

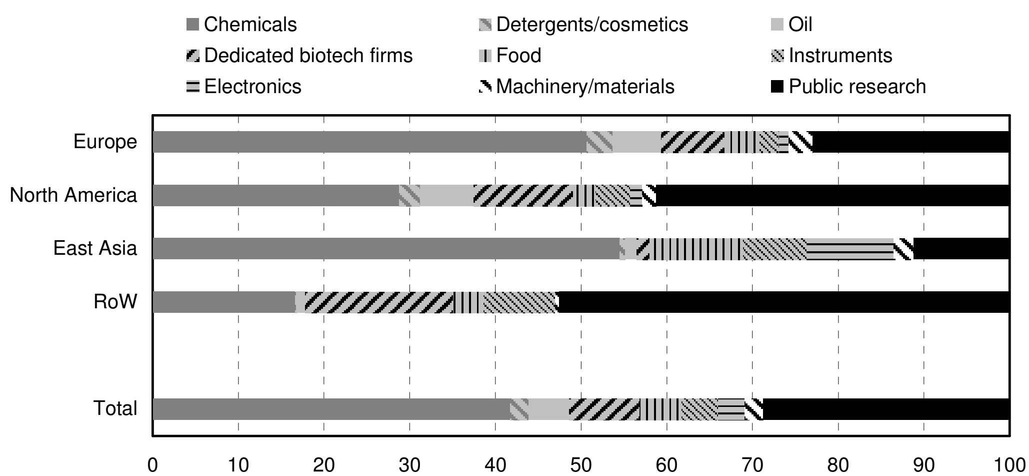
| Total | 100 | 100 | 100 | 100 | **100** |
|---|---|---|---|---|---|

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

### *Sector affiliation of applicants*

If one looks at the sector affiliation of industrial biotechnology applicants, i.e. if one assigns industry sectors to industrial biotechnology patents based on the main market an applicant is present, the picture becomes more disperse. For this purpose the most active applicants were assigned to one industrial or institutional sector based on their main economic activity. In Europe and East Asia, applicants from the chemical industry clearly dominate, while in North America, public research constitutes the largest sector from which industrial biotechnology patents emerge. The large share of patents from public research in North America can also be ascribed to a strong patenting related to pharmaceutical applications, but with technological relevance for industrial biotechnology, too. Patents from chemical firms are the second largest group in North America whereas research institutions are second in Europe.

**Figure 5-14: Sector affiliation of industrial biotechnology patent applicants (EPO/PCT), by region (average of 1981-2007 applications, percent)**

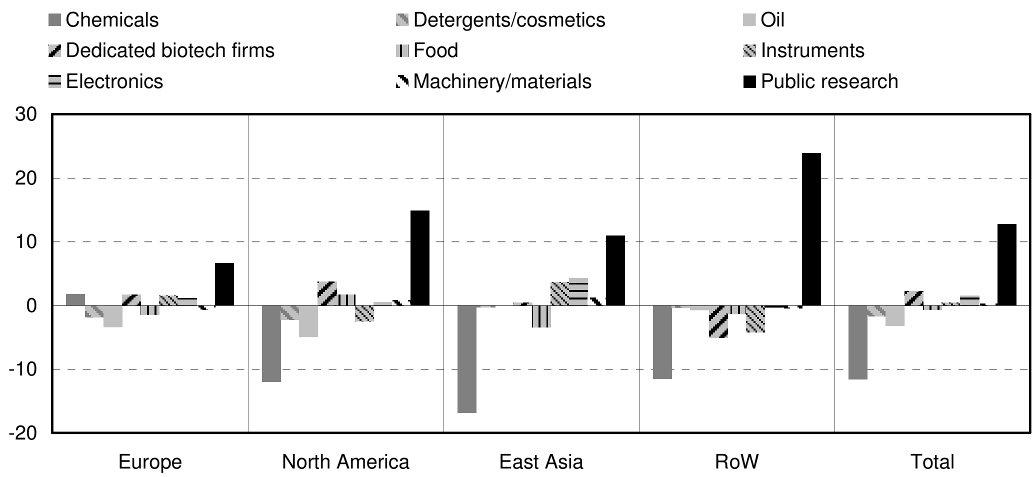



** Including patents in the fields of red and green biotechnology that are technologically relevant to industrial biotechnology.*
*Source: EPO: Patstat. ZEW calculations.*

The share of dedicated biotechnology firms in industrial biotechnology patenting is rather pronounced in North America while in Europe and East Asia industrial biotechnology activities are conducted by larger firms as one line of activity, as for example in chemical firms.

Comparing the sector affiliation of industrial biotechnology patent applications before and after the end of 1999 - which splits the total sample of industrial biotechnology patents in two subsamples of similar size - reveals a shift of industrial biotechnology patenting from the chemical industry towards public research and biotechnology start-ups. The public research sector could increase its share in the total number of industrial biotechnology patents from 23 to 36 percent. Biotechnology start-ups could raise their market share form 7 to 10 percent. Significantly decreasing shares are reported for the chemical industry (from 47 to 35 percent). In East Asia, the electronics industry gained in importance as producer of new technological knowledge in industrial biotechnology which can be associated with an increasing interest in bioelectronics.

**Figure 5-15: Change in the sector affiliation of industrial biotechnology patent applicants before and after the end of 1999 (EPO/PCT), by region (percentage points)**




*Source: EPO: Patstat. ZEW calculations.*

The list of the 15 largest industrial biotechnology applicants of the three regions (in terms of the number of patents applied since 2000) is given in Table 5-4 for information purposes.

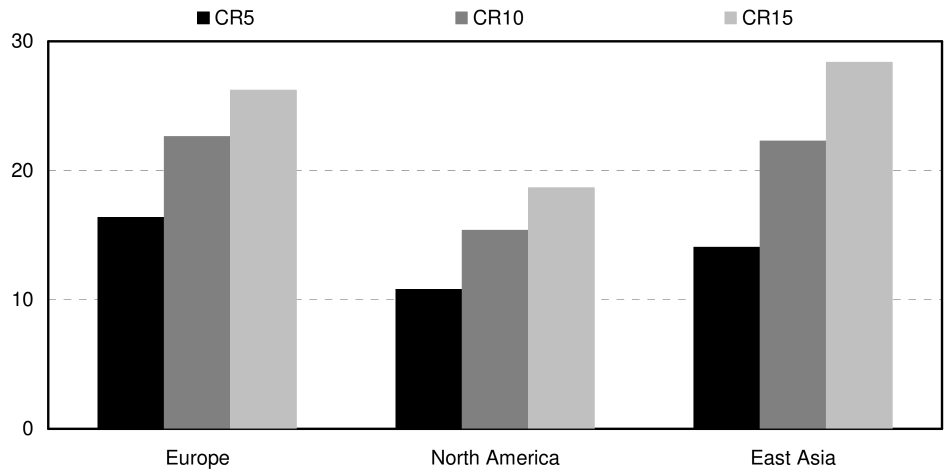
**Table 5-4: 15 main patent applicants in industrial biotechnology by region (EPO/PCT patents, 2000-2007 applications)**

| Rank | Name | Country | Sector | No. of Patents |
|---|---|---|---|---|
| **Europe** | | | | |
| 1 | BASF | DE | chemicals | 235 |
| 2 | Novozymes | DK | chemicals | 159 |
| 3 | Evonik Degussa | DE | chemicals | 136 |
| 4 | Bayer | DE | chemicals | 74 |
| 5 | Danisco | DK | chemicals | 74 |
| 6 | DSM | NL | chemicals | 55 |
| 7 | Cons. Sup. de Invest. Cientif. | ES | research | 51 |
| 8 | CNRS | FR | research | 49 |
| 9 | Shell | NL | oil | 41 |
| 10 | Fraunhofer | DE | research | 38 |
| 11 | Cognis | DE | chemicals | 36 |
| 12 | Max-Planck-Gesellschaft | DE | research | 30 |
| 13 | Henkel | DE | detergents | 26 |
| 14 | Comm. à l'energie atomique | FR | government | 20 |
| 15 | Plant Bioscience | GB | biotech | 20 |
| **North America** | | | | |
| Rank | Name | Country | Sector | No. of Patents |
| 1 | Du Pont | US | chemicals | 126 |
| 2 | Univ. of California | US | research | 119 |
| 3 | Applera | US | biotech | 61 |
| 4 | Rohm and Haas | US | chemicals | 56 |
| 5 | Univ. of Wisconsin | US | research | 39 |
| 6 | ExxonMobil | US | oil | 38 |
| 7 | Univ. of Florida | US | research | 36 |
| 8 | Univ. of Texas | US | research | 35 |
| 9 | North Carolina State Univ. | US | research | 33 |
| 10 | 3M | US | chemicals | 32 |
| 11 | U.S. Government | US | government | 32 |
| 12 | Cargill | US | food | 32 |
| 13 | Johns Hopkins Univ. | US | research | 30 |
| 14 | MITSUBISHI RAYON CO., LTD. | US | research | 29 |
| 15 | Univ. of Pennsylvania | US | research | 28 |
| **East Asia** | | | | |
| Rank | Name | Country | Sector | No. of Patents |
| 1 | Matsushita Electric | JP | electronics | 69 |
| 2 | Mitsubishi Chemical | JP | chemicals | 63 |
| 3 | Sumitomo Chemical | JP | chemicals | 58 |
| 4 | Ajinomoto | JP | chemicals | 49 |
| 5 | Kaneka | JP | chemicals | 47 |
| 6 | JSTA | JP | research | 45 |
| 7 | Canon | JP | instruments | 40 |
| 8 | Asahi Kasei | JP | chemicals | 32 |
| 9 | NIAIST | JP | research | 31 |
| 10 | Kao | JP | chemicals | 28 |
| 11 | Daicel Chemical | JP | chemicals | 25 |
| 12 | Fuji Film | JP | chemicals | 24 |
| 13 | Olypmus | JP | instruments | 24 |
| 14 | Toyo Boseki | JP | chemicals | 21 |
| 15 | Hitachi | JP | electronics | 21 |

*Source: EPO: Patstat. ZEW calculations.*

Patent applications in industrial biotechnology are not much concentrated on a few firms but are rather widespread. Figure 5-16 shows the concentration of patenting activity on the basis of three concentration measures indicating the share of patents for which the 5 percent (CR5), 10 percent (CR10) and 15 percent (CR15) most patenting active firms account for. In Europe, 26 percent of all patents were applied by the 15 largest applicants. In North America, this ratio is significantly lower while patenting is more concentrated in East Asia.

**Figure 5-16: Concentration of patenting activity in industrial biotechnology (EPO/PCT patents, 2000-2007 applications)**

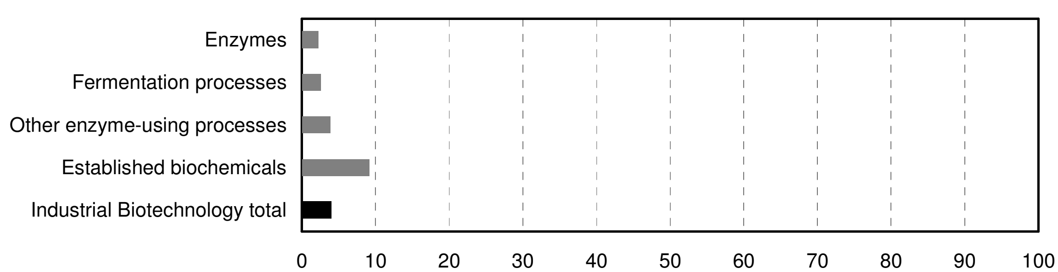



*Source: EPO: Patstat. ZEW calculations.*

### *Links to other KETs*

Related to the issue of sector links is the degree to which industrial biotechnology patents are linked to other KETs. One way to assess likely direct technological relations is to determine the share of industrial biotechnology patents that are also assigned to other KETs (because some IPC classes assigned to an industrial biotechnology patent are classified under other KETs). The degree of overlap of industrial biotechnology patents with other KET patents by subfields is shown in Figure 5-17. Except for established biochemicals, for which about 10 percent of all patents are at the same time assigned to other KETs, direct links are very rare. Only 4 percent of all industrial biotechnology patents have been assigned to another KET.

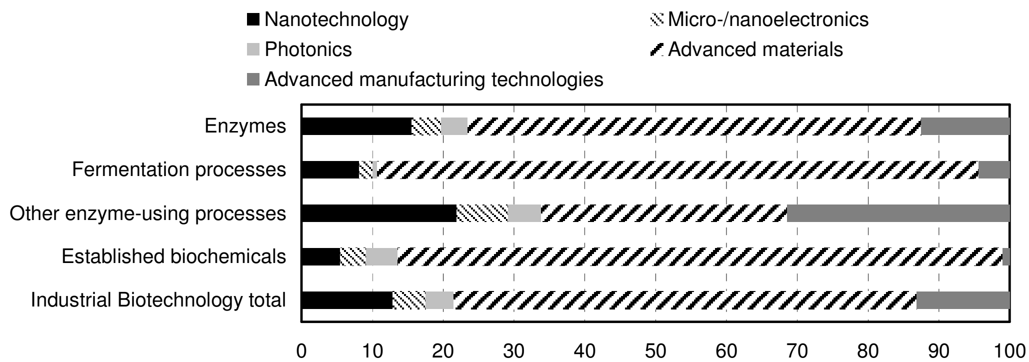
**Figure 5-17: Share of industrial biotechnology patents linked to other KETs by subfield (EPO/PCT patents 1981-2007, percent)**




*Source: EPO: Patstat. ZEW calculations.*

For those industrial biotechnology patents that are linked to other KETs, one can see that most of them overlap with advanced materials (Figure 3-18). Some industrial biotechnology patents form the subfields of enzymes and other enzyme-using processes are also linked to nanotechnology, and some patents in the subfield of enzyme-using processes are also assigned to advanced manufacturing technologies. Overlaps to microelectronics and photonics are extremely rare.

**Figure 5-18: Links of industrial biotechnology patents to other KETs by subfields (EPO/PCT patents 1981-2007, only patents with links to other KETs, percent)**




*Source: EPO: Patstat. ZEW calculations.*

### 5.2.3. Market Potentials

One reason for the large future potential is that until now the endless biodiversity is known only to a small extent. In addition, owing to increasingly scarce resources and rising energy prices it is expected that the share of biotechnology applications increases in the coming years (BMBF, 2008).

*Biochemicals*

While for 2007 on estimation for biotech sales in chemicals were around €48 billion (3.5 percent of total chemical sales), the sales are expected to increase to around €135 billion (7.7 percent of total chemical sales) in 2012 and to around €340 billion (15.4 percent of total chemical sales) in 2017 (without pharmaceutical products but including active pharmaceutical ingredients; Festel Capital, 2009). A more conservative estimate for biochemical sales is announced by McKinsey (2009). They predicted an increase from €65 billion to €88 billion in 2012. The United States Department of Agriculture expects the bio-based share of chemical production to be around 11 percent in 2010 and to reach one quarter by 2025 (USDA, 2008). In another study it is expected that the value of biochemicals (other than pharmaceuticals) will lie between 12 percent and 20 percent by 2015 (OECD, 2009a). Formerly conducted analyses expected an increase to the range between 15 to 20 percent already by 2010 (Festel, 2006; Frost & Sullivan, 2003; McKinsey, 2003; BMBF, 2008).

The segment of active pharmaceutical ingredients is expected to remain the segment with the highest share of biotech sales. This share is predicted to increase to 34 percent by 2012 and to 50 percent by 2017 (OECD, 2009b). Biotechnological processes are also expected to make up half of fine chemical production by 2025 (USDA, 2008). Again, former studies expected the biobased share of fine chemicals to reach 60 percent already by 2015 (Riese and Bachmann, 2004; Festel, 2006; BMBF, 2008).

*Industrial enzymes*

For the market for enzymes, which is not assignable to a specific application, an annual growth about 6.5 percent is expected for the next years (OECD, 2009a). About three quarters of the enzymes are used in food, feed and detergents (ETEPS AISBL, 2007). Global sales should amount to about $7.4 billion in 2015. Selecting and developing more effective enzymes contributes to cost savings, to a more environmentally production process through reduced energy consumption and to the elimination of harmful by-products (OECD, 2009a).

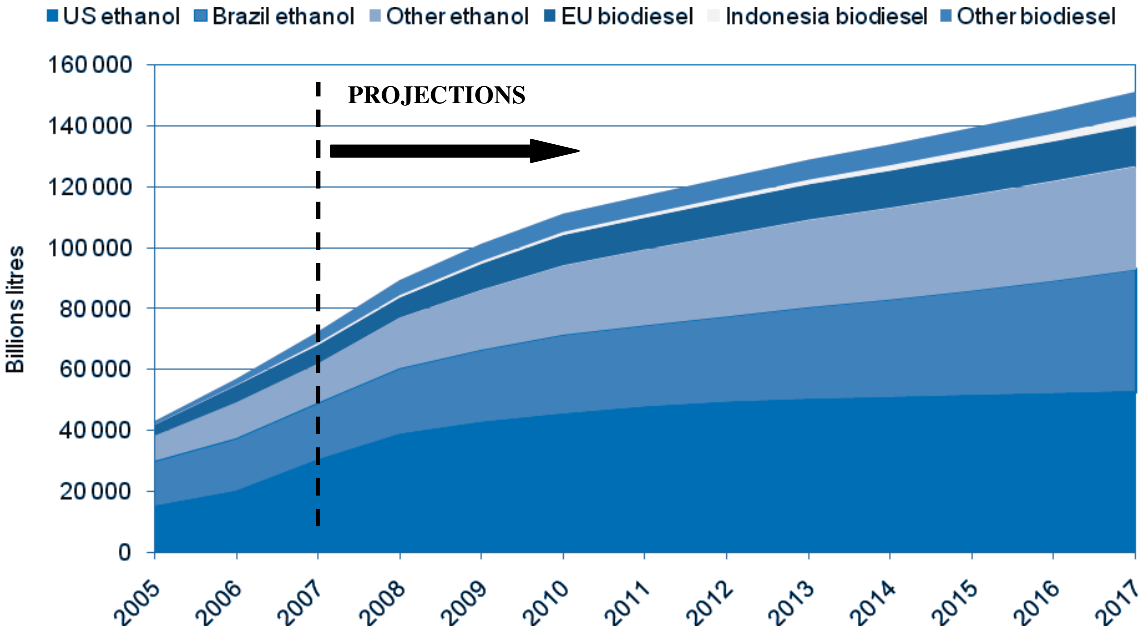
*Biomaterials: bioplastics*

The production of bioplastics is based on polymers and is expected to experience significant growth. Thereby the rate of growth will depend on the necessary technological advances and will be larger if petroleum prices increase. The upper limit for the substitution of bio-based plastics replacing petroleum-based plastics is seen at 33 percent (USDA, 2008). In 2010/2011 the global production of biopolymers is expected to be between 500 and 1500 kilo tonnes, which represent between 0.2 and 0.6 percent of the production of all polymers (OECD, 2009a). This share is predicted to increase to between 10 and 20 percent by 2020 (OECD, 2009a) or by 2025 (USDA, 2008).

*Biofuels*

Besides biochemicals and biomaterials, the field of biofuels is an expanding sector which is assumed to have the highest growth rates. In the last decade biofuel production increased considerably. Between 2000 and 2007 the ethanol production tripled to 52 billion litres; biodiesel increased 11-fold to 11 billion litres (OECD-FAO, 2008). Biofuel sales were about €34 billion in 2007 (McKinsey, 2009). Biofuel production is predicted to more than double by 2017 (see Figure 5-19). The European Council agreed to the Action Plan 2007-2009 Energy Policy for Europe (EPE) in which it set a mandatory minimum target to be achieved by all Member States for biofuels of 10 percent of vehicle fuel by 2020. In 2005, the biofuel share was about 1 percent in the EU-25 (Council of the European Union, 2007).

**Figure 5-19: World ethanol and biodiesel production: projections to 2017**




*Source: OECD (2009a: 124).*

However, figures on the expected market volume have to be interpreted with care. Excessively high projections of market sizes in the different subfields of biotechnology made in the early years of the new century have raised very high expectations. They turned out to be unrealistic despite the high growth rates that biotechnological products still exhibit. A potential downside of these high projections is that important investments into biotechnology might be diverted as a more realistic market assessment becomes apparent. In this respect, it seems sensible to draw an overall very positive picture of the market potential in industrial biotechnology but at the same time to hint at general growth trends in the chemicals industry of which biotechnology cannot be isolated.

Table 5-5 summarises available estimates and forecasts on the market potential in industrial biotechnology and selected subfields.

**Table 5-5: Estimates and forecasts the size of subfields of the global industrial biotechnology market (billion US-$ unless otherwise specified)**

| Subfield | Source | 2005/06 | 2007/08 | 2010/11 | 2012/13 | ~2015 | ~2017 | ~2025 | Cagr* |
|---|---|---|---|---|---|---|---|---|---|
| **Biochemicals (excl. pharmaceuticals)** | | | | | | | | | |
| Fine | USDA (2008) | 15 | | 25-32 | | | | 88-98 | |
| Polymer | USDA (2008) | 0.3 | | 15-30 | | | | 45-90 | |
| Specialty | USDA (2008) | 5 | | 87-110 | | | | 300-340 | |
| Commodity | USDA (2008) | 0.9 | | 5-11 | | | | 50-86 | |
| Base chemicals (billion €) | Festel Capital (2009) | | 12 | | 34 | | 113 | | 25 |
| Consumer che- | Festel Capital | | 11 | | 32 | | 84 | | 23 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| micals (billion €) | (2009) | | | | | | | | |
| Speciality chemicals (billion €) | Festel Capital (2009) | | 15 | | 38 | | 73 | | 17 |
| Active pharmaceut. ingredients (billion EURO) | Festel Capital (2009) | | 10 | | 31 | | 70 | | 21 |
| Commercial amino acids | BCC (2009) | | 1.1 | | 1.3 | | | | 3 |
| Synthetic biology | BCC (2009) | | 0.08 | | 1.6 | | | | 82 |
| Traditional bio-based chemicals (billion €) | McKinsey (2009) | | 46 | | 60 | | | | 5 |
| Chemicals by fermentation (billion €) | McKinsey (2009) | | 14 | | 21 | | | | 8 |
| Chemicals by enzymatic processes (billion €) | McKinsey (2009) | | 5 | | 7 | | | | 7 |
| Total | USDA (2008) | 21.2 | | 132-183 | | | | 483-614 | |
| Total (billion €) | McKinsey (2009) | | 65 | | 88 | | | | |
| Total (billion €) | Festel Capital (2009) | | 48 | | 135 | | 340 | | 22 |
| **Enzymes for industrial application** | | | | | | | | | |
| Total | BCC (2008) | 2.1 | | | 2.7 | | | | 4 |
| Total | Reiss et al. (2007) | | | | | 7.4 | | | 6.5 |
| **Biomaterials** | | | | | | | | | |
| Bioplastics (1,000 tonnes) | OECD (2009a) | | | 500-1500 | | | | | |
| **Biofuels** | | | | | | | | | |
| Biofuels (billion €) | McKinsey (2009) | | 34 | | 65 | | | | 14 |
| Biodiesel (billion litres) | OECD-FAO (2008) | | 11 | | | | | | |
| Ethanol (billion litres) | OECD-FAO (2008) | | 52 | | | | | | |
| **Industrial Biotech** | | | | | | | | | |
| Total (billion €) | McKinsey (2009) | | 99 | | 153 | | | | 9 |

** Compound annual growth rate in nominal terms (percent).*

*Source: Compilation by ZEW based on the sources quoted.*

## 5.3 Success Factors, Barriers and Challenges: Cluster Analysis

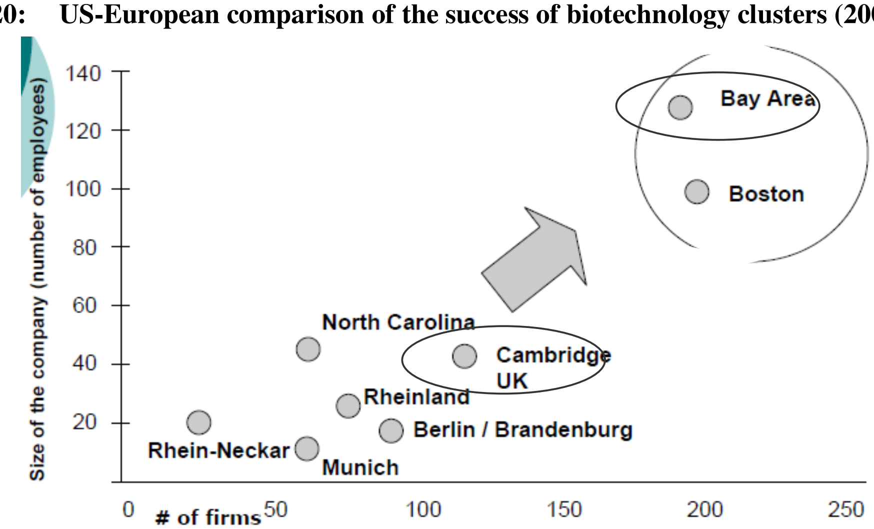
The geographical distribution of industrial biotechnology clusters can be summarised in four regions: West- and North Europe, American West coast, American East coast, and East Asia. In Europe, the strongest biotechnology clusters are in the United Kingdom (Cambridge) and Germany (Heidelberg). Denmark (Aarhus), France (Marseille) and Sweden (Uppsala) are in earlier development stages and therefore have not reached maturity yet. On the American West coast, clusters in Seattle, San Francisco Bay Area and San Diego are well positioned, while on the American East coast, Montreal (Canada), Boston and the research triangle in

North Carolina are major hubs. Finally, East Asia is mainly represented by Japan, Taiwan, China (Shanghai) and Singapore on the global industrial biotechnology market.

Europe is the world leader in key industrial biotechnologies such as enzyme technologies and fermentation. The most important enzyme producers are located in Europe with a total of about 80 in Europe compared to 20 in the US (EC, 2008b). Nearly 70 percent of the estimated $313 billion spent in 2006 on R&D of relevance to biotechnology by leading companies in industrial applications, was spent by European firms (OECD, 2009a).

The two chosen case studies are Cambridge (United Kingdom) and the Bay Area (United States of America). Cambridge in UK is the most important cluster in Europe and one of the strongest (industrial) biotechnology areas on a worldwide level (Chiesa and Chiaroni, 2005). The Bay Area around San Francisco is not only the birthplaces of biotechnology (the first biotechnology company Genentech was found there in 1976), but it is also a well established and renowned biotechnology cluster with a similar age and historical development as Cambridge. Which makes them also interesting to compare is the fact that they had the same form of cluster creation in the past. Cambridge and the Bay Area could both be classified as spontaneous clusters, which is the result of a spontaneous concentration of the key factors enabling its birth and development, without major influence of governmental commitment (which would indicate policy-driven clusters) (Chiesa and Chiaroni, 2005).

**Figure 5-20: US-European comparison of the success of biotechnology clusters (2003)**

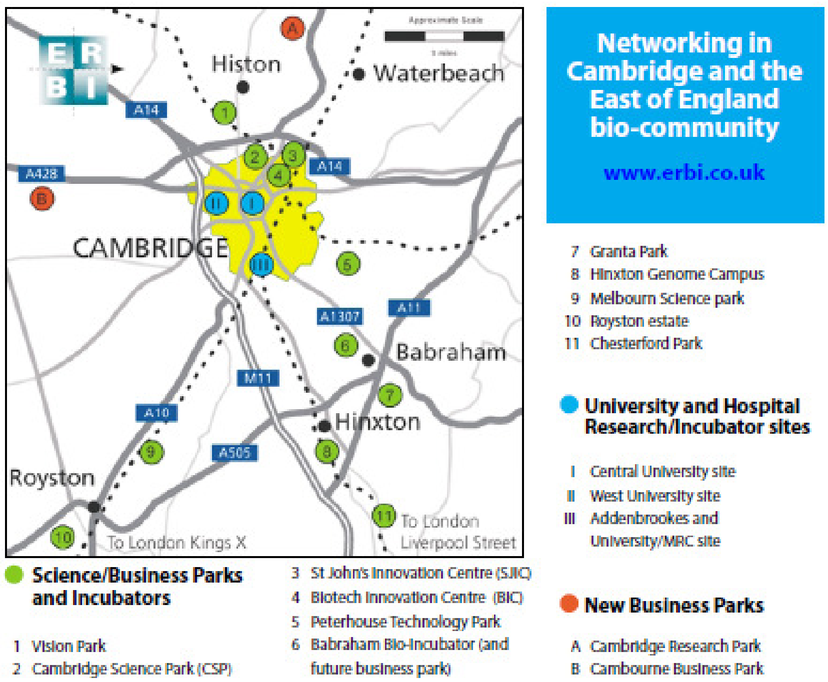



*Source: http://iis-db.stanford.edu/docs/190/Casper_biotech_clusters.pdf*

### 5.3.1. Industrial biotechnology cluster Europe: Cambridge (United Kingdom)

The cluster of Cambridge in UK comprises the area around the city with a radius of nearly 30 km. The biotechnology cluster is embedded within 30 government-funded laboratories and seven renowned universities in the Cambridge region. Currently, there are more than 250 biotechnology companies present on Cambridge campus, accompanied by 29 public firms and a large number of service providers. These biotechnology companies were mainly founded on campus rather than becoming established from external sites. Larger companies from the outside are getting involved in the Cambridge cluster mainly through M&As. All dedicated biotechnology companies have a combined number of employees of around 10,000: the whole biotechnology cluster, including universities and supporting activities, employs 25,000 people.[52] The Cambridge biotechnology cluster is served by local support providers and receives large investments (2004: €600 million).

**Figure 5-21: Actors in the Cambridge biotechnology cluster**

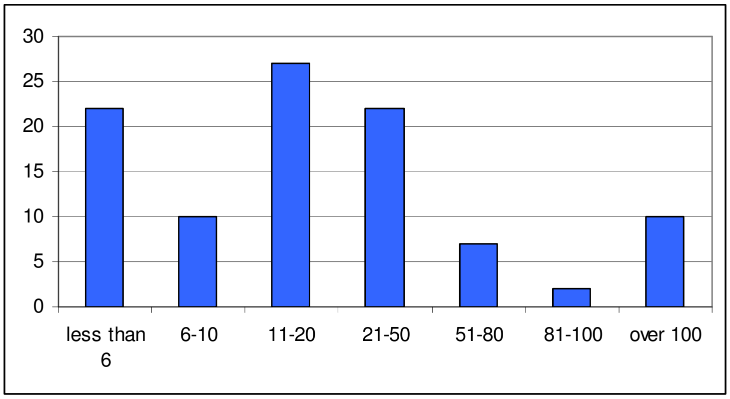



*Source: Walker (2005).*

Although there are larger biotechnology companies with more than 250 employees, most firms in the Cambridge cluster have approximately 11-20 employees (see Figure 5-22). These SMEs focus on R&D and license-out technology to larger players with manufacturing and marketing capabilities. Furthermore, there are many companies with less than six employees, indicating the continuous development of start-ups within the cluster.

[52] http://www.protoneurope.org/news/7th-annual-conference-2010-athens/friaday-29-january-2010/the-heidelberg-model/attachment_download/file

**Figure 5-22: Distribution of the number of employees in biotechnology firms in the Cambridge cluster**



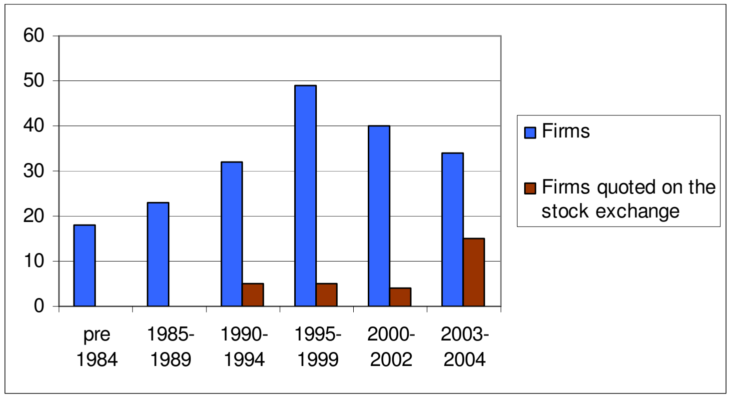

*Source: Chiesa and Chiaroni (2005: 55).*

## *Short history of the cluster*

The industrial biotechnology cluster in Cambridge emerged in the early 1980s. Initial companies were founded within the Cambridge Science Park and were embedded in an environment of existing and established electronics and computing industries. The number of biotechnology companies grew steadily until the mid 1990s, when international investments in high-tech industries also nurtured the biotechnology cluster in Cambridge. Through this, the Science Park was soon dominated by biotechnology companies and was viewed primarily as a biotechnology location. These companies were accompanied and supported by biotechnology research organisations such as the University of Cambridge, the Institute of Biotechnology and the Babraham Institute. As the cluster developed critical mass it attracted scientific, technical and business service providers, building a cluster with a balanced mix of academic and commercial expertise with local support providers.

Figure 5-23 illustrates the historic growth of the cluster. The time period 1995-1999 showed the highest growth rate, driven by two factors. Commercial awareness of biotechnology during this period as well as a rapidly growing global economy investing venture capital in high-tech industries have spurred the cluster’s growth. Growth came to a hold, however, as the stock market declined in 2001/02 and in the following years, and the number of new companies in the cluster declined. In addition to this, there were more IPOs than in the years before, increasing the number of publicly listed firms.

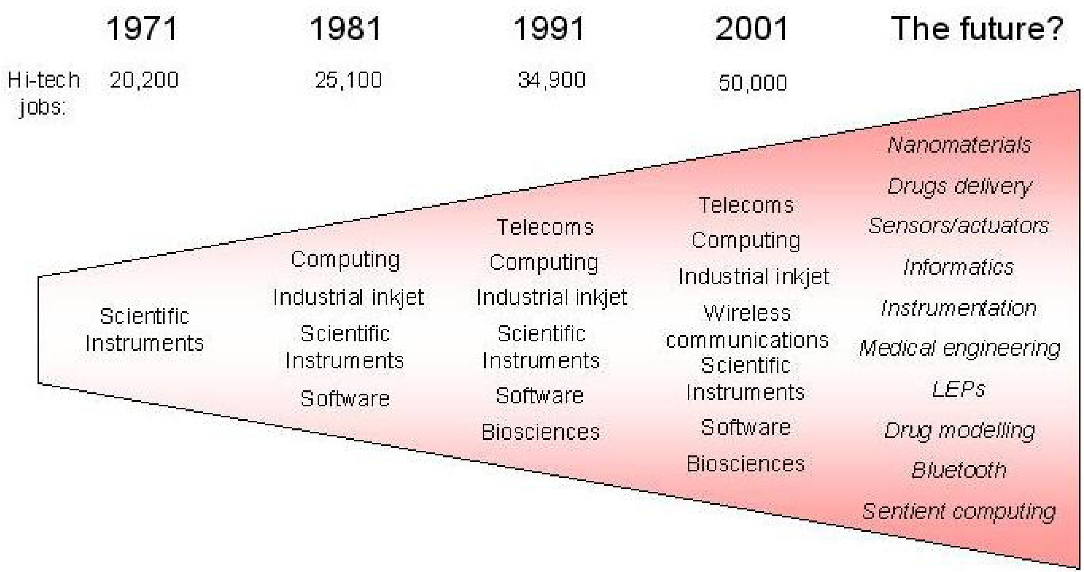
**Figure 5-23: Number of new biotechnology firms in the Cambridge cluster**




*Source: Chiesa and Chiaroni (2005: 52).*

Biotechnology is not the only technology represented in Cambridge. As Figure 5-24 shows, a wide range of teFchnologies emerged there over the last decades. This multidisciplinarity had an influence on the success of the cluster, since many research fields are interrelated. This opened collaboration opportunities between technology specialists.

**Figure 5-24: The emergence of technology clusters in Cambridge over time**




*Source: Barrel (2004).*

### *System failures and system drivers for growth*

*Infrastructure*

Infrastructure was available right from the beginning, since the biotechnology companies were founded within the premises of the University of Cambridge. Biotechnology firms have a wide range of choices for biology and chemistry laboratories, which are located in several science parks on campus or in the greater Cambridge area (Cambridge Science Park, Granta Park, Cambridge Research Park, Chesterford Research Park). Next to this, firms have also access to UK's most successful bio-incubator, which is located on the Babraham Research Campus.

The Cambridge biotechnology cluster has a good balance between academic institutions (e.g. University of Cambridge), locally established companies (e.g. Cambridge Antibody Technology), companies from overseas (Amgen USA), spin-offs from universities and research institutes (e.g. Akubio Ltd.), and spin-offs from biotechnology companies (e.g. Sareum Ltd.) (see Walker, 2005). Furthermore, the biotechnology cluster is embedded into a larger technology network in Cambridge. Next to biotechnology, there are also strong research efforts in nanotechnology/materials and information technology, with many collaborative R&D projects in an interdisciplinary environment. Finally, there is also a growing number in supporting companies and services, including law firms, accounting firms, patent agents, consulting firms, and international banks, which contribute to the cluster's success (Barrel, 2004).

*Institutions*

*Norms and values:* It is proposed that culture change is one of the enabling factors that stimulated the growth and development of the cluster. This change is related to the generation of a more entrepreneurial spirit and the establishment of a common belief and purpose of the Cambridge science community (Barrel, 2004).

*Public policy and funding:* The cluster is unique in Europe in a way that not a single person or individual organisation has consciously played a significant role in the creation of the cluster and its development over time. Cluster development was driven by many different players and factors, but without a strong commitment of public actors in the beginning. Only when the biotechnology industry was already well established in the area and forming a cluster, many agencies were created to act as central actors in guiding the cluster development (e.g. bioindustry association, East Region Biotechnology Initiative, East Anglia Development Agency) (Chiesa and Chiaroni, 2006).

The national government supports the regional activities through its Biotechnology and Biological Sciences Research Council (BBSRC). Their main policy is to ensure a sustainable and world-class research base in the UK to attract investments in bioscience research. To do so, they support the development of new approaches and technologies, and they accelerate the transformation of research outputs into commercially successful products and processes. Within BBSRC, there is also a 'Bioscience for Industry Strategy Panel', providing strategic input on industrial user needs, knowledge transfers and interactions with the industry.[53]

[53] http://www.bbsrc.ac.uk/organisation/organisation-index.aspx

Furthermore, public policies for biotechnology are also created through a number of other governmental organisations. The Bioscience Unit of the Department of Trade and Industry (DTI) has the oversight for the biotechnology sector and promotes industry-related R&D and technology transfer. The Office of Science and Technology (OST) is also part of DTI and responsible for overall science policies. Regulatory competence lies with the Department of Health (DoH). Since biotechnology activities often originate from university research, the Department for Education and Skills (DfES) plays an important role in university policy and funding in relation to biotechnology. Tax breaks and tax credits created through The Treasury are key policies and one of the most significant initiatives in stimulating investments in biotech. Introduced in 2000, tax credits are widely used. SMEs are entitled to tax breaks on their non-capital R&D expenditure over £10,000 at 150 percent. If the firm makes no taxable profit (which is the case for many biotechnology firms), losses can be surrendered to the Exchequer in return for a cash payment of 24 percent of total eligible R&D spend. This scheme is estimated to support the industry with £150 million. Finally, many regional Development Agencies (RDAs) identified biotechnology as a key technology and thus created a range of models to reinforce the foundation of new companies and/or to strengthen existing ones (House of Commons, 2003). In general, the UK has an advantage over countries such as Germany and the USA because of the comparatively liberal regulatory framework within biotechnology R&D is conducted.

On a national level, the government's research councils run a number of initiatives to encourage the commercialisation of research. The BBSRC (bioscience for the future) is one of the seven research councils, which is funded by the Department for Business, Innovation and Skills (BIS). Its budget is around £450 million (2008) and supports 1600 scientists and 2000 research students in universities and research institutes in the UK. Cambridge University receives quite a large share of this budget (160 grants with a sum of £55 million in 2008) for its own biotechnology research and commercialisation activities in form of exploitation of research outcomes.[54]

*Venture capital:* The cluster has also access to financial resources at all investment stages, which has shown to be critical for growth. The business angel network in Cambridge is one of the most active in Europe (Walker, 2005). The biotechnology cluster is served through the 'Great Eastern Investment Forum' and the 'Cambridge Angels'. Next to their primary function of providing capital, these business angels offer professional advice, contacts, and practical help. Another new angel initiative is the 'Cambridge Capital Group', which supports companies with linkages to university research with private investments. Once the start-ups enter the global market, they are accompanied by the regional operating 'Cambridge Gateway

[54] http://www.bbsrc.ac.uk/organisation/organisation-index.aspx

Fund' in pursuing venture capital. Furthermore, venture capital is also available through the proximity to the large financial market in London. For example, the Barclays Bank dedicated large sums to the promising high-tech industry, with many smaller venture capitalists following this development (Page, 2003).

*Interactions*

Companies in the region enjoy access to local suppliers of technical and professional services and this has created a regional supply chain that is unrivalled in Europe. Several other factors contributed to the success of the cluster. A number of biotechnology entrepreneurs were attracted by the mixture of increased funding, availability of premises and the high-tech atmosphere on campus. At the same time, several organisations helped to found and support start-ups in a variety of ways. But none of these organisations was responsible for the creation of the cluster, rather than the combination and synergy effects of actions across organisations. For example, the Babraham Bioincubator offered small laboratories and offices for flexible and temporary work, but it did not provided subsidised services. Later on, when the biotechnology cluster was already established, it was (and still is) supported by the East Region Biotechnology Initiative (ERBI), which is an industry led initiative which was formally started in 1997 by the local biotechnology community and local and national government officials. Initially, it obtained its financial resources from the Department of Trade and Industry. Now, ERBI receives the majority of funding from private sources. ERBI aims on enhancing the growth and development of biotechnology in Cambridge and the East of England, with the mission of asserting the region as a world-renowned centre of excellence. The organisation promotes local, national and international networking, supports successful growth on new and emerging ventures, and makes sure that the infrastructure enables a steady growth of the biotechnology community (Chiesa and Chiaroni, 2005).

In addition to ERBI's activities, there is a huge amount of sharing of best practice, contacts and experiences, and newcomers to the cluster can easily and quickly integrate into the scientific and business communities. In addition to this, the critical mass of activity in the region has created a so-called 'bio re-cycling' phenomenon, meaning that nothing is redundant for very long. People, laboratories, IP, and equipment are quickly re-absorbed into the local biotechnology cluster (Walker, 2005).

*Capabilities*

The Cambridge biotechnology cluster combines world renowned research universities with important research institutes. Furthermore, Cambridge has a well established entrepreneurial culture with many biotechnology firms originating from university spin-offs, which were and still are supported by number of incubators and Science Parks.

***Market failures and drivers for growth***

*Market structure*

With currently more than 250 biotechnology companies, the cluster created a strong profile as a excellent location for early stage companies and start-ups with high growth rates and innovative technologies. They are not only attracted by the cutting edge research centres, but also by large established biotechnology organisations (number of employees higher than 250), which offer potential knowledge transfers and learning opportunities through collaboration activities. Therefore, Cambridge has a well established entrepreneurial culture with university spin-offs (dating back to the 1980s).

Investors are also keen for biotechnology companies to locate in the area, in order to benefit from other advantages, such as local venture capitalists and business angels, a range of supporting services with legal, patent, recruitment, and property advisers, and regional biotechnology associations. Finally, they want to associate the new company with the image of Cambridge as a leading scientific centre.[55]

*Market demand*

Next to the relatively easy access to financial resources and markets in London, other high-tech clusters in the UK and bio hubs in Europe, the exceptional strategic location of the region enables research institutes and biotechnology companies to sell products and services throughout Europe to all kind of different markets. With the Stansted airport only half an hour away, Cambridge is very good connected to most major European cities and biotechnology communities in continental Europe (Walker, 2005).

***Conclusion***

The Cambridge biotechnology cluster is a world-leader and the biggest of its kind in Europe. It was created spontaneously without major support from the government. Cambridge is so successful, because it has a unique set of characteristics: it combines top ranked research institutes, world class universities, intense commercial activity with small start-ups as well as multinational companies, incubators, company creators, science parks, a range of professional advisers and services (including biotechnology associations), a culture that respects risks, and last but not least a strategic location close London's large financial market, providing access to venture capitalists and business angel networks.

[55] http://www.berr.gov.uk/files/file28706.pdf

*System and market failures and drivers*

*Public funding:* During the early stages of cluster development, the government had very little impact on the formation of the cluster. There was limited financial support, guidance and commitment on the part of public actors. After the cluster reached a more mature stage, the government started to assist in its further development by implementing supporting association, initiatives and agencies and creating specific research councils (BBSRC) for public funding. Nevertheless, the UK government has only committed limited amounts of public money to subsidising the biotechnology industry. The lack of government support could be the right choice, since the biotechnology sector is able to survive without large public funding. But on the other hand, the industry is highly reliant on business angles and venture capital. This could result in a twin obstacle of market failure and absence of public support at one point in time (House of Commons, 2003).

*Tax incentives:* Tax breaks and tax credits created through The Treasury are key policies and one of the most significant initiatives in stimulating investments in biotech. It boosts R&D activity on a national scale, up to 10 percent in the long-term.

*Public procurement and lead markets:* We found no specific information on the role of public procurement and lead markets.

### 5.3.2. Technology cluster Non-Europe: Bay Area (United States of America)

The San Francisco Bay Area is one of the most commercially successful biotechnology clusters. Over the last 30 years, the biotechnology cluster has grown to 1.400 life science firms with 90,000 employees and generating over $2 billion in exports annually.[56] More specifically, the 69 public biotechnology firms generated $17.7 billion in revenues (2006).[57] These companies are accompanied and supported by several private research institutes, nine regional universities and public officials at all levels of government.[58] The total market capitalisation is estimated at $144 billion.

**Figure 5-25: San Francisco Bay Area biotechnology public company financial highlights ($m) 2005 (percentage change over 2004)**

| Region | Number of public companies | Market capitalization 12.31.05 | Revenue | R&D | Net loss (income) | Cash and short-term investments | Total assets |
|---|---|---|---|---|---|---|---|
| San Francisco Bay Area | 67 | 162,261 | 15,431 | 4,284 | 246 | 11,861 | 31,951 |
| | 0% | 53% | 25% | 5% | –60% | 21% | 13% |

*Source: modified from Su and Hung (2009: 612).*

56 http://www.protoneurope.org/news/7th-annual-conference-2010-athens/friaday-29-january-2010/the-heidelberg-model/attachment_download/file

57 http://www.oslocancercluster.no/index2.php?option=com_docman&task=doc_view&gid=25&Itemid=39

58 http://www.baybio.org/wt/page/history

***Short history of the cluster***

The biotechnology cluster in the Bay Area started in the late 1970s, supported by a large scientific base (University of California in San Francisco, Berkeley and Davis) and the accessibility of venture capital. Genentech, founded 1976 in San Francisco, was the first biotechnology company in the world. During the 1980s, Genentech acted as an anchor company, which was followed by the emergence of 50 other biotechnology firms, creating a expansion of workforce up to 19,000 jobs and a turnover of $2 billion (1987). Part of these new firms were actually founded from previous Genentech senior managers (16 percent of all Genentech senior managers founded their own biotechnology company). In the early years, the region did not appear as one coherent cluster, but rather as a collection of small clusters of firms linked to multiple venture capitalists (Owen-Smith and Powell, 2006). In the 1990s, the cluster achieved a certain level of maturity, with a shift from exploration to exploitation of biotechnology. This development was accompanied by the growth of the most successful companies, such as Genetech and Amgen and by taking the leadership position on a worldwide level. During the period 1988-1999, the Bay Area network involved 159 organisations (82 DBFs, 12 PROs, and 64 venture capital firms), connected by 243 local contractual ties. It is important to notice that no public intervention or any centralised organisation had a role in the development of this cluster (Chiesa and Chiaroni, 2005).

***System failures and system drivers for growth***

*Infrastructure*

The geographic proximity of scientific centres of excellence played an important role in the cluster development because of potential knowledge spillovers. But it was the availability of venture capital and other supportive institutional infrastructure which made the cluster successful in its early days. Nowadays, the combination of public funding and venture capital nurtures the cluster development. In absolute figures, the biotechnology cluster raised more than $4 billion in capital, including $600 million in venture financing (2006).[59]

*Institutions*

*Rules and regulations:* The activities in the Bay Area are also supported by US specific laws regarding the ownership of intellectual property, which were clarified in the 'Bayh-Dhole University and Small Business Patent Act' (1980). This act promotes the commercialisation of scientific research by giving universities the rights on their patents, thus clarifying IP ownership among research staff, departments, knowledge transfer offices and universities.[60]

[59] http://www.oslocancercluster.no/index2.php?option=com_docman&task=doc_view&gid=25&Itemid=39
[60] http://www.berr.gov.uk/files/file28741.pdf

There are improvements in the FDA regulations, which created faster pathways for the production of biotechnology products and processes.[61]

But there are also public regulations which hinder the development process of certain biotechnologies. For example, the Californian Air Resources Board (CARB) approved specific rules for Low Carbon Fuel Standards (LCFS) and new measurements for carbon intensity, which go into effect in 2011. According to this new way of calculating, the carbon footprint of biofuels is higher than for fossil fuels. This overregulation of biofuels generation is a threat for R&D activities in advanced biofuels and cellulosic ethanol.[62]

*Norms and values:* The success of the Bay Area biotechnology cluster is built on a culture of entrepreneurship. Is assumption is bases on the relatively high rates of IPOs and new venture creation in this region.

*Public policy and funding:* Funding from the federal government level originates from the National Institute of Health and the National Science Foundation (NSF, $2.2 billion in 2007), The US department of Agriculture, NASA (office of life and microgravity sciences) and the US department of Energy (office of Biological and Environmental Research). These funds are channeled through universities and research institutes to stimulate innovations in basic research. Also the city of San Francisco provides public funds for the creation of labs and office parks as well as a number of taxpayer-funded research grant.[63] Furthermore, California and the city of San Francisco offer several tax breaks and incentives for biotech-related activities.

*Venture capital:* Venture capital is available to support the commercialisation of scientific research and the transition of knowledge to the market. There is a large number of local venture capitalists investing in biotechnology start-ups, accounting for 34 percent of all active venture capital firms in the United States (see Su and Hung, 2009). Finally, there is one federal programme to support the foundation of biotechnology start-ups. The Small Business Innovation Research Program (SBIR) financially encourages university faculties to create commercial-oriented spin-offs of their research.[64]

*Interactions*

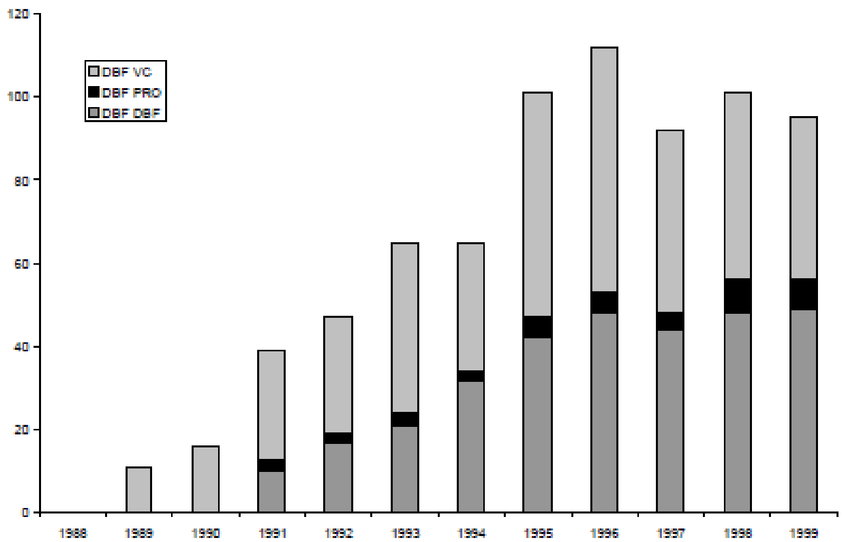
During the formation of the cluster, universities in the region tried to a create links to biotechnology firms. The UC (University of California) administration set up an initiative called BioSTAR to promote research collaborations between academics scientists and

[61] http://epscor.unl.edu/ppts/Panetta.ppt
[62] http://www.baybio.org/wt/page/energy_research
[63] http://legacy.signonsandiego.com/news/business/20041205-9999-mz1b5cluster.html
[64] http://www.sbir.gov/about/index.htm

dedicated biotechnology firms (DBF). More than 100 biotechnology firms participated, investing $32 million in the first four years.

After the cluster reached maturity (at the end of the 1990s), venture capital became increasingly important, while at the same time the involvement of public research organisations (PROs) was shrinking. Even more importantly, the cluster witnessed a rapid growth of direct ties between DBF. In 1999, DBF-DBF connections outnumbered the other two types of ties (venture capital, PROs) (Owen-Smith and Powell, 2006). These collaborative partnerships create strong network ties and build the social capital of this area, which is one of the key success factors for this cluster (Su and Hung, 2009).

**Figure 5-26: Bay Area main component ties by dyad**



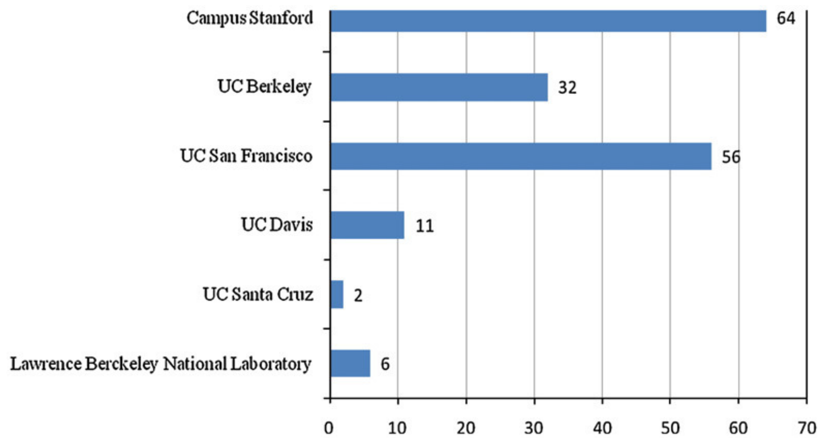

*DBF = dedicated biotechnology firm, VC = venture capital, PRO = public research institutes.*
*Source: Owen-Smith and Powell (2004: 33).*

To support the interaction between biotechnology companies, research institutes, venture capitalist, etc., the BayBio bioscience association was found. It offers the bioscience community networking opportunities, advocacy, group purchasing and access to organisations that support research, development and commercialisation of biotechnology products.

*Capabilities*

The biotechnology cluster in the Bay Area had a strong science base because of numerous top-level research universities and institutions. Many of their scientists founded their own biotechnology companies with their research results, which created more than 170 academic spin-offs. This means that the success of many biotechnology firms in this region is based on technological knowledge rather than organisational knowledge (Su and Hung, 2009).

**Figure 5-27: Academic spin-offs in the Bay Area since the origin of the cluster**




*Source: Chiesa and Chiaroni (2005).*

### *Market failures and drivers for growth*

*Market structure*

During the 1980s, Genentech acted as an anchor company, which was followed by the emergence of 50 other biotechnology firms, creating a expansion of workforce up to 19,000 jobs and a turnover of $2000 million (1987). Part of these new firms were actually founded from previous Genentech senior managers (16 percent of all Genentech senior managers founded their own biotechnology company). Today, the cluster is becoming a hub of biotechnology and all related activities, with relatively low entry and exit barriers for organisations.

*Market demand*

The biotechnology cluster in the Bay Area is market-oriented and a hub of biotechnology and biotech- related activities, with relatively low entry and exit barriers for organisations.

### *Conclusion*

The Bay Area in San Francisco has a dense concentration of biotechnology companies and major research and intellectual centres (notably UCSF, UC Berkeley and Stanford University). Along with a mature infrastructure of bio-savvy law firms, venture capitalists and other support organisations, it remains a biotechnology hotbed for the coming years.[65]

*System and market failures and drivers*

The cluster originated from a tight social network among biotechnology firms, venture capital and research institutions. Now, the direct links between DBFs are building the main network

[65] http://www.theatlantic.com/business/archive/2009/05/is-bay-area-biotech-in-trouble/17701

structure. Next to the social network effect, also the heterogeneity of individuals and organisation regarding knowledge, skills and experiences contributed to the succes of the cluster. Finally, the cluster was and still is market-oriented, becoming a hub of biotechnology and all related activities, with relatively low entry and exit barriers for organisations.

*Public funding:* Public funding or other government activities played no major role in the early development of the cluster. Since the cluster is in place and reached a certain size, cluster development is supported by some institutions on federal government level, such as NSF, US department of Agriculture, NASA, US department of Energy. These public funds mainly aim on basic research and do not provide incentives to create commercial spin-offs. There is only one federal programme (Small Business Innovation Research Program) to support the foundation of biotechnology start-ups.

*Tax incentives:* California and the city of San Francisco offer several tax breaks and incentives for biotech-related activities.

### 5.3.3. Conclusion of industrial biotechnology cluster comparison

*Strengths and weaknesses*

The Cambridge and the Bay Area clusters have many similarities. Both are very mature and internationally renowned clusters with similar age and historical development. Both of them developed spontaneously without strong policy interference compared to most of the other clusters discussed in this research. Both have kept world leading market positions in Europe and United States over the last decades.

In both cases, most biotechnology firms were not created or relocated from the outside, but originated from within the area, with cluster growth mainly taking place around internationally leading research institutes. They are also similar in their strong interactions and relationships between science, industry and public spheres, combined with a very strong entrepreneurial culture.

A difference between the clusters is that in Cambridge, universities played the largest role in creating biotechnology firms through spin-offs, while in the Bay Area, the combination of one large player (Genentech) and a strong academic science base was the origin for many start-up biotechnology firms, founded either by former employees of Genentech or by former university staff. There, the anchor company took the dominant role and was supported by the surrounding university infrastructure. This development led to a situation that biotechnology firms in the Bay Area were more commercially oriented than firms in Cambridge.

The only possible weakness of both clusters is potentially that the clusters are based on ‘old’ biotechnology and need to refocus their activities on new biotechnology application areas, giving them ample ground for future competitiveness. As will be argues later, clusters are path dependent: once a cluster acquires momentum it will likely continue to grow and prosper. The opposite also holds true: once a cluster loses its competitive edge it will be hard to regain it and not decline further.

*Public policy, funding and tax incentives*

Although the government has not had a dominant role in the start of these clusters, the clusters did receive substantial support. Both receive government support through tax breaks and other fiscal incentives to nurture further growth. Unique to these clusters are sufficient financial resources for all investment stages, i.e. there is no clear 'valley of death'. This can be explained by the maturity and success of the clusters: once the cluster and its companies have developed a sufficient track record and reputation, they will attract funding from additional sources and will become less dependent on (basic) research focused public funding. In a similar vein, the maturity and success of the cluster has attracted all sorts of professional services to the area (think of specialist lawyers, brokers, marketing experts, international IPR specialists) and complementary services and activities, giving the clusters the full dynamism and creative density of a full grown cluster. This dynamism created a virtuous circle, where the primary cluster operations are supported by secondary services, which in turn reinforce cluster development by providing an healthy infrastructure to attract new biotechnology firms.

*Lead markets: The role of lead actors / anchor firms*

In the cases of Cambridge there is no clear role of one lead firm or market. However, it is clear that the Cambridge cluster was traditionally dominated by pharma-orientated biotech. The area knows some very large pharmaceutical companies that found its local suppliers and collaboration partners in that area. These companies were perhaps not anchor firms, but did play a role as lead customers to give the cluster momentum. The recent development towards industrial biotechnology has not gone through such a well pronounced development yet.

The situation in the Bay Area is different: also there many large firms acted as accelerators for growth by stimulating R&D, commercialisation, spin-offs and internationalisation of activities and knowledge transfer. But it was Genentech as the world's very first biotechnology firm that had a special function in creating new start-ups in the Bay Area, being the main collaboration partner and anchor firm for many R&D and business activities.

**Table 5-6: Summary of findings from industrial biotechnology cluster comparison**

| | Cambridge – United Kingdom | Bay-Area – United States |
|---|---|---|
| History | Long history of science and high tech developments<br>Biotechnology development since 1980s<br>Rich university Colleges enable growth and development of science parks | Established in 1976 with first bio-tech company Genentech<br>Spin-offs of anchor company leads to growth<br>Research / public funding plays important |

| | | |
|---|---|---|
| | | role in development<br>Venture capital & commercialisation important to reach maturity |
| Size | ~280 firms<br>25,000 people (incl. academics and supporting activity firms/organisations) | ~1400 live science firms, from which ~100 are dedicated biotechnology firms<br>The whole cluster employs 90,000 people, annual exports are $2 billion |
| Classification | (Post-)mature | (Post-)mature |
| Infrastructure | Cluster developed around world leading universities<br>Availability of public and private research facilities<br>Strong incubator: Babraham Research Campus<br>ERBI: private cluster platform | Strong knowledge infrastructure with large universities close by |
| Institutions | *Rules and regulations*<br>Cambridge has an advantage over countries such as Germany and the USA because of the comparatively liberal UK regulatory framework within biotechnology R&D is conducted.<br>*Norms and values / culture*<br>Strong cluster identity, also consciously promoted by ERBI<br>Strong entrepreneurial spirit as well as collaborative attitude between scientists | *Rules and regulations*<br>Clear IPR: giving Universities rights on IP<br>Patent law enhances commercialisation<br>Improved FDA regulation speeds up process<br>New regulations on carbon emissions threat to the industry<br>*Norms and values / culture*<br>Culture of entrepreneurship<br>Strong collaborative culture |
| Public policy / funding / taxation | No clear role public policy in promoting the cluster – self originated<br>Support in later stages from national and regional bodies<br>Funding available at all stages of research & development<br>Good access to private funding: VC, business angels, banks.<br>Tax credit on their non-capital R&D expenditure over £10,000 at 150 percent; losses can be surrendered to the Exchequer in return for a cash payment of 24 percent of total, eligible R&D spend | No public policy involvement in creating the cluster<br>Good availability of venture capital → promotes commercialisation<br>Availability of start-up support<br>Tax-breaks / incentives: biotechnology firms are exempt from paying payroll taxes for up to 7.5 years (2004) |
| Interactions | Strong industry-university linkages<br>Strong relationships locally between researchers (personal relationships)<br>Strong links internationally | BioSTAR: promotes university-industry collaboration<br>BayBio bioscience association: collaboration PPP and VC<br>Strong social networks of university graduates and ex-employees of large companies that start their own company |
| Capabilities | World leading scientists on biotechnology<br>Very strong position in research, development and commercialisation | Strong scientific basis<br>170 university spin-offs (start-ups) |
| Market demand | Strategic position in European market<br>Large companies serve as lead customers and finance new developments | Bay Area supplies world wide to pharmaceutical enterprises |
| Market structure | Good mix of small and large firms.<br>Start-ups and spin-offs.<br>Market open for new entrants | Strong mix of small entrepreneurial firms and large companies that provide route for commercialisation |

| | | |
|---|---|---|
| | Supportive financial structure available to grow companies | Enough space for start-ups and spin-offs<br>Dynamic and entrepreneurial |
| Cluster features | Self originated, no policy result<br>Financing for all stages<br>Concentrated in 30m range<br>Strong informal networks support collaborative structures | Self originated, no policy result<br>Big role for entrepreneurship, spin-offs and spin-offs<br>Financing for all stages of development |

*Source: TNO compilation.*

### 5.3.4. Factors influencing the future development of industrial biotechnology

***Factors influencing the future market potential of industrial biotechnology***

Industrial biotechnology is a continuously evolving field of technology. Although biotechnology is well established in the chemical industry it is still a niche there and overall it is in its infancy. Until now the endless biodiversity which serves as basis for applications in industrial biotechnology is known only to a small extent. Industrial biotechnology provides the opportunity to improve the quality of existing products and to develop completely new products which cannot be produced by traditional synthetic methods and processes. In addition, industrial biotechnology is a powerful technology to provide solutions for environmental friendly processes. Industrial biotechnology has the potential to substitute processes in the chemical industry and scarce resources. In the light of increasingly scarce resources and rising energy prices it is expected that the share of biotechnology applications increases in the coming years to achieve a sustainable development. Thus, the demand for sustainable solutions will be powerful driver for industrial biotechnology applications. But biotechnology must compete with alternative production technologies such as purely chemical processes. Becoming more cost-competitive through the increase of output efficiency is thereby an important goal.

But industrial biotechnology is a cross-disciplinary field of research. Thus, future development critically depends on scientific advances in other research areas which provide key knowledge for industrial biotechnology. These areas include microbiology and bioinformatics but also just emerging areas such as synthetic biology or systems biology.

Besides, broad public support and acceptance of industrial biotechnology is essential, and social implications and concerns such as the provision of sufficient land to satisfy food demand and negative impacts of biotechnological inputs must be addressed

***The role of public support***

Universities and public research organisations play a very prominent role in industrial biotechnology by providing new technological knowledge. In recent years, patenting by public research has increased rapidly accounts for about 30 percent of the patents. Therefore, the maintenance and funding of public research institutions as a public support measure contributes significantly to advancements and the success of industrial biotechnology.

Second, it is important to facilitate the exchange between universities, public research organisations and industry. National programmes at the federal level as well as EU programmes have been shaped to improve interaction between research institutions and companies. Thereby, not all funding support instruments distinguish between the different application areas of biotechnology and target explicitly on industrial biotechnology. For example, in Germany in the framework programme for biotechnology invested 980 million Euros in this technology area.[66] The funding initiative "BioIndustrie 2010" (within the framework programme) focuses on industrial biotechnology and has a budget of €60 million between 2006 and 2011. Besides stimulating additional R&D investments in companies, sustainable networks of firms and scientific institutions should be established in order to exploit the innovative potential and competences by transferring ideas and research output from the scientific community into commercial applications and products. The 7th framework programme of the EU directs their activity also in biotechnology.[67] A European knowledge-based bio-economy should be built by bringing together science, industry and other stakeholders.

In addition, financial support for spin-offs from public research can help to enlarge the community of industrial biotechnology start-ups. In the US funds of the Small Business Innovation Research Program (SBIR) provide critical seed money to new business innovators, including biotechnology companies. Between 1983 and 1997 there was more than $240 million in SBIR awards for biotechnology companies from the Department of Defense (a restriction to industrial biotechnology is not possible). There is compelling evidence that the SBIR program has had a positive impact on developing the U.S. biotechnology industry. The program contributed to the creation of high-technology small firms and enhancing U.S. competitiveness (Audretsch, 2003). Thus, the success of the biotech sector in the US is also a result of public support.

In biofuels, government policies such as subsidies and mandated use of biofuels have been key factors for the tremendous growth in biofuels production and consumption play, for example in Brazil, the USA and China; countries which have a comparative advantage in biofuels production. Subsidies are allocated at many points in value chain, from subsidies for crops, subsidies to production of biofuels to subsidies for the purchase of biofuels or for the

[66] http://www.fz-juelich.de/ptj/rahmenprogramm-biotechnologie/

[67] http://ec.europa.eu/research/fp7

purchase or operation of a vehicle. Total government support for biofuels in the United States reached approximately $6.3 to $7.7 billion in 2006 (Koplow, 2007). Total annual support for biofuels provided by EU governments reached €3.7 billion in 2006 (Kutas et al., 2007). An evaluation of the cost-effectiveness and impacts of biofuel policies is still missing.

***Contribution of industrial biotechnology to social wealth***

Industrial biotechnology offers several potential contributions to social wealth. In particular it provides opportunities to achieve a sustainable development Industrial biotechnology can help to limit the consumption energy and scarce resources, to provide alternative sources of energy as well as to decrease the waste resulting from industrial process. With respect to health and quality of life, industrial biotechnology offers for example vitamins, functional food or improved cosmetics such as regenerative skin creams.

***Importance of sustaining production capabilities***

Scientific research is the most important knowledge source in this KET. In particular for advances in the creation of new enzymes and microbial cells scientific input from related scientific disciplines is crucial. At present about two-thirds of the enzyme producing firms are located in the EU. To push industrial biotechnology by integrating biotechnological and chemical processes a close interaction between firms and public is a critical element. In this respect, sustaining production capabilities for intermediate products such as enzymes as well as chemicals can be regarded as important.

## 5.4 Conclusions and Policy Implications

***State of technology***

Biotechnology is a fast developing technology. Enzyme products for the manufacture of detergents, food, textiles, chemical and pharmaceutical industry are well established on the market although only about 130 different enzymes of the thousands of known enzymes are used industrially (BMBF, 2008). Industrial biotechnology provides the opportunity to improve the quality of existing products and to develop completely new products which cannot be produced by traditional synthetic methods and processes. Sales of products produced by biotechnological processes accounted for €99 billion in 2007 of which the majority is generated by biochemicals (McKinsey, 2009).

***Europe's technological position***

Europe, North America and East Asia have always the highest market share of patents at their respective regional patent office (EPO, USPTO and JPO). With respect to triadic patents the market is similar distributed between the three regions. At EPO/PCT Europe contributes with 36 percent only slightly more than North America to total industrial biotechnology patenting. In terms of patents per GDP, Europe still produces the highest number of patents but the distance to East Asia is not as pronounced.

The two largest subfields within industrial biotechnology are enzymes (33 percent) and other enzyme processes which comprise organic acids, amino acids, vitamins, proteins except enzymes (30 percent), followed by fermentation processes and established chemicals. While in North America and the Rest of the World patents on enzymes are relatively more important; in Europe and East Asia fermentation and other established biochemicals are more pronounced.

Although the patents on enzymes are most frequently their commercialisation is limited. Enzymes can be regarded as an input. Sales are generated mainly by their “end-product” like biochemicals.

Within Europe, the distribution of patent applications by subfield does not vary to a large extent between the countries of applicants. Exceptions are the strong focus on enzyme patents in Denmark which is due to the location of the world largest producer of enzymes there. Germany is more specialised in established biochemicals, reflecting its strong chemical industry.

***Links to disciplines, sectors and other KETs***

Industrial biotechnology patenting is a cross-disciplinary field of research that affects a multitude of industries. But almost half of all industrial biotechnology patents are linked to pharmaceuticals, 23 percent to the chemical industry, 17 percent to the manufacture of instruments (optical, medical, measurement, steering instruments). The importance of pharmaceuticals might be overestimated since patents in the area of enzymes are not already assignable to the different types of biotechnology. Enzymes used for the red (medical) biotechnology may be still in the sample of analysis.

Industrial biotechnology patents are closely linked to applicants from the chemical industry, accounting for 42 percent of all industrial biotechnology patents. Public research plays a very prominent role in patenting, accounting for about 30 percent. In recent years, patenting by public research has increased rapidly compared to a decrease in most business sectors.

***Market prospects and growth impacts***

All existing market forecasts for industrial biotechnology and the various submarkets suggest a strong increase in sales in the next decade. Market estimates are difficult to compare and integrate since different subfields of the industrial biotechnology markets are defined. The most optimistic forecasts for biochemicals – the most important field of industrial biotechnology – expect global sales in 2025 of more than 600 billion US-$. So far, previous forecasts have proved to be too optimistic, however. But there is no doubt that demand for products which involve industrial biotechnology will increase clearly above the total market expansion.

For the predictions estimations on the development for specific technologies are needed. But the estimations are challenging since, for example, the rates of development in the emerging field of synthetic biology or to competing technologies are unknown (OECD 2009a). Advances in the improvement of enzyme's characteristics will be important as well as the integration of biotechnological and chemical technologies.

An important driver for the industrial biotechnology sector will be the stronger use of renewable raw materials and efficient bioprocesses to achieve a sustainable development. But biotechnology must compete with alternative production technologies such as purely chemical processes. Becoming more cost-competitive through the increase of output efficiency is thereby an important goal.

***Policy options***

As exploiting the potential of industrial biotechnology is eventually based on further massive advances in research, it thus seems essential to promote Europe's industry and science such that further research efforts are possible. Scientific research is the most important knowledge source in this KET. Linking industry and science and smoothly transferring scientific findings into commercial applications is a critical element. A close interaction between firms and public research is required. Cluster initiatives have proved to facilitate this exchange significantly.

Besides, in particular scientists are of great importance for the industrial biotechnological industry through foundations by scientists researching in this technology field. The spin-offs are expected to contribute significantly to the further technological development of industrial biotechnology. In addition, start-ups founded by scientists are regarded as important transmission media which allow transferring new scientific knowledge in economic activities and thus introducing new biotechnological products and methods on the market. Typically, they concentrate on very specific industrial biotechnology applications and explore the business prospects of new research results. For the diffusion it is also essential that the products fit to the needs of customers in terms of (sustainable) performance and costs.

In order to establish a dynamic sector of industrial biotechnology companies, venture capital funding as well as public support to R&D conducted by these firms is essential. Small biotechnology firms have limited financial resources. In order to realise growth the provision of capital funding is essential. While in the 1990s a generous venture capital industry supported a variety of start-ups, today there is a shortfall in venture capital market. Private venture capital companies very carefully evaluate the business prospects of young firms and most often provide only limited funding, focussing on close-to-market-introduction projects and not on early stage projects of biotechnology start-ups. In addition, most investors are only given little attention to industrial biotechnology although industrial biotechnology requires lower investments and is less risky as, for instance, red biotechnology. This is attributed to the fact that industrial biotechnology mainly develops new processes for the production of already known chemicals (OECD 2009c). Therefore, raising the attention and point out the chances of this field can improve the funding opportunities for industrial biotechnology firms. In Europe 78 percent of biotechnology SMEs faced problems to raise funds to continue important R&D projects (EuropaBio 2009). In this situation, policy will have to compensate for this “market failure” in the financial market.

First, financial support for spin-offs from public research can help to enlarge the community of industrial biotechnology start-ups. Secondly, programmes to actively commercialise public research patents though out-licensing is another promising option. Thirdly, industrial biotechnology research programmes at public research should be designed in a way that combines basic research with more application-oriented development, involving partners from the business enterprises sector. Competence centres and R&D co-operation programmes have proved to be helpful in this respect.

Another starting point for policy action is a claim for sustainable development. The regulatory framework set by policy can push the development and use of renewables. Industrial biotechnology is a powerful technology to provide solutions for environmental friendly processes. This instrument is already in place. With respect to biofuels the European Council agreed to the Action Plan 2007-2009 Energy Policy for Europe (EPE) in which it set a mandatory minimum target to be achieved by all Member States for biofuels of 10 percent of vehicle fuel by 2020.

Further policy actions should relate to providing a stable regulatory environment, particularly with respect to likely safety and health of industrial biotechnology. Another aspect is to secure that sufficient land is available to grow food in order to satisfy food demand in order to relieve public worries.

# 6 PHOTONICS

## 6.1 Definition and State of Technology

Photonics is a cross-sectoral technology, bringing together the disciplines of physics, nanotechnology, materials science, and electrical engineering (EC 2008). 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 (Jahns, 2001). Photonics has exceptional properties like high focusability, speed of light, ultra-short pulses, and high-power. The importance of Photonics can be seen from the multitude of application sectors where it is increasingly seen to be driving innovation (see Table 6-1). These sectors include information processing, communication, imaging, lighting, displays, manufacturing, life sciences and health care, and safety and security (EC, 2008a).

*Information and Communication:* Optical networks have opened the way to almost unlimited digital communication, building the very foundations of our Information Society. The major highways of communication and information flow are based on optical technology. Photonics enables the processing, the storage, the transport and the visualisation of the huge masses of data. Information and knowledge are becoming our most valuable commodities – unlimited access to which is becoming arguably the most significant driver of productivity and competitiveness. It is optical transmission networks that are enabling all of this, giving data accessibility to anyone, anywhere (Photonics21, 2006).

*Industrial Production / Manufacturing and Quality:* Light is the tool of the future. In manufacturing (laser-) light is used as a fast and precise tool for many purposes, materials and objects. Laser material processing is welding, cutting or drilling with unprecedented flexibility, precision, quality, cost structure and productivity. Laser technology offers numerous advantages in comparison with conventional processes. Pulsed laser systems are particularly suitable for micro-structuring of both sensitive and hard materials because of the low thermal loading of the components and the contactless nature of the process. The processing speeds are high and any signs of wear on the tool are avoided. The market of laser systems for material processing developed from a small niche market in the beginning of the 1980s to a market of €4.75 billion in 2005. This development is typical for a sector driven by photonic technologies (Photonics21, 2006).

*Life Sciences and Health:* Modern health care has been revolutionised by the use of optical applications in examination, diagnosis, therapy and surgery. Modern surgical microscopes have become key tools and image guided systems make use of computer tomography in navigated surgery. Laser diagnosis and treatments in ophthalmology, dermatology and other medical fields have evolved into standard procedures. The role of photonics will grow tremendously in the future, because of the capability of photons to monitor biomaterial in real-time, non-contact and without affecting the life processes (Photonics21, 2006).

**Table 6-1: Application sectors and important products in the field of photonics**

| *Field of Technology* | *Applications Examples* |
|---|---|
| Production Technology | Laser Materials Processing Systems<br>Lithography Systems (IC, FPD, Mask)<br>Lasers for Production Technology<br>Objective Lenses for Wafer Steppers |
| Optical Measurement and Machine Vision | Machine Vision Systems and components<br>Spectrometers and Spectrometer Modules<br>Binary Sensors<br>Meas. Systems for Semiconductor Industry<br>Meas. Systems for Optical Communications<br>Meas. Systems for Other Applications |
| Medical Technology and Life Science | Lenses for Eyeglasses and Contact Lenses<br>Laser Systems for Medical Therapy and Cosmetics<br>Endoscope Systems<br>Microscopes and Surgical Microscopes<br>Medical Imaging Systems (only Photonics-Based Systems)<br>Ophthalmic and Other in Vivo-Diagnostic Systems<br>Systems for In-Vitro-Diagnostics, Pharmac. & Biotech R&D |
| Optical Communications | Optical Networking Systems<br>Components for Optical Networking Systems |
| IT: Consumer Electronics, Office Automation, Printing | Optical Disk Drives<br>Laser Printers and Copiers, PODs, Fax and MFPs<br>Digital Cameras and Camcorders, Scanners<br>Barcode Scanners<br>Systems for Commercial Printing<br>Lasers for IT<br>Sensors (CCD, CMOS)<br>Optical Computing<br>Tetrahertz Systems in Photonics |
| Lighting | Lamps<br>LEDs<br>OLEDs |
| Flat Panel Displays | LCD Displays<br>Plasma Displays<br>OLEDs and Other Displays<br>Display Glass and Liquid Crystals |
| Solar Energy | Solar Cells<br>Slar Modules |
| Defence Photonics | Vision and Imaging Systems, Including Periscopic Sights<br>Infrared and Night Vision Systems<br>Ranging Systems<br>Munition / Missile Guiding Systems<br>Military Space Surveillance Systems<br>Avionics Displays<br>Image Sensors<br>Lasers |
| Optical Systems and Components | Optical Components and Optical Glass<br>Optical Systems ("Classical" Optical Systems)<br>Optical & OE Systems & Components Not Elsewhere Classified |

*Source: Photonics21 (2007b), ZEW compilation.*

*Lighting and Displays:* Innovative lighting systems create convenient surroundings and save energy. Semiconductor light sources –LEDs (light emitting diodes) and organic LEDs (OLEDs)– provide advantages like: long service life, no maintenance, IR/UV-free lighting, low energy consumption and chromatic stability. The OLED technology is the first real area light source technology in history.

*Photovoltaics:* It denominates the direct transformation of sun light (incident photons) into electric energy by means of solar cells. The technology has already developed so far that solar modules with an efficiency of over 40 percent have demonstrated under laboratory conditions. The global output of solar cells is growing rapidly by 68 percent in 2007 (Initiative Photonik 2020).

In 1905 discovered Einstein that light does not flow like a continuous fluid, but consists of indivisible elementary unity that we now call photons. The term Photonics was coined in 1967 by Pierre Aigrain, who gave the following definition: 'Photonics is the science of the harnessing of light. Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind' (EC, 2008a). Photonics has a decisive impact since the 1960s when with the development of electronics, laser technology and fibres, optics created the technological environment for optical communication (Jahns, 2001).

The next innovation boost in this field will come from mastering the manipulation of the elementary particles of nature, exploiting the effects of quantum physics, further reducing the footprint of optical elements to the micro- and nanometer scale, tailoring the propagation of electromagnetic waves with the help of metamaterials, extending Photonics to spectral regions like THz which at present are underexploited, and learning from biology how to manipulate and process light. Photonics holds a huge potential – not only for new and even better forms of communications and entertainment but also in many other applications, including manufacturing, medicine, displays, and a whole range of sensors for chemicals, biological materials and in the environment. Ultimately, photonics even promises to completely replace microelectronics as the technology that computers use to 'think' (optical computing), leading to a huge increase in performance (EC, 2008a).

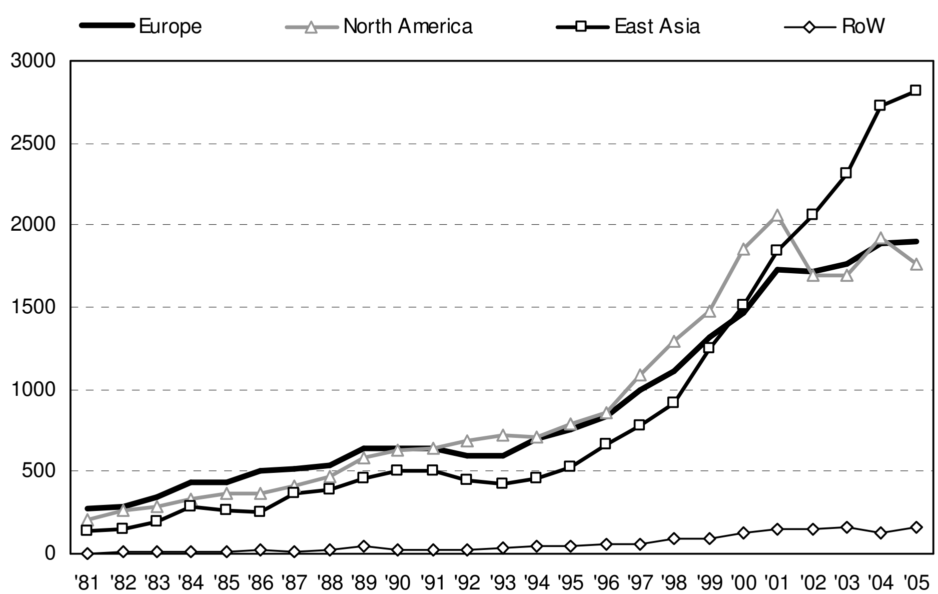
## 6.2 Technological Competitiveness, Industry Links and Market Potentials

### 6.2.1. Technological Competitiveness

*Market Shares*

Europe's performance in producing photonics patents is compared to that of applicants from North America (USA, Canada, Mexico) and East Asia (Japan, Korea, Taiwan, Singapore and China, incl. Hong Kong). Measured in terms of patents applied at EPO or through the PCT procedure (EPO/PCT patents), the number of photonics patents applied per year increased markedly to roughly 6,650 patent applications in 2005. East Asian applicants applied the largest number of photonics patents thanks to a rapid increase in patenting over the past ten years (Figure 6-1). European and North American applicants produce about the same annual number of photonics patents. In contrast to East Asia, photonics patenting in these two regions did not increase substantially after 2001.

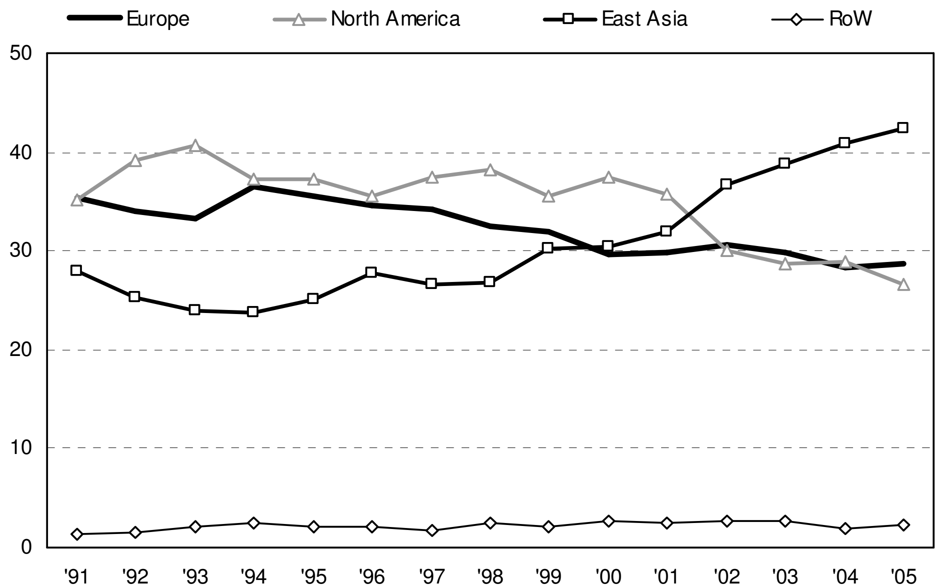
**Figure 6-1: Number of photonics patents (EPO/PCT) 1981-2005 by region of applicant**




*Source: EPO: Patstat, ZEW calculations.*

In 2005, European applicants had a share of 29 percent in total photonics patent applications at EPO/PCT, compared to 27 percent for North American applicants and 42 percent for East Asian applicants (see Figure 6-2). Europe’s market share decreased slightly over the past 15 years (starting from 35 percent in 1991).

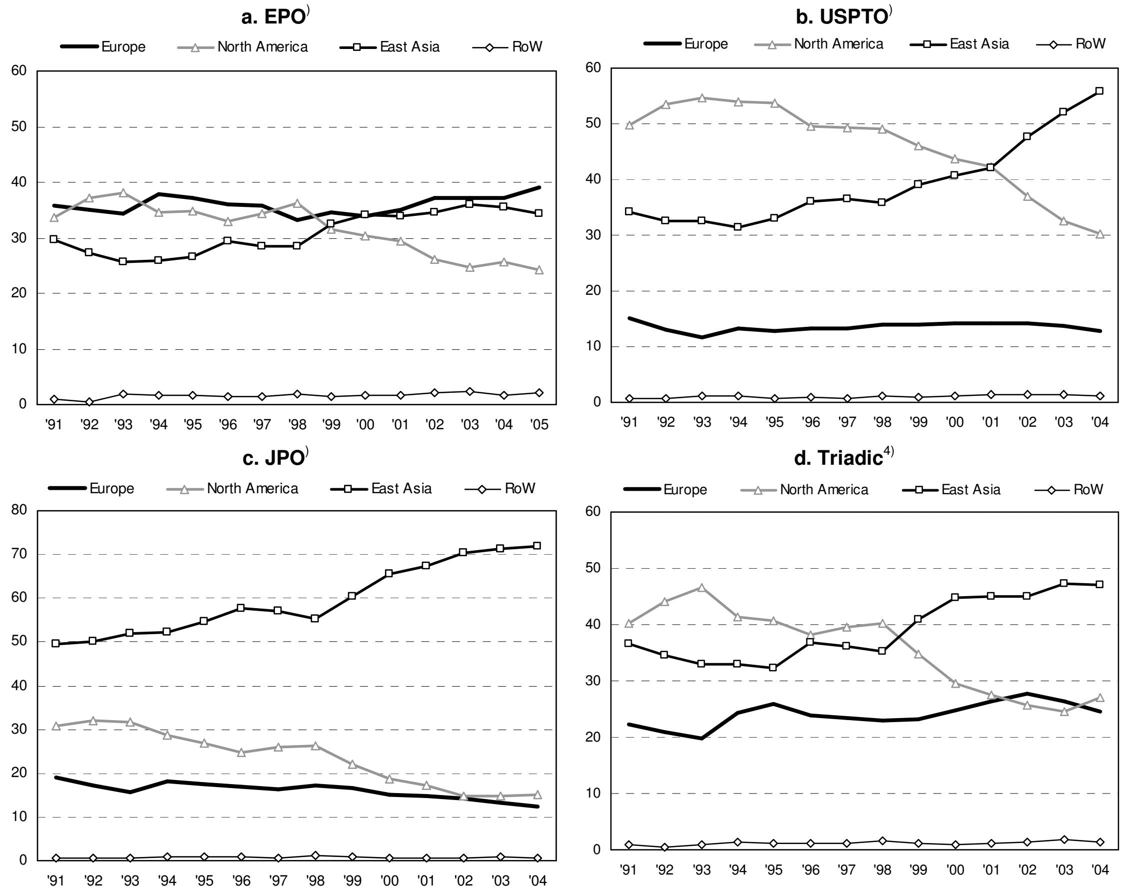
**Figure 6-2: Market shares in photonics patents (EPO/PCT) 1991-2005, by region of applicant (percent)**




*Source: EPO: Patstat, ZEW calculations.*

In order to account for "home office" effects in patenting (i.e. the propensity for applicants from a particular region to use predominantly their regional patent office for applications), patent applications in photonic at USPTO (North America) and JPO (East Asia) are analysed as well. The shares of patent applications differ significantly when looking at regional patents as shown in Figure 6-3. When only considering EPO applications, Europe was most of the time ahead with a share in total EPO photonics patents of 33 to 39 percent, while European applicants are of less significance when looking at USPTO, JPO or triadic patents. For USPTO patents, North American applicants show a share of around 50 percent or higher up to the year 1996. Their share decreased drastically afterwards to 30 percent in 2004. The overall picture of the market shares in photonics patents shows a significant increasing of East Asia applicants, while the share of North America applicants is substantially decreasing since the mid-nineties. Europe's share remains rather stable.

**Figure 6-3: Market shares in photonics patents 1991-2005 for national applications and triadic patents (percent)**




*1) EPO applications*

*2) USPTO applications*

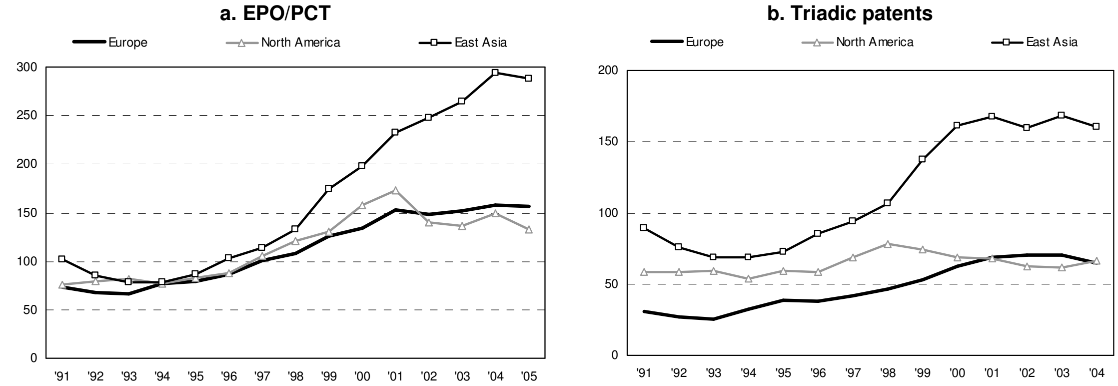
*3) JPO applications*

*4) Patents for which 1), 2) and 3) applies (including PCT applications transferred to national patent offices from all three regions).*

*Source: EPO: Patstat, ZEW calculations.*

In order to determine the relative importance of photonics patents for a region, patent intensities are calculated (see Figure 6-4). The patent intensity is defined as the number of patents per year form applicants of a certain region to the GDP of that region. This type of specialisation indicator shows that North America and Europe produce similar numbers of photonics patents per GDP. One striking observation is the significant increase in patent intensity of East Asian applicants since 1998.

**Figure 6-4: Patent intensity 1991-2005 for photonics patents (number of EPO/PCT and triadic patents per 1 trillion of GDP at constant PPP-$)**




*Source: EPO: Patstat, OECD: MSTI 02/2009. ZEW calculations.*

### *Patenting by subfields*

The field of photonics is divided in four subfields based on the following IPC classes:

Solar: F21K, F21V, H01L 25, H01L 31/42,

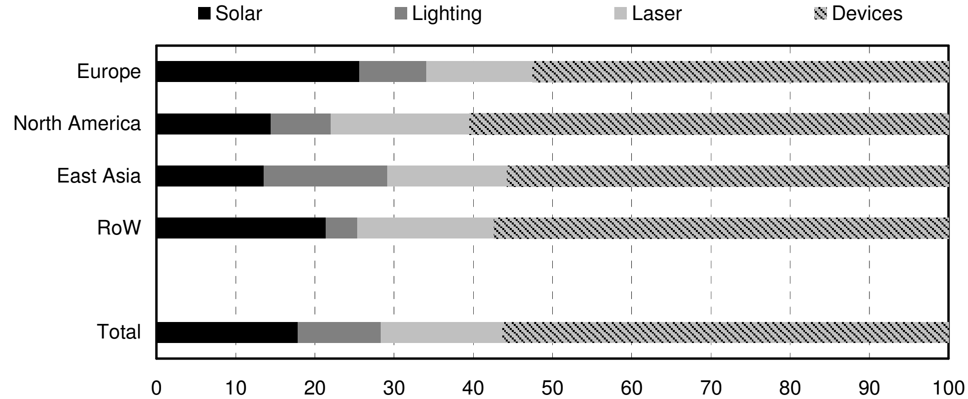
Lighting: H05B 31, H05B 33, H01L 51

Laser: H01S 3, H01S 4, H01S 5

Optical devices: H01L 31, H02N 6, G02B 1, G02B 5, G02B 6, G02B 13/14

The largest subfield is optical devices, accounting for roughly 56 percent of all photonics patents (Figure 3-5). All three main regions show similar shares for this subfield. About 18 percent of all photonics patents fall in the subfield of solar cells while Europe is ahead with 26 percent. Laser follows with 15 percent and lighting with 10 percent. East Asia reports well above average shares of 16 percent for lighting while the shares for Europe and North America were only half the level of East Asia.

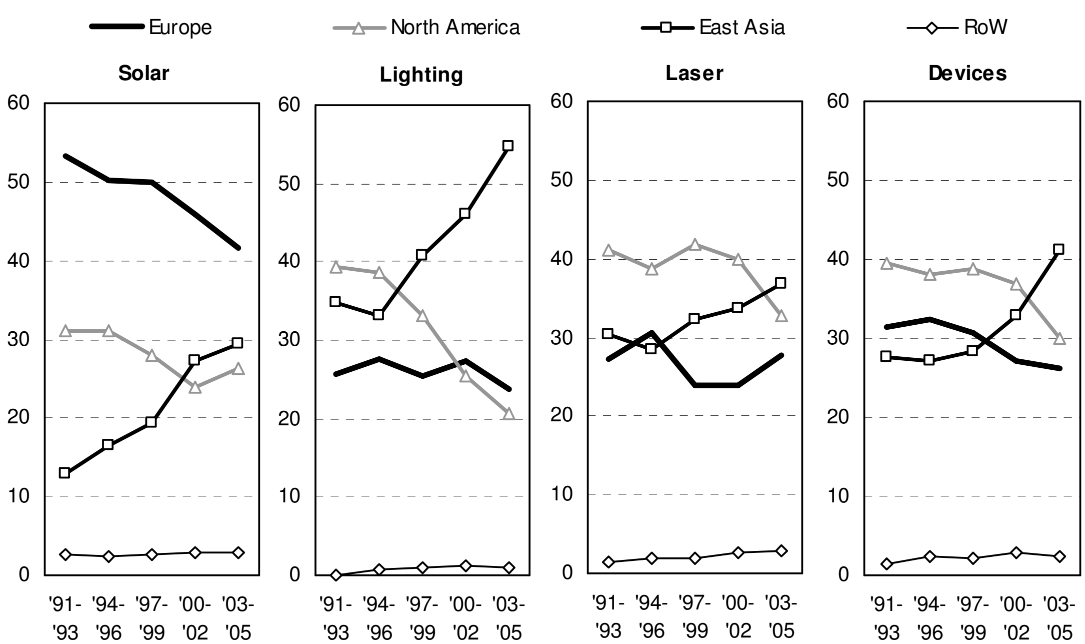
**Figure 6-5: Composition of photonics patents (EPO/PCT, 1981-2007 applications) by subfields (per cent)**




*Source: EPO: Patstat. ZEW calculations.*

When looking at the technology market shares by subfield over time (Figure 6-6), Europe shows rather high, though falling market shares in solar cells and lower but rather stable market shares in lighting, laser, and optical devices. East Asia's market share increased significantly in all four subfields while North America falls back.

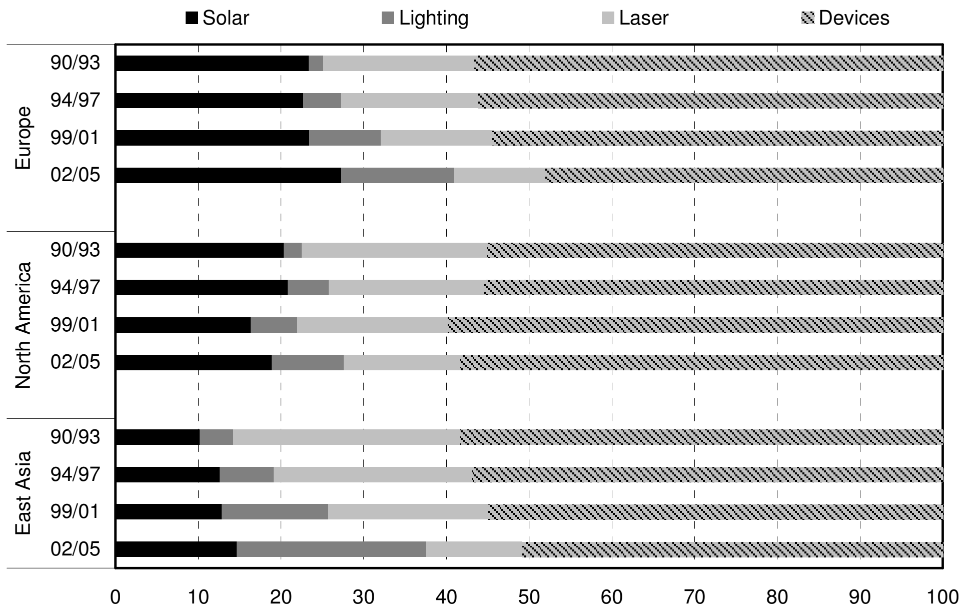
**Figure 6-6: Market shares for EPO/PCT photonics patents by subfields 1991-2005 (percent)**




*Source: EPO: Patstat, ZEW calculations.*

The composition of photonics patents by subfields is rather stable over time in all three regions (see Figure 6-7). However, patent applications related to lighting have gained some importance in all three regions, particularly in East Asia. Furthermore, patent applications in photonics by European applicants are more focused on solar than the one of North American and East Asia applicants. North American applicants show a specialisation on optical devices, whereas East Asia reports a comparably high share for lighting.

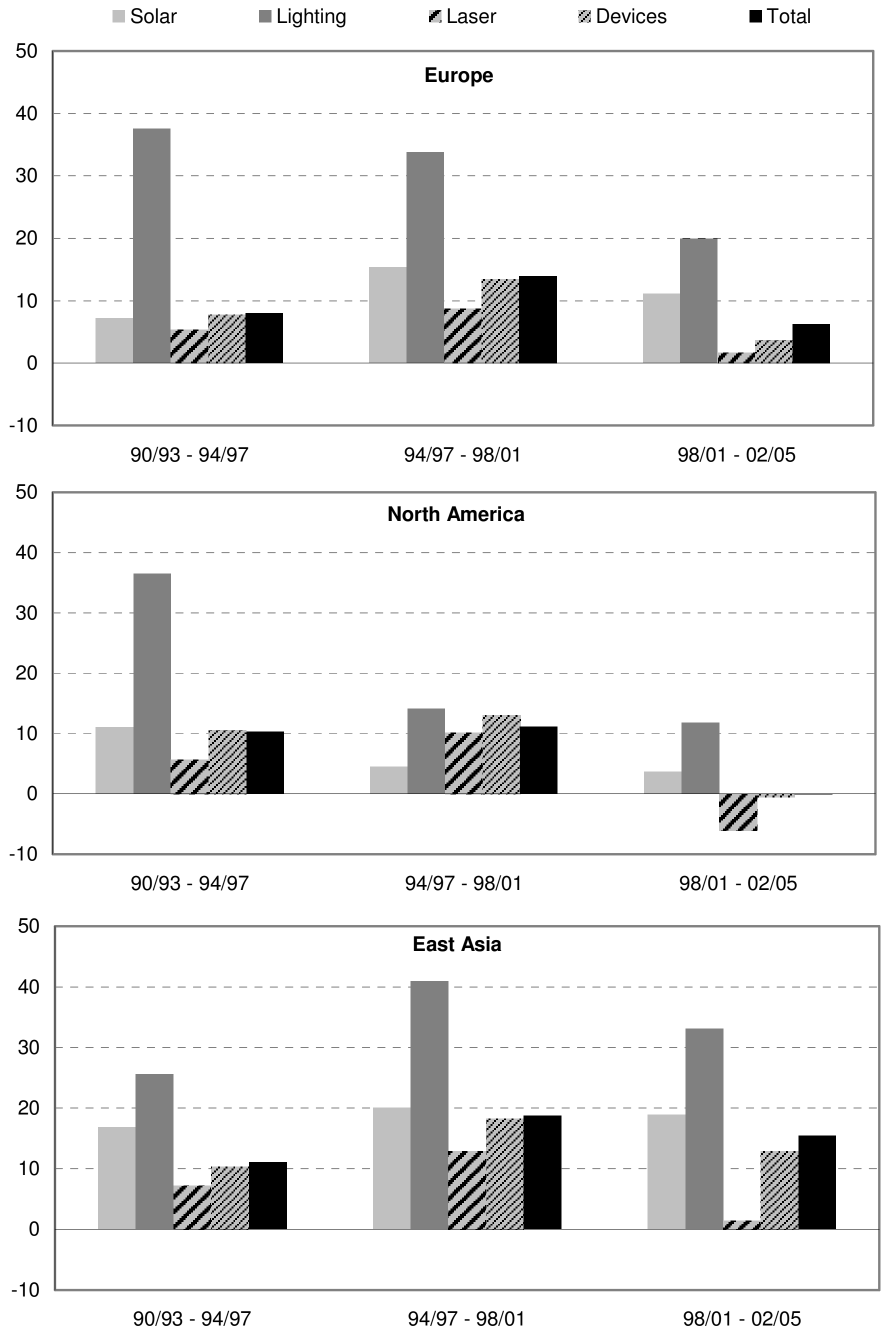
**Figure 6-7: Composition of photonic patents (applications at home patent offices), by region, subfield and period (percent)**




*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

Dynamics in photonics patent applications at the regional home offices significantly differ by subfield and region. In all three regions and all three periods, patenting in the field of lighting increased at the highest rate. While Europe shows particularly high growth rates for the early 1990s, East Asia reports the highest growth for the most recent period (1998/01 to 2002/05) (see Figure 6-8). Patenting dynamics in laser were rather low in the most recent period in all three regions. Patenting in optical devices grew slowly in the most recent period in Europe and North America, but increased significantly in East Asia. Patenting in the field of solar shows rather modest growth rates which were highest in the late 1990s in all three regions.l

**Figure 6-8: Average annual rate of change in the number of photonics patents (applications at home patent offices), by region, subfield and period (percent)**



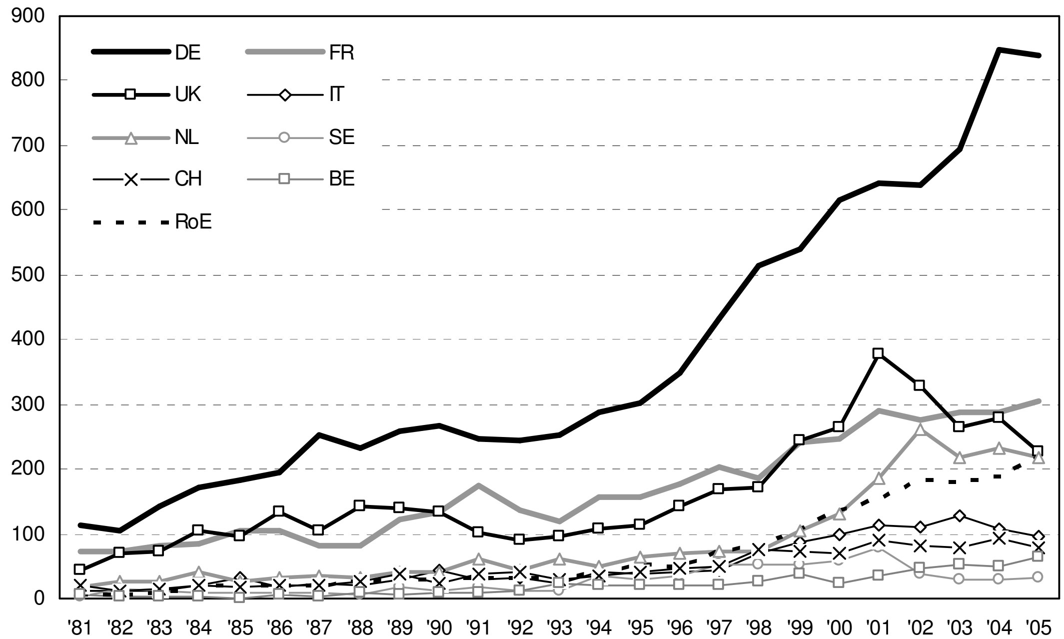

*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*

*Source: EPO: Patstat, ZEW calculations.*

### *Patenting at the country level in Europe*

Within Europe, inventors from Germany represent the largest group of producers of photonics patents. Over the past three decades, they accounted for 38 percent of all photonics patents applied at EPO/PCT, followed by inventors from France (16 percent), the UK (15 percent) and the Netherlands (9 percent). The number of photonics patents by German inventors reached the highest level in 2004 (see Figure 6-9). The number of patents from the UK increased significantly from 1999 to 2001 and the Netherlands expanded patent output in photonics from 1998 to 2002. France shows a more moderate but continuous growth in photonics patenting.

**Figure 6-9: Number of potonics patents in Europe (EPO/PCT) 1981-2005 by country of inventor**

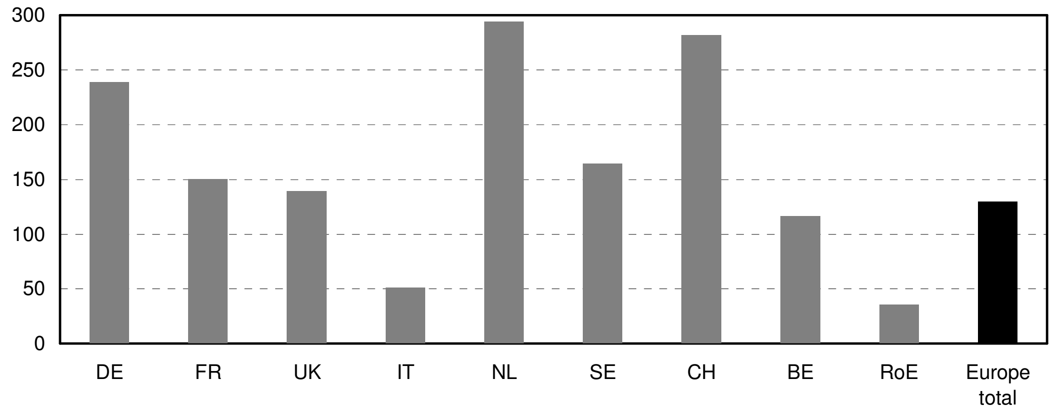



*Eight European countries with the largest number of photonics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The economic significance of photonics patenting differs substantially by country (Figure 6-10). Photonics patent intensity -that is the ratio of the number of photonics patents to GDP- is highest in the Netherlands, Switzerland and Germany. Intensities above the European average are also reported for Sweden, France and the UK. Belgium and Italy are the only two countries among the eight largest photonics patents producers in Europe with a patent intensity below the European average. The countries not belonging to the group of the eight largest patent producers in this KET show a very low patent intensity.

**Figure 6-10: Patent intensity in photonics 1991-2005 of European countries (EPO/PCT patents)**



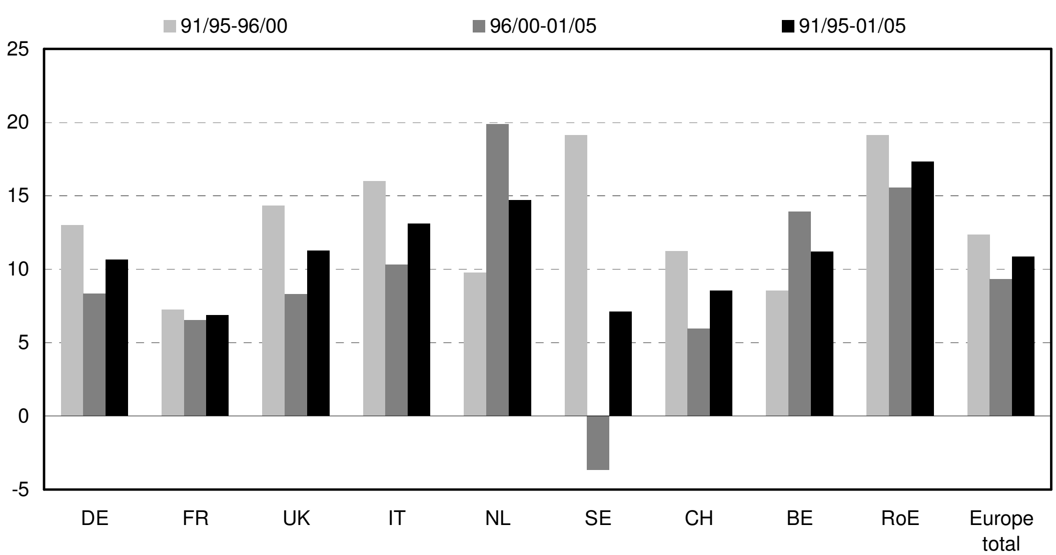

*Patent intensity: number of EPO/PCT patents applied between 1991 and 2005 per trillion GDP at constant PPP-$ in the same period.*

*Eight European countries with the largest number of photonics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Growth rates in photonics patenting also differ among European countries. The Netzerlands and Italy as well as the group of countries not belonging to the eight largest photonics patents producers in Europe could increase their patent output between the first half of the 1990s (1991-95) and the first half of the 2000s (2001-05) above the European average at compound annual rates between 13 and 17 percent (Figure 6-12). Growth rates at about the European average (11 percent) are reported for Germany, the UK and Belgium while growth rates were rather low in France, Sweden and Switzerland.

**Figure 6-11: Change in the number of photonics patents between 1991/95 to 1996/00 and 1996/00 to 2001/05, by country (EPO/PCT patents; compound annual growth rate in percent)**



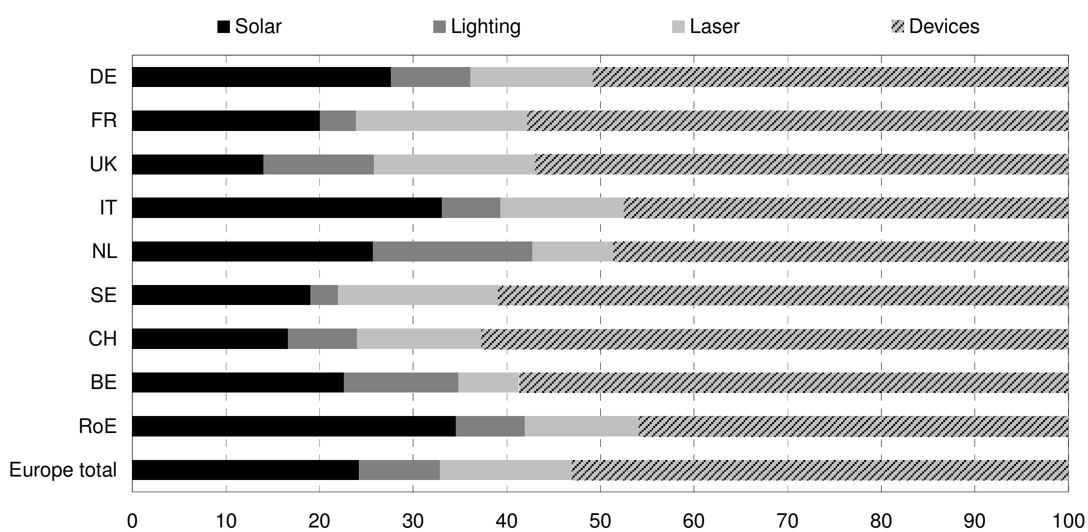
*Eight European countries with the largest number of photonics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Most countries show higher growth rates for the 1990s (1991/95 to 1996/00) than for the early 2000s (1996/00 to 2001/05), excpet for the Netherlands and Belgium. Countries with early growth in photonics patents were Sweden, Italy, the UK and Germany.

The composition of photonics patent applications by subfields and country of inventor is depicted in Figure 6-12. 53 percent of photonics patents in Europe fall into the field of optical devices. The second largest subfield is solar cells (24 percent). 14 percent are related to laser and 9 percent to lighting. Sweden, Switzerland and Belgium are the countries with the highest share of patents in the field of optical devices while Italy and the "rest of Europe" show high shares in the subfield of solar cells when compared to the European average. The Netherlands and Belgium are rather focused on lighting.

**Figure 6-12: Composition of photonics patents by subfields and countries (EPO/PCT, 1981-2007, percent)**

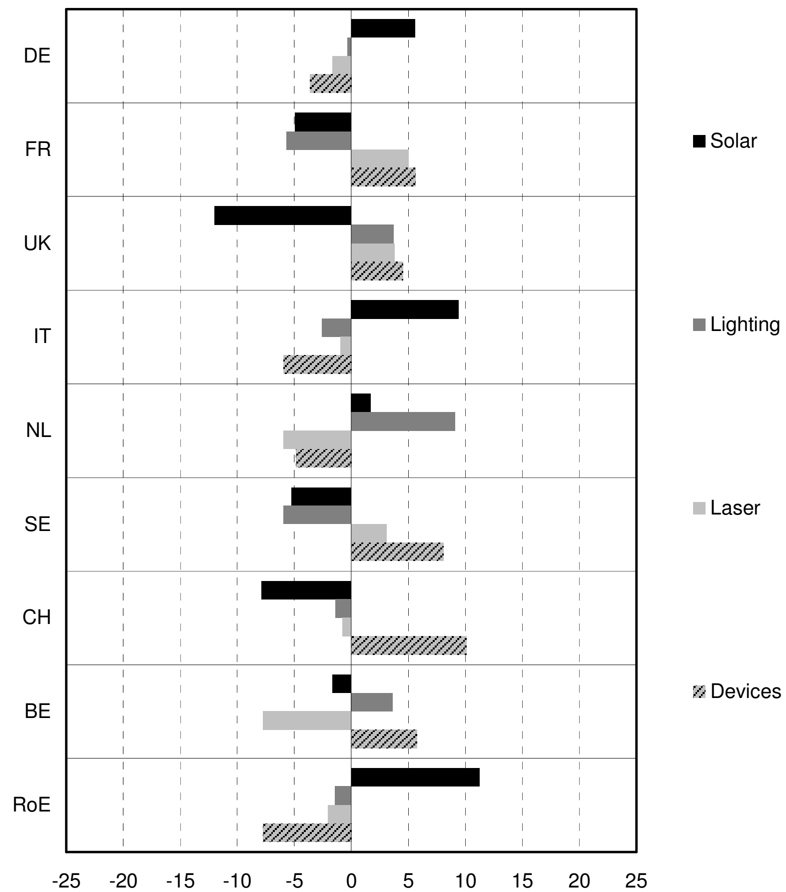



*Eight European countries with the largest number of photonics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Specialisation patterns in photonics patenting are shown in Figure 6-13. This figure reports the difference between the share of a subfield in a country's total photonics patents and the respective share for Europe total (excluding the country of consideration). Germany, Italy and the "rest of Europe" are specialised in the field of solar while the Netherlands, the UK and Belgium report above average patenting activity in lighting. Laser is a subfield where France, the UK and Sweden show some specialisation. France, the UK, Sweden, Switzerland and Belgium are specialised in optical devices.

**Figure 6-13: Specialisation patterns of photonics patenting in Europe, by subfield and country, relative to Europe total (percent)**




*Difference between the share of a subfield in a country's total photonics patents and the respective share for Europe total (excluding the country under consideration).*

*Eight European countries with the largest number of photonics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

European countries show different trends in photonics patenting by subfield (Table 4-1). When comparing the growth in the number of patents applied by subfield for the 1990s (i.e. between the number of patents over the 1991-95 and the 1996-2000 periods) and the early 2000s (i.e. between 1996-00 and 2001-05), one can see an extremely high growth in lighting in both periods and only low patenting dynamics in laser. Growth rates in solar and optical devices were higher in the former period. Most countries follow this general pattern. Notable deviations include the Netherlands and Belgium in the field of solar where both countries report high growth rates for the more recent period. In the field of lighting, Italy shows particularly high increases in patent output in both periods. Danymics in laser patenting were rather high in Sweden, Belgium and the "rest of Europe" in the 1990s while the UK and the Netherlands report high growth rates for the early 2000s. The Netherlands and the "rest of Europe" were able to maintain high growth rates in the field of optical devices in the recent period.

**Table 6-1: Change in the number of photonics patents between 1991/95 to 1996/00 and 1996/00 to 2001/05 by subfield and country (EPO/PCT patents, compound annual growth rate in percent)**

| | DE | | FR | | UK | | IT | | NL | | SE | | CH | | BE | | RoE | | Europe total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Solar | 16 | 10 | 7 | 11 | 13 | 6 | 11 | 12 | 17 | 22 | 19 | -10 | 9 | 8 | -1 | 40 | 19 | 11 | 14 | 11 |
| Lighting | 24 | 27 | 34 | 33 | 51 | 21 | 84 | 45 | 36 | 30 | 8 | 37 | 23 | 17 | 31 | 34 | 80 | 19 | 34 | 26 |
| Laser | 10 | 6 | 5 | 2 | 4 | 10 | 11 | -2 | -15 | 9 | 23 | -4 | 10 | 1 | 17 | 5 | 28 | 17 | 7 | 6 |
| Optical devices | 12 | 6 | 8 | 6 | 15 | 6 | 20 | 8 | 11 | 18 | 18 | -3 | 11 | 5 | 10 | 6 | 19 | 18 | 12 | 7 |
| Photonics total | 13 | 8 | 7 | 7 | 14 | 8 | 16 | 10 | 10 | 20 | 19 | -4 | 11 | 6 | 9 | 14 | 19 | 16 | 12 | 9 |

*a: compound annual growth rate of patent applications between 1991/95 to 1996/00*
*b: compound annual growth rate of patent applications between 1996/00 to 2001/05*

*Eight European countries with the largest number of photonics patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

### 6.2.2. Links to Sectors and Fields of Technologies

#### *Technological links to sectors*

Patenting in photonics is important to a number of sectors as as revealed by direct technological links between photonics patents and industrial sectors. 43 percent of the optical devices patents are technologically linked to the electronics industry, 29 percent are technologically related to the manufacture of instruments and 8 percent are linked to the machinery and equipment industry (see Table 6-2). Further industries that are technologically affected by photonics patenting are chemicals, glass/ceramics/concrete, metals, rubber/plastics and vehicles. There are little differences in the sector composition of technological links of photonics patents among the three regions.

**Table 6-2: Technological links to sectors of photonics patents (EPO/PCT), by region (1981-2007 applications, percent)**

| | Europe | North America | East Asia | **Photonics total** |
|---|---|---|---|---|
| Food | 0 | 0 | 0 | **0** |
| Textiles | 0 | 0 | 0 | **0** |
| Wood/Paper | 1 | 1 | 0 | **1** |
| Chemicals | 5 | 4 | 6 | **6** |
| Pharmaceuticals | 1 | 1 | 1 | **1** |
| Rubber/Plastics | 3 | 2 | 2 | **2** |
| Glass/Ceramics/Concrete | 4 | 3 | 3 | **4** |
| Metals | 4 | 2 | 2 | **3** |
| Machinery | 8 | 7 | 9 | **8** |
| Electronics | 43 | 45 | 49 | **43** |
| Instruments | 29 | 33 | 26 | **29** |
| Vehicles | 3 | 2 | 2 | **2** |
| Total | 100 | 100 | 100 | **100** |

Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.

Patenting in the fields of solar and laser are most closely linked to the electronics industry whereas optical devices show a stronger technological relation to the instruments industry (Table 6-3). Lighting patents are technologically linked to electronics and machinery, but also show a significant impact on the chemicals industry.

**Table 6-3: Technological links to sectors of photonica patents (EPO/PCT), by subfield (1981-2007 applications, percent)**

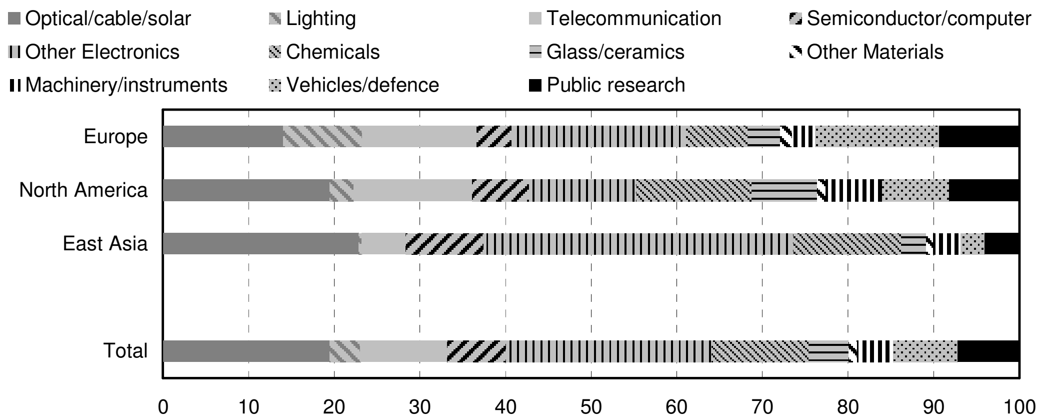
| Sector | Solar | Lighting | Laser | Optical devices | **Photonics total** |
|---|---|---|---|---|---|
| Food | 0 | 0 | 0 | 0 | 0 |
| Textiles | 0 | 0 | 0 | 0 | 0 |
| Wood/Paper | 2 | 0 | 0 | 1 | 1 |
| Chemicals | 2 | 12 | 2 | 7 | 6 |
| Pharmaceuticals | 0 | 3 | 0 | 1 | 1 |
| Rubber/plastics | 2 | 0 | 0 | 3 | 2 |
| Glass/ceramics | 2 | 2 | 2 | 6 | 4 |
| Metals | 3 | 2 | 2 | 3 | 3 |
| Machinery | 6 | 27 | 5 | 5 | 8 |
| Electronics | **62** | **43** | **69** | 34 | **43** |
| Instruments | 14 | 8 | 19 | **40** | 29 |
| Vehicles | 6 | 1 | 1 | 1 | 2 |
| Total | 100 | 100 | 100 | 100 | 100 |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

### *Sector affiliation of applicants*

If one looks at the sector affiliation of patent applicants in photonics, i.e. if one assigns industry sectors to the applicants of photonics patents based on the main market an applicant is present, a similar picture emerges. The electronics industry (incl. computer and semiconductor) and the optical industry (including lighting, cable and solar cells manufacturers) together account for almost 60 percent of total photonic patents. This share is particularly high in East Asia (more than 70 percent). Another important source for photonics patents is the chemical industry (11 percent, particularly in North America and East Asia). In Europe, the vehicles and defence industry are relatively important groups of photonics patent applicants. Public research is of less significance for this KET as a producer of patents. Its share in total photonics patenting is almost 9 percent in Europe, 8 percent in North America and just 4 percent in East Asia.

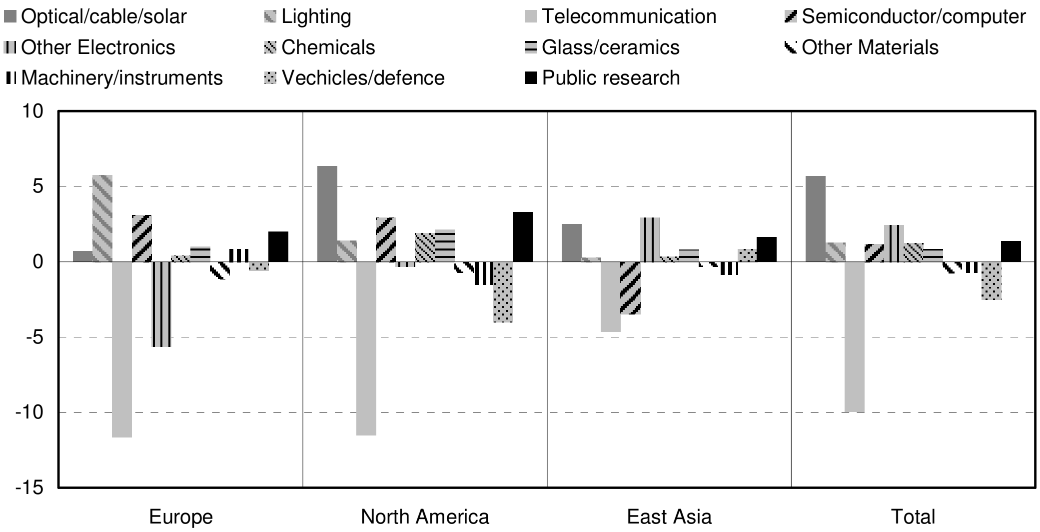
**Figure 6-14: Sector affiliation of applicants of photonics patents, by region (EPO/PCT, 1981-2007 applications, percent)**




*Source: EPO: Patstat. ZEW calculations.*

Comparing the sector affiliation of photonics patent applications before and after the end of 1999 - which splits the total sample of photonics patents in two subsamples of similar size - reveals a shift of photonics patenting from telecommunication towards the optical industry (Figure 6-15). This trend is particularly strong in North America. In addition, the semiconductor and computer industry, the chemical industry and the glass and cermaincs industry gained in importance at the expense of the vehicles and defence industry. In Europe, telecommunication as well as other electronics lost importance as photonics patents producers while the lighting industry and the semiconductor industry gained shares. In all three regions, public research increased its market share in photonics patenting, though only at a moderate rate.

**Figure 6-15: Change in the sector affiliation of photonics patents applicants before and after the end of 1999 (EPO/PCT), by region (percentage points)**




*Source: EPO: Patstat. ZEW calculations.*

Other electronics (i.e. electronics companies not specialised in telecommunication, semiconductors, computers or lighting) is the most important applicant sector for all four subfields in photonics. 30 percent of all lighting patents and 27 percent of all solar patents were filed by this industry (Table 6-4). Other important industries for generating solar patents are companies from the lighting industry, the optical industry, the vehicles industry, the defence industry and the chemicals industry. Lighting patents are often filed by companies belonging to the optical industry and the chemicals industry. Laser patents orginated from electronics, telecommunication, optical and semiconductor companies, but also public research is a relevant actor for patenting in this subfield. Patents in the field of optical devices are most often produced by electronics and optical companies, as well as by companies from the chemicals and telecommunication industry.

**Table 6-4: Sector affiliation of applicants of photonics patents, by subfield ((EPO/PCT 1981-2007 applications, percent)**

| | Solar | Lighting | Laser | Devices |
|---|---|---|---|---|
| Optical/cable/solar | 12 | 21 | 17 | **21** |
| Lighting | 17 | 5 | 2 | 1 |
| Telecommunication | 2 | 2 | 18 | 11 |
| Semiconductor/computer | 5 | 9 | 10 | 6 |
| Other Electronics | **27** | **30** | **24** | **21** |
| Chemicals | 10 | 17 | 4 | 14 |
| Glass/ceramics | 2 | 2 | 3 | 6 |
| Other Materials | 1 | 1 | 1 | 1 |
| Machinery/instruments | 3 | 2 | 6 | 4 |
| Vehicles/defence | 16 | 4 | 7 | 6 |
| Public research | 4 | 9 | 10 | 7 |

| | | | | |
|---|---|---|---|---|
| Total | 100 | 100 | 100 | 100 |

*Source: EPO: Patstat. ZEW calculations.*

The list of the 20 largest photonics applicants by region (in terms of the number of patents applied since 2000) is given in Table 6-5 for information purposes. Applications by subsidiaries are assigned to the parent company. Patents applied by firms that later have be acquired by other companies are assigned to the latter. For patent applications by more than one applicant fractional accounting applies.

**Table 6-5: 20 main patent applicants in photonics by region (EPO/PCT patents, 2002-2007 applications)**

| Europe | | | | | North America | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | Name | Country | Sector | # pat. | Rank | Name | Country | Sector | # pat. |
| 1 | Osram* | DE | lighting | 650 | 1 | 3M | US | chemicals | 748 |
| 2 | Alcatel Lucent | FR | telecommunication | 450 | 2 | Corning | US | glass | 739 |
| 3 | Philips | NL | electronics | 399 | 3 | Eastman Kodak | US | optical | 553 |
| 4 | Siemens | DE | electronics | 314 | 4 | Agilent | US | telecommunication | 276 |
| 5 | Carl Zeiss | DE | optical | 281 | 5 | General Electric | US | electronics | 236 |
| 6 | Valeo | FR | automotive | 276 | 6 | Du Pont | US | chemicals | 234 |
| 7 | Thales | FR | defence | 223 | 7 | Intel | US | semiconductors | 215 |
| 8 | Comm. à l'energie atom. | FR | government | 172 | 8 | Honeywell | US | machinery | 179 |
| 9 | Infineon | DE | semiconductors | 169 | 9 | Hewlett-Packard | US | computer | 174 |
| 10 | Schott | DE | glass | 166 | 10 | ADC Telecommunications | US | telecommunication | 165 |
| 11 | Fraunhofer | DE | research | 165 | 11 | MIT | US | research | 147 |
| 12 | Bookham Technology | GB | electronics | 154 | 12 | Avanex | US | electronics | 138 |
| 13 | Draka Comteq | NL | optical | 146 | 13 | Tyco Electronics | US | electronics | 136 |
| 14 | Essilor | FR | optical | 141 | 14 | Univ. of California | US | research | 114 |
| 15 | Hella | DE | lighting | 137 | 15 | Raytheon | US | defence | 114 |
| 16 | Merck | DE | chemicals | 129 | 16 | Cree | US | optical | 114 |
| 17 | STMicroelectronics | IT | semiconductors | 114 | 17 | Finisar | US | optical | 111 |
| 18 | Ericsson | SE | telecommunication | 107 | 18 | JDS Uniphase | US | optical | 111 |
| 19 | Pirelli | IT | automotive | 100 | 19 | Northrop Grumman | US | defence | 91 |
| 20 | Robert Bosch | DE | automotive | 90 | 20 | Motorola | US | telecommunication | 89 |

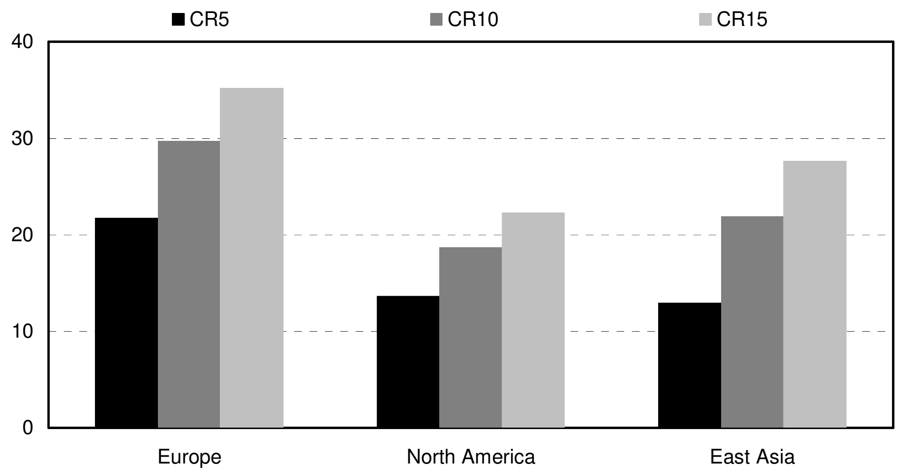
| East Asia | | | | |
|---|---|---|---|---|
| Rank | Name | Country | Sector | # pat. |
| 1 | Samsung | KR | electronics | 1029 |
| 2 | Matsushita Electric | JP | electronics | 750 |
| 3 | Fuji Film | JP | optical | 698 |
| 4 | Sumitomo Electric | JP | electronics | 631 |
| 5 | Sharp | JP | electronics | 564 |
| 6 | Sony | JP | electronics | 467 |
| 7 | Canon | JP | optical | 450 |
| 8 | Nitto Denko | JP | materials | 398 |
| 9 | Konica | JP | optical | 380 |
| 10 | Seiko Epson | JP | optical | 373 |
| 11 | LG Electronics | KR | electronics | 363 |
| 12 | Seminconductor Energy | JP | semiconductors | 358 |
| 13 | Pioneer | JP | electronics | 357 |
| 14 | Fujitsu | JP | computer | 353 |
| 15 | NEC | JP | telecommunication | 336 |
| 16 | Idemitsu Kosan | JP | oil | 295 |
| 17 | Hamamatsu Photonics | JP | optical | 285 |
| 18 | Furukawa Electric | JP | electronics | 278 |
| 19 | Mitsubishi Chemical | JP | chemicals | 239 |
| 20 | Nikon | JP | optical | 233 |

** Part of Siemens.*

*Source: EPO: Patstat. ZEW calculations.*

Photonics patenting in Europe is concentrated on a few industrial actors. More than one in five patent applications of the past 27 years has been applied by only five companies (Figure 6-16). In North America and East Asia, concentration is a bit less marked. In Europe, the 15 largest applicants are responsible for more than a third of total patent output in photonics, compared to 22 percent in North America and 28 percent in East Asia.

**Figure 6-16: Concentration of applicants in photonics patenting (EPO/PCT patents) 1981-2007, by region (percent)**



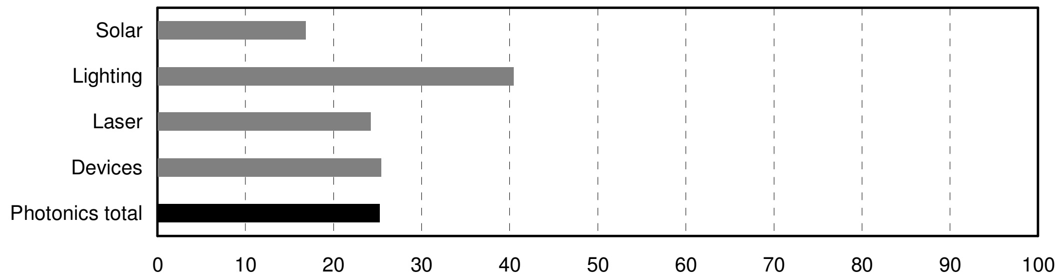

*CR5 is the number of patents applied by the 5 largest patent applicants in the total number of patent applications. CR10 and CR15 are calculated accordingly.*

*Source: EPO: Patstat. ZEW calculations.*

### *Links to other KETs*

Related to the issue of sector links is the degree to which photonics patents are linked to other KETs. One way to assess likely direct technological relations is to determine the share of photonics patents that are also assigned to other KETs (because some IPC classes assigned to a photonics patent are classified under other KETs). The degree of overlap of photonics patents with other KET patents by subfields is shown in Figure 6-17. About a quarter of all photonics patents have been assigned to other KETs, too. The highest share is reported for lighting, followed by devices and laser. Overlaps are low for solar patents.

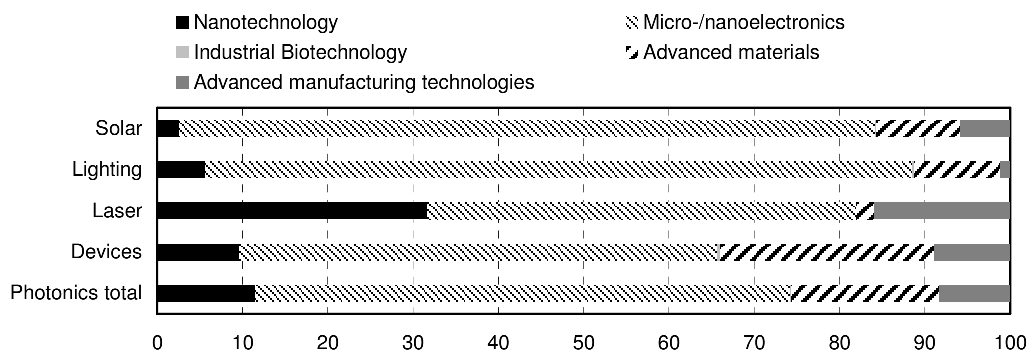
**Figure 6-17: Share of photonics patents linked to other KETs by subfield (EPO/PCT patents 1981-2007, percent)**




*Source: EPO: Patstat. ZEW calculations.*

For those photonics patents that are linked to other KETs, one can see that the largest overlap is with the field of microelectronics (Figure 6-18). This is particularly true for solar and lighting and less for devices and laser. A significant share of laser patents that have been co-assigned to other KETs are related to nanotechnology and another relevant fraction is related to advanced manufacturing technologies. Patents in optical devices with overlaps to other KETs show a relatively high share of patents co-assigned to advance materials.

**Figure 6-18: Links of photonics patents to other KETs by subfields (EPO/PCT patents 1981-2007, only patents with links to other KETs, percent)**

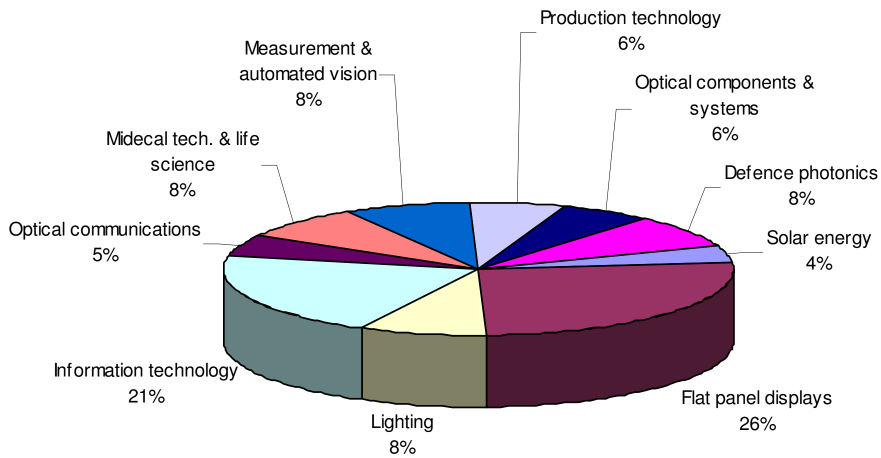



*Source: EPO: Patstat. ZEW calculations.*

### 6.2.3. Market Potentials

The European photonics industry accounted in 2006 for revenues of €49 billion, corresponding to a growth rate of 12 percent. In 2005 the industry sector employs 246 000 persons in Europe, not including employment with subcontractors (Photonics21, 2007b). In addition to directly employed people ("some 200,000"), two million other jobs depend on the photonics industry in Europe (EC 2008). The world market for Photonics accounted in 2005 for €228 billion. Figure 6-19 shows the segmentation of the world market by sectors (BMBF, 2007; Photonics21, 2007b).

**Figure 6-19: Photonics World Market by Sector, 2005**




Source: BMBF (2007), Photonics21 (2007b)

An average annual growth rate of 7.6 percent is expected for the Photonics world market for the ten years period of 2005 through 2015 and the highest growth rate (13.2 percent) is expected for the solar energy sector (Photonics21, 2007b). Table 6-6 summarises available estimates and forecasts on the market potential in photonics and selected subfields.

**Table 6-6: Estimates and forecasts for the size of the global photonic market and selected subfields**

| Subfield | Source | 2005/06 | 2007/08 | 2009/10 | 2011/12 | ~2013/14 | 2015 | ~2018 | Cagr* |
|---|---|---|---|---|---|---|---|---|---|
| **In billion US-$** | | | | | | | | | |
| Microscopes, accessories and supplies | BCC (2009) | | 2.4 | | | 3.6 | | | 7 |
| Terahertz radiation systems | BCC (2008) | | 0.077 | | | | | 0.521 | 21 |
| Process spectroscopy | BCC (2008) | 0.946 | | | | 1.9 | | | 10 |
| Organic light emitting diodes (OLEDs) | BCC (2009) | | | 3.9 | | 8.1 | | | 16 |
| Light emitting diodes for lighting applications | BCC (2006) | 5.8 | | | 10.5 | | | | 10 |
| Light emitting diodes for lighting applications | BCC (2010) | | 5.2 | | | 8 | | | 7 |
| **In billion EUR** | | | | | | | | | |
| Lithography | BMBF (2007) | 5.95 | | | | | 16.1 | | 10 |
| Laser Materials Processing | BMBF (2007) | 6.8 | | | | | 14.2 | | 8 |
| Image Processing | BMBF (2007) | 7.4 | | | | | 16 | | 8 |
| Measurement systems | BMBF (2007) | 11.6 | | | | | 23 | | 7 |
| Medical Technology & Life Science | BMBF (2007) | 18.6 | | | | | 38.8 | | 8 |
| Optical Communication | BMBF (2007) | 12 | | | | | 31 | | 10 |
| Information Techn. & Printing | BMBF (2007) | 47.7 | | | | | 88 | | 6 |

| | | | | |
|---|---|---|---|---|
| Lighting | BMBF (2007) | 18.5 | 31.9 | 6 |
| Flat Panel Displays | BMBF (2007) | 61 | 119 | 7 |
| Solar Energy | BMBF (2007) | 9 | 31 | 13 |
| Optical Components & Systems | BMBF (2007) | 12.7 | 30.6 | 9 |
| **Total market** | | | | |
| World market | BMBF (2007) | 210 | 439 | 8 |
| European market | Photonics21 (2007b) | 43.5 | | |

** Compound annual growth rate in nominal terms (percent).*

*Source: Compilation by ZEW based on the references quoted.*

## 6.3 Success Factors, Barriers and Challenges: Cluster Analysis

On a global level, production is (increasingly) located in low-cost countries, predominantly in Asia. In 2005 Japan represented 32 percent, Europe 19 percent North America 15 percent, Korea 12 percent and Taiwan 11 percent of world production. High value-added engineering and complex systems level integration, however, seems still to be located in the so-called advanced economies. Within Europe for example, Germany accounts for 39 percent of European production volume, followed by France and the UK (12 percent each), the Netherlands (10 percent) and Italy (8 percent) (Optech, 2007). Unfortunately, reports on the subject do not compare global regions by R&D expenditure but only production output. With high volume production concentrated in Asia research intensity[68] is likely to be lower than the 9 percent in Europe (Photonics 21, 2006).

Another structural characteristic of the industry is that global niche players are very common. Even very small photonics companies with a special competence have global reach and may control a significant share of the global market for which maybe only one or two other companies or even research organisations compete. As a consequence it is a characteristic of this industry that there are rarely entire supply chains present within a specific region. This, however, depends largely on the specific technology and the fields of application in question. (Sydow *et al.,* 2007)

Even though the field of photonics can be described as a relatively young high technology industry with a global reach, a number of established traditional clusters (in the past being based on classical optics) can be identified: Jena in Germany; Rochester, New York, and Tucson, Arizona, in the U.S.; and Wuhan in China. All of these are based on a long tradition of developing optics capabilities in the region. On the other hand, fairly recently a large

[68] Research intensity differs by sub-segment. In Germany for example research intensity in photonics is 9.7 percent, while higher in the sub-segments of production technology (13 percent) and measurement & automated vision (14 percent). In the sub-segments medical technology and optical components & systems it ranges between 7 percent and 10 percent, while lower in lighting (5 percent) and solar energy (3 percent) (BMWi, 2007).

number of newly developing photonics clusters have been observed. This development can partly be attributed to the advancement, differentiation and specialisation in photonics technology and the perceived need to work closely together with other competent actors, but also to local and national governmental initiatives that promote regional clustering activities (Sydow et al., 2007).

SPIE, the International Society for Optical Engineering, identifies a number of optics and photonics clusters globally (www.photonicsclusters.com). However, while having mapped many clusters in Europe and North America there are only few examples from Asia where the majority of production takes place. This could indicate a bias in the information available, particularly on Japan of which no cluster is registered. On the other hand this could also mean that most research takes place not in the countries with the largest production volume but high income regions. In that context it is also interesting to note that some photonics clusters in the Triad have even begun to form inter-cluster alliances (Sydow et al., 2007).[69]

For this analysis we have chosen to compare one European cluster with one international counterpart. With Germany representing 39 percent of output in photonics we chose the OpTecBB (Berlin-Brandenburg) cluster in Germany. As comparison we chose the "Quebec photonics network" (Canada), which exists since the 1970s and is a leader on photonic application markets.

### 6.3.1. Photonics Europe: The Optical Technologies Berlin-Brandenburg cluster (OpTecBB)70

The photonics cluster Berlin-Brandenburg is represented by a regional network of firms, research institutes and universities called OpTechBB. It was founded in 2000 and is part the national association called OptecNet, coordinating nine regional networks in the field of optical technologies in Germany.[71] It nominally covers the region of Berlin-Brandenburg, two of the German Länder, but its members are geographically concentrated in the metropolitan region of Berlin (Adlershof) (Sydow et al, 2007).

About 260 firms and 40 research organisations employing in total 7,400 people and annual turnover of around €1,8 billion are forming this photonics cluster (Sydow et al., 2007). However, this data is based on a survey from 2002. Others in the meantime (2007) speak of

[69] Since 2005 the photonics clusters in Berlin-Brandenburg, Tucson, Arizona, and Ottawa, collaborated in the so called "Tri-Cluster Berlin-Tucson-Ottawa Alliance". Activities include easing market access for cluster firms improve collaboration and information exchange including a rotating summer school. This initiative is perceived as successful with first imitators at an early stage between the photonics clusters in Bavaria, Germany, and Québec, Canada (Sydow et al., 2007).

[70] The information here is largely based on a cluster study by Sydow et al. (2007) who conducted 10 semi-structured interviews in summer 2004 and 81 semi-structured telephone interviews with OpTecBB firms. In 2006 a further round of interviews was conducted for network analysis (86 interviews).

[71] http://www.optecnet.de/welcome-to-optecnet-deutschland-e-v?set_language=en

more than 300 firms employing around 12,000 people with annual turnover of around €12bn. Around 90 of these organisations are formal members of the OpTecBB network.

Of the firms, 95 percent employ less than 250 people, while the large majority (90 percent) are small firms employing less than 50 people (Sydow et al., 2007). The remaining 5 percent of large firms, however, account for the largest proportion of turnover and employees. But important for cluster development, these large firms do not actively develop the cluster (Sydow et al., 2007).

The cluster indirectly benefits of a strong research landscape present in and around the German capital of Berlin. There are in total four universities in Berlin and Potsdam, including a large university hospital (Charité), and 10 universities of applied sciences with about 140,000 students. In addition, the region houses more than 70 publicly funded research institutes from one of the four main non-university research organisations (Max Planck, Leibniz, Helmholtz and Fraunhofer). These represent an annual R&D budget of €1.8 billion including 50,000 academic and research staff.[72]

***Short history of the cluster***

While the cluster is still in development with the cluster initiative OpTecBB founded in 2000, the region has a much longer tradition in optical technologies. Beginning in 1801, glasses for spectacles, lenses and cameras but also microscopes and other optical instruments were produced in the region in the 19th century. In the 20$^{th}$ century firms like Auer, Pintsch, Siemens, AEG and later OSRAM produced light bulbs in large volumes for national and international markets making Berlin known as the 'City of Light'. Around that time Planck and Einstein worked on photonic-related issues at the then Berlin University and the newly-established non-university research facilities in Berlin (Sydow et al., 2007).

This development was interrupted by two historic events: World War II and German re-unification. During World War II most of the industrial base of Berlin was destroyed. After that the separated and isolated location of West-Berlin meant that firms such as Siemens, OSRAM, Kodak, and Philips relocated to regions in Western-Germany, while in the Eastern part the left over industrial base was shipped to the Soviet Union as reparation. During the division of Berlin the two parts of the city developed independent and in parts duplicate capabilities in photonics evolved (Sydow et al., 2007). This resulted in dramatic downsizing of eastern institutions during the post-reunification era in Berlin. While this resulted in many job losses also quite a number of spin-off companies and new research institutes in Berlin-Adlershof were founded. To strengthen the geographical concentration a number of the

[72] For details see Berlin science navigator: http://www.berlin.de/sciencesnavigator/

institutions located in West-Berlin were relocated to, or newly established, in Adlershof towards the end of the 1990s. The OpTecBB cluster initiative hence can be seen as a re-enforcement initiative of a long existing cluster. This could explain why the cluster as developed so positively in a relatively short period of time (Sydow et al., 2007).

***System failures and system drivers for growth***

*Infrastructure*

Next to the wider research infrastructure outlined in the introduction, the cluster benefits from a large (public) research infrastructure in the field of optical technologies. There are four universities and three applied universities with Physics departments or photonics research groups. Additionally, there are more than 20 public non-university research organisations that have some activities in photonics, ranging from basic research (e.g. BESSY and the Max Born Institute) to more applied photonics research (e.g. Ferdinand Braun Institute or Heinrich Hertz Institute). (Sydow et al., 2007). Also the historic base, despite its destruction during and after World War II, is an important factor with a number of spin-offs having emerged from the former research institutions of Eastern Germany. However, in contrast to other clusters[73] there are no formal shared research facilities lowering entry barriers for start-ups and small firms.

*Institutions*

*Rules and regulations:* photonics, in contrast with bio- or nanotechnology, is not a radically new technology with potential health risks in need for regulation. Rules and regulation are hence not mentioned by any of the analyses as a relevant factor.

*Norms and values:* affect the cluster initiative at several levels. On the one hand a global trend in research towards centres of excellence can be observed. OpTecBB as one regional competence network, financed through a larger national initiative (OptecNet) in the field of optical technologies, is one example of this trend explaining the relatively large public funds going into this initiative.

On the other hand also at the cluster level, norms and values of members seem to make a difference. In comparison to other global photonics clusters[74], legitimacy among members of OpTecBB scores highest, with the members well informed about the purpose and path of the cluster initiative and their active involvement from the start. Also the boundary of the cluster is clearer contributing to binding members, despite the fact that only about one out of three

[73] One example of shared research facilities is the Philips open innovation campus in Eindhoven, the Netherlands.
[74] South Arizona (USA), Scotland and West Midlands, UK.

cluster firms is a member of the cluster network organisation (Sydow et al., 2007). These factors also contribute positively to the external recognition of the cluster.

*Public policy:* plays a critical role in re-enforcing old industrial structures in the field of photonics in Berlin-Brandenburg. Both the national and regional government[75] have actively supported the cluster. On the one hand several public research institutes have been relocated to the cluster or newly founded (see history of cluster above). Secondly, the cluster network organisation OpTecBB has been supported politically and financially by public authorities since 2001 as part of the national Optec initiative.

The financial resources are used to finance three FTE at OpTecBB as well as to keep the internal database up to date, to publish press releases and the bi-annual newsletter, and to organise the annual 'Networking Days' and annual members meeting. Half of the OpTecBB budget comprises membership fees matched by state funding from regional and national authorities. (Sydow et al., 2007). Compared to other clusters the financial resources of the cluster organisation are significant. A compared cluster in South Arizona (US) hardly receives any financial support, whereas in Scotland some financial resources are available (Sydow et al., 2009).

*Financial incentives*: There are no specific tax incentives or subsidies known to attract photonic firms to the OpTecBB cluster. However, there are general tax incentives and subsidies available to stimulate economic development in former Eastern Germany that firms located in the cluster region could benefit from. The tax burden for companies locating in Brandenburg for example is most favourable compared to many other regions in Germany with a low municipal tax. Furthermore, Brandenburg as one of the EU's Objective-1 regions benefits from EU structural funds.[76] However, these are not targeted at the OpTecBB cluster development and financial incentives are only one factor in a complex equation determining location decisions of firms. For example one firm specifically chose not to locate at the Adlershof campus despite the offered subsidies, as its location in West-Berlin was of key importance to maintain its network relationships.[77]

Tax incentives and subsidies seem to be more widely used outside Europe to attract firms to cluster locations. Hausberg et al. (2008) show that these instruments are seen sceptical by German but also European actors in terms of frequency used and importance. In contrast Canada offers the most generous R&D tax incentives among G-7 countries complemented by further provincial tax incentives to attract research activities of large international firms.

[75] OpTecBB is supported by the national Ministy of Economic Affairs, the regional ministries of Berlin and Brandenbur, the Technologiestiftung-Innovationszentrum Berlin and the Technologie Stiftung Brandenburg (OpTec, 2010)
[76] http://www.zab-brandenburg.de/files/documents/Der_Standort_Brandenburg_7__Auflage_Dezember_2009_englisch.pdf
[77] http://www.attoworld.de/junresgrps/attosecond-dynamics/pressrelease/optics_laser_Jul2008pdf.pdf

*Venture capital*: No coordinated venture capital activities are known to exist at the OpTecBB cluster. However, Sydow et al. (2007) also report no start-up support at comparable international clusters.

*Interactions*

Interactions play a critical role in cluster success. The OpTecBB initiative is primarily a cluster network initiative with a formal cluster platform. The cluster management has two core functions. First, it represents the activities of cluster firms to the outside world through a website, database, press releases but also coordinated events at industry fairs globally. Secondly, it facilitates interaction between cluster firms, although interaction between firms is only partly centrally organised. Interaction is facilitated through the annual two-day strategy workshop called “Networking Days” organised by the OpTecBB, and the event “Members Introduce Themselves”. Members Introduce Themselves is an event where cluster members invite other cluster members to take a tour through their facilities and present their firm. This event takes place about four times per year.

According to a cluster comparison by Sydow et al. (2007) the level of interaction at the Berlin-Brandenburg cluster is high, with high involvement of individual firms in cluster management. With the formal cluster-building approach having created social space for personal interaction, a lot of informal interaction has developed Though these relations have generated quite a number of important collaborative R&D projects, they have not led to an equal amount of commercial relationships that go beyond joint R&D (see Lerch et al., 2006). However, this is also partly explained by the cluster structure comprising relatively many research organisations and small firms.

Also at the inter cluster level interaction is emerging. OpTecBB is interacting with photonics clusters in Tucson (USA) and Ontario (Canada) including reciprocal visits of regional representatives, an international summer school, and joint events at photonics trade fairs. However this alliance was still in an infant stage in 2007 and will have to evolve.

*Capabilities*

Capabilities of actors can be best described by strong technological capabilities with many internationally renowned research institutes (Max Planck, Helmholtz, Fraunhofer) and universities (Humboldt University, Charité, Free University Berlin, Technical University Berlin) present, supporting the emerging capabilities of small, specialised firms. Also Sydow et al. (2007) categorise the OpTecBB cluster primarily as scientific. An important success factor in the heterogonous optical industry is a high degree of specialisation which allows to capturing large shares in global ‘niche’ markets.

### *Market failures and drivers for growth*

The cluster primarily consists of small and medium-sized firms, and a relatively large number of research institutes. As a potential weakness the lack of a large anchor firm is mentioned (Sydow *et al.,* 2009). In terms of demand photonics is a global industry, with small firms highly specialised, able to capture large shares of global market segments. The lack of a large anchor firm means that no important lead users are located at the cluster. Instead the strong science base is the driving force for firms to be located in the region.

### *Conclusion*[78]

The OpTecBB cluster is built on a long and rich industrial history in the field of optics and electronics dating back to the 19th century. However, World War II and German separation have resulted in a interruption of this historical tradition, with efforts to revitalise the cluster after German unification. The strong historical base in the field of photonics is the main reason why the cluster has developed so positively over the last years, next to the very strong research base. But also in terms of size and level of agglomeration, Berlin compares favourable to other photonics clusters in Germany (Lerch, 2008). The cluster is furthermore dominated by small companies and has a focus on research activities.

*System and market failures and drivers*

The strengths of the cluster and success of its recent evolution is based on a very strong (public) research base in the region. This creates a positive ecosystem with significant spill-over effects. Secondly, OpTecBB has created a strong and overarching member based network that is very open to outsiders yet has managed to form a clear identity and purpose for its members. This results in an advanced interconnectedness of actors at the cluster. Also OpTecBB has significant financial resources compared to other international clusters being supported by a federal initiative (OptoNet) and membership fees. Lastly, the cluster is geographically concentrated despite its nominally wide reach with more than half of OpTecBB members located in Berlin-Adlershof.

However, next to its strengths there are also a number of weaknesses of the cluster. There is no large anchor firm that can act as a coordinator, provide economic stability and strong international research links. Instead, this role is in part filled by larger public research institutes. But these cannot compensate the missing competences in commercialisation and marketing. Secondly, the high share of small firms means that capital resources are thin, being a potential barrier to innovation. Also no venture capital activity is reported in at the

[78] Even the limited number of cases engaged within this study is sufficient to demonstrate that, within one (high-tech) industry clusters can develop very differently (Sydow et al., 2007).

OpTecBB cluster. And thirdly, photonics and micro-systems are currently insufficiently recognised by regional economic and innovation policy. (Sydow et al., 2009)

*Public funding:* Public funding for the OpTecBB has been critical in two respects. First, it supported the set-up of the cluster network organisation as part of a wider national initiative. Secondly, the many public research organisations which give the cluster its strong scientific base rest on public financing. The research organisations were partly newly founded and partly relocated to concentrate activities geographically in the cluster.

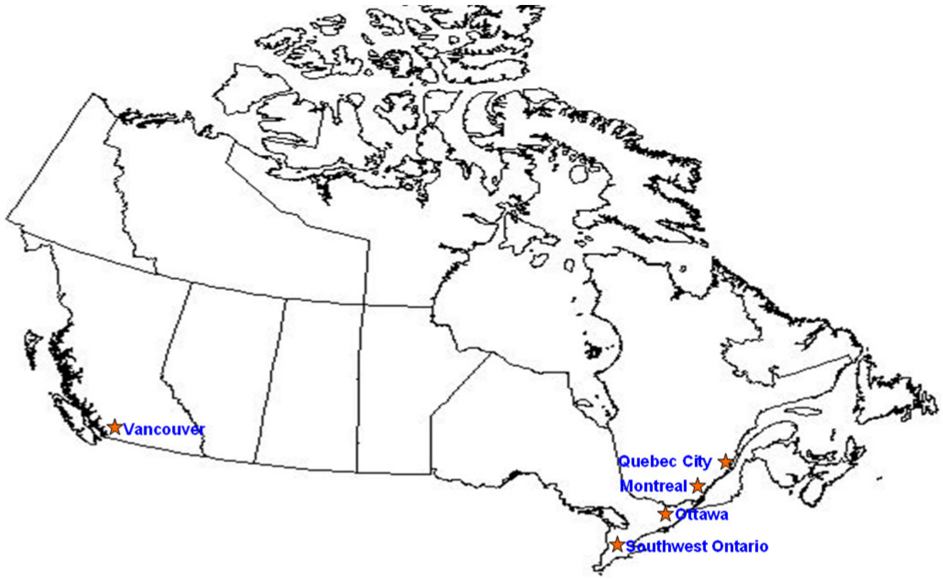
*Tax incentives:* While there are general subsidies and tax incentives available for firms to locate in Eastern Germany at EU, national and regional level, these are not targeted at the cluster development. For firms this is only one factor affecting their location decision, while the wider ecosystem is at least as important. Furthermore, tax incentives are not a widely used tool for cluster development in Germany.

*Public procurement and lead markets:* Public research institutes play an important role for the cluster development. But public procurement is not used directly as few products of the cluster are suitable for public procurement. The products of firms located at the cluster are highly specialised in industrial apparatuses aiming at a global market.

### 6.3.2. Photonics Non-Europe: Quebec photonics network

The Quebec photonics cluster is located inside the wider Canadian Photonic Corridor spreading from Quebec City over Montreal to Ottawa (see Figure 6-20). With the National Optical Institute (INO), the Research Center for photonic/optical and laser of the Laval University, and the Canadian Defense Research and Development Center, Quebec represents a key actor in the Canadian photonics activities (GC, 2010).

**Figure 6-20: Location of the Quebec photonics network**




*Source: http://www.ryerson.ca/ors/funding/resources/download/photonics.ppt*

About 100 companies[79] active in optics-photonics in Quebec employ about 4,750 specialists generating close to $60 million annual turnover. Most of the companies are located in Montréal and Québec City, a few others can be found in the Sherbrooke and Gatineau areas. These firms represent about a quarter of all photonics firms in Canada, one fifth of total employment and about 15 percent of total turnover (CPC, 2009). About one third of these jobs are in field of research. The photonics industry in Québec province comprises mainly small and medium-sized firms, covering the entire value chain. The sector nationally is dominated by small firms: ¾ have turnovers less than $1 million and 85 percent of firms employ less than 100 people.

This diverse range of photonics and optical firms primarily support applications in the telecommunications sector, but have also gained a reputation in emergent technologies like bio-photonic, safety and instrumentation as well as optical systems for information.[80]. Currently, the photonics industry in Quebec supplies goods to many industry sectors, mainly telecommunications equipment (36 percent), electronic equipment (20 percent), industrial process control (18 percent), instruments and measurement (18 percent), medical instruments (5 percent) and avionics (3 percent) (QPN, 2010).

The cluster is represented by the 'Quebec Photonic Network', a non-for-profit organisation with mandate to accelerate the advancement of the Optics - Photonics industry in the Province

[79] The most important firms are: ABB Analytical, ART Research et Technologies, Avensys, Creaform, EXFO, Fiso division of Roctest, Forensic Technology, Infodev Systèmes Électroniques, LxSix Photonics, Lyrtech, MPB Technologies, Optel Vision, OptoSecurity, Perkin Elmer Optoelectronics, Servo-Robot, Silonex, StockerYale, Telops, TeraXion

[80] http://www.quebecphotonic.ca/PhotonicsCorridor.html

of Quebec. The Quebec Photonic Network primarily acts as an information hub and a representative for all actors involved. It brings together public authorities, with research institutions and industry actors. It furthermore facilities networking between cluster inhabitants and facilitates access to public support mechanisms (e.g. tax incentives). Thirdly it promotes the cluster nationally and internationally and fosters the development of new markets. Lastly, it plays a role in supporting research initiatives, the transfer of technology and training in the field of photonics.

### *Short history of the cluster*

Quebec has a long history in the development of the amplification of light starting with one of the first inventions of optical instruments in 1704 by Samuel de Champlain, a founder of Quebec City. Since the 1940s a strong history in optics and photonics research has been built up with key research centres, such as the National Optics Institute, striving to innovate at the basic research and industrial levels. This meant that since the 1970s, the City of Québec area has been a leader in photonic market applications, from instrumentation to imagery, vision systems, optical communications and high-performance fibre optics.

While photonics activities in the province of Quebec have a long tradition, the cluster has experienced a very dynamic development over the last 20 years. Where in the late 1990s around 20 organisations formed the photonics cluster this has grown to 118 in 2007 (IQ, no date). Growth rates of 20 percent annually in output and 12 percent in employment could be observed in the last years with many new being founded. For example the National Optics Institute alone generated over 20 spin-off companies since its establishment in 1985. (Northern Lights, 2010)

### *System failures and system drivers for growth*

*Infrastructure*

Quebec has a very specialised research infrastructure focused on niche markets (Wolfe, 2005). This includes eight world-class centres ranging from the Centre d'optique photonique et laser (COPL), the largest university research centre in optics-photonics in Canada to the Canadian Institute for Photonic Innovations (CIPI), the head of a network of 18 universities that offer technology exploitation and innovation programmes. (GC, 2010) COPL is Canada's largest university research centre in optics/photonics striving to perform both fundamental and applied research, to support industry, and to train the next generation of optics/photonics scientists. CIPI on the other hand is a national network of excellence for Canadian photonics research. Of the 111 Canadian university chairs in the field of photonics 40 percent are located in Quebec (CIPI, 2010)). Other important research actors in Québec province are the National Optics Institute (NOI) with 240 researchers and the Defence R&D Canada facility in

Valcartier, Québec with 350 researchers (Ouimet, 2004). This research infrastructure is an important backbone for the cluster providing highly qualified technical personnel but also important technical knowledge that is used by firms through closely working together with research institutes.

*Institutions*

Rules and regulation have not been mentioned by any report as playing a role for the photonics cluster. Evidence on informal relations in the cluster is scarce. However, the CEO of the Quebec Photonics Network sees the relatively dense social network of Québec City confined to a relatively small area as a reason why collaboration might be easier. Also the fact that competition in the sector is global provides incentive for local actors to work together (Northern Lights, 2010).

*What is role public policy*: Public policy seems to be critical in two respects: 1) through tax legislation, and 2) through a regional development agency. In addition the public infrastructure as outlined above plays also an important role.

*Financial incentives*: Canada offers the most generous R&D tax incentives among G-7 countries complemented by further provincial tax incentives to attract research activities of large international firms. According to the Quebec's Photonics Network the R&D fiscal assistance system results in net cost of $49 for every $100 R&D investment. But also in terms of corporate tax rates, Quebec has one of the lowest rates (30.9 percent) in North America (IC, no date). Furthermore, the research environment is also attractive given the low turnover rate of research specialists and competitive salary levels. This means that corporate research in Quebec is growing at rates of 10 percent annually, also with 2 percent of GDP higher than in the EU. (QPN, 2010)

Local economic development agency Pôle Québec Chaudière-Appalaches works closely with Montréal-based Investissement Québec as well as companies and institutions from the area to ensure the success of photonics-related endeavours. The agency does many things, from facilitating the formation of research and business partnerships between local entities to hosting events and conferences to promoting the area as a desirable spot for expanding foreign companies. (Marshall, 2010). But Investissement Quebec also assists firms financially in the form of loans, loan guarantees or non-repayable contributions for innovative product development (IQ, no date)

*Venture Capital*: Quebec has access to the highest concentration of venture capital in Canada (QPN, 2010). Innovatech Québec-Chaudière-Appalaches is particularly active in the optics/photonics industry. Also the National Optics institutes plays an important role in this context having generated 20 spin-offs over the last years. While start-up capital is abundant, the region suffers from the lack of venture capital firms with the level of capital required to insure the development of firms (Ouimet, 2004).

*Interactions*

The Quebec Photonics Network is a formal cluster organisation that acts as an information hub between the cluster and the outside world. Its further role is to cooperate with national and international Photonics Networks and support the support the sales and marketing efforts of its members (QPN, 2010). Interaction is also facilitate by the geographic structure of the region with close proximity of many actors supporting informal interactions.

Next to the cluster network organisation the large research institutes such as CITR, or CRIM, play a central role in the network at the photonics cluster, which in part confirms that this is a science-based cluster. Research in 2003 has found that all organisations are directly connected to at least one other organisation and that 62.6 percent of the ties within the cluster are weak and 37.4 percent are strong. Looking only at firms, the percentage of weak ties even increases to 78.5 percent, reflected in strong ties of non-firms (44.7 percent) e.g. research institutes (Ouimet, 2004). Interestingly, Ouimet *et al.* (2004) found that Quebec optics and photonics firms with the highest degree of innovation have a highly diversified network, which is mainly based on weak ties. One can hence not conclude that strong ties are more desirable than weak ties.

With more than 80 percent of output going into exports, primarily the US, it is not surprising that national and international relationships are found to be much stronger than local ones Quebec's photonic industry (Ouimet, 2004). This characteristic of the industry is also reflected in international cooperation between international photonics clusters including German (Bavaria) and French (Bordeaux) clusters.

*Capabilities*

The cluster is a science based cluster with word leading research institutes. Cluster firms export more than 80 percent being a strong indicator for their global competitive position. However, in a survey few seem to track closely their competitors indicating that marketing competencies are potentially underdeveloped (Ouimet, 2004).

***Market failures and drivers for growth***

The photonics industry in Quebec is characterised by small and medium-size firms thriving on a strong research community and a high quality local business environment. They largely source their inputs regionally with 63 percent of the firms buying more than 50 percent of their supplies in the Quebec City area. But firms do not consider their local suppliers as a source of ideas or knowledge (Ouimet, 2004). On the other hand very few customers of photonics firms are regionally located. Around 80 percent of output is exported, with the Canadian photonics industry supplying 47 percent to the USA, 24 percent to Europe, 5 percent to Asia/Pacific, and 9 percent to the rest of world (CIPI, 2010). This is against claims of Porter that vibrant clusters require a broad base of demanding sophisticated local clients and fits the pattern that can be found for photonics clusters internationally. But this does not mean that firms do not rely on the exchange of ideas, information and knowledge with customers for innovation. On the contrary photonics firms spend long periods of time with customers (6 to 12 months) to develop customer fit solutions. (Ouimet, 2004)

***Conclusion***

While photonics activities in the province of Quebec have a long tradition, the cluster has experienced a very dynamic development over the last 20 years. Where in the late 1990s around 20 organisations formed the photonics cluster this has grown to 118 in 2007 (IQ, no date). Growth rates of 20 percent annually in output and 12 percent in employment could be observed in the last years making it a success case.

However, compared to other global photonics clusters the industry is relatively small, dominated by SMEs that are also relatively younger (Ouimet, 2004). The cluster can hence be classified as a developing cluster (Wolfe, 2008). The cluster is furthermore, science based with a number of world leading research organisations playing critical role for the cluster.

*System and market failures and drivers*

The key factors driving the photonics industry in the province of Québec are:

the presence of world-class research centres and institutes working closely with industry,

the availability of highly qualified technical personnel,

a dynamic business environment and a strong commitment from governments to support the industry, and

the proximity to key markets in the US and Canada

The lack of a large anchor firm that could stimulate and guide the cluster development may be seen as a weakness. Also the small size of firms and their limited availability of capital is a potential barrier to growth and innovation.

*Public funding:* Public funding of an excellent research infrastructure with world leading research institutes is a critical factor. Also funding programmes stimulating collaboration between public research and industry is available. In addition the regional development agency (IQ) provides loans, loan guarantees and no-refundable contributions to stimulate innovation and employment

*Tax incentives:* Canada has one of the most attractive R&D tax incentives of among industrialised countries. In addition provincial tax credits are made available to attract international firms to locate.

*Public procurement and lead markets:* Public procurement is not a suitable policy tool for development of photonics clusters as the products are highly specialised industrial products.

### 6.3.3. Conclusions on Photonics Cluster Comparison

*Strengths and weaknesses*

Both clusters have similar strengths growing quickly over the last years. This can be explained with the relatively small scale of previous activities but also the growing commercialisation prospects for photonics applications. They also both are built on a long industrial tradition in the optical technology industry. Furthermore, they benefit from a strong scientific base with world-class research centres and institutes working closely with industry. This also results in a strong labour pool with highly qualified technical personnel available. A particular strength of the OpTecBB cluster is its geographic concentration and financial resources creating a strong cluster identity and interconnectedness of actors located at the cluster. A particular strength of the Quebec cluster is its dynamic business environment and proximity to key markets in the US and Canada.

Both clusters have similar weaknesses mainly related to the structure of the sector consisting of predominantly small, specialised firms. For example, both clusters do not have a large anchor firm that can act as a coordinator, provide economic stability and strong international research links. Instead, this role in case of OpTecBB is in part filled by larger public research institutes. But these cannot compensate the missing competences in commercialisation and marketing. Secondly, the high share of small firms means that capital resources are thin, being a potential barrier to innovation. Also no venture capital activity is reported in at the OpTecBB cluster.

*Public policy, funding and tax incentives*

Both clusters have received considerable support from national and regional governments for a cluster platform, public R&D infrastructure and collaboration. In addition, the Canadian authorities also have specific support mechanism to help start-up firms to commercialise new products. Also the Quebec region attracts the highest concentration of US venture capital in Canada. At the OpTecBB no venture capital activities are reported.

Next to the provision of a strong public research infrastructure, specific policy tools differ. Canada uses predominantly R&D tax incentives to attract and support firms, whereas Germany focuses on collaboration and network support. However, the OpTecBB cluster being located in former Eastern Germany benefits from local tax incentives in support of regional development. But these are not technology related.

*Lead markets: The role of lead actors / anchor firms*

Both Berlin-Brandenburg and Quebec have some larger firms located in their clusters but these are not mentioned as playing a role as lead or anchor firms. Instead the role of anchor is played by large research organisations. This is a potential weakness as large firms have the added advantage of having strong international marketing power. But this lack can be explained with the structure of the industry that comprises many small, highly specialised firms exporting globally. Many of the smaller firms are hence market leaders in 'their' segment that is often globally shared between a handful of competitors.

**Table 6-7: Summary of findings from photonics cluster comparison**

| | **OpTecBB – Berlin-Brandenburg Germany** | **Quebec Photonic Network, Canada** |
|---|---|---|
| History | Long history, since 1801<br>Cluster platform since 2000 | Long history, since 1704<br>Since 1940 Optics & Photonics research<br>The cluster is a very fast developing cluster, with high firm growth and turn-over |
| Size | ~300 firms<br>12,000 people<br>€12 billion of annual sales | ~100 firms<br>4,500 people<br>€0.6 billion of annual sales |
| Classification | Developing | Fast growing |
| Infrastructure | Strong knowledge infrastructure: Universities and Public research institutes | Strong knowledge infrastructure – focused on niche markets |
| Institutions | *Rules and regulations*<br>minor role<br>*Norms and values / culture*<br>Strong cluster identity – strong external recognition | *Rules and regulations*<br>no particular role<br>*Norms and values / culture*<br>Entrepreneurial culture contributing to fast growth |
| Public policy / funding / taxation | Considerable support for cluster platform<br>Support through available publicly funded research orgs<br>No specific tax/financial incentives related to technology, but Brandenburg has favourable tax regime for regional development<br>No venture capital scheme in place | Strong role through:<br>Tax legislation<br>Support from regional development agency<br>Availability of public knowledge infra<br>Most generous R&D tax incentives among G-7<br>Tax incentives to attract large MNCs<br>Low corporate taxes<br>Low labour costs<br>Favourable loans available from Investissement Quebec<br>Funding available for collaboration<br>High level of Venture Capital (lack though for firm growth) |
| Interactions | High level of interaction: formal and informal<br>High level R&D collaboration<br>High firm involvement in cluster platform<br>Linkages to international clusters | Informal interaction through proximity of cluster firms<br>Formal interaction in cluster platform<br>Good mix of strong and weak ties leading to optimal innovativeness |

| | | |
|---|---|---|
| | | Very strong international relationships: >80 percent for export |
| Capabilities | Scientific knowledge, belong to international top | Strong science based knowledge base, belong to international top |
| Market demand | Lack of lead-firm(s) | Strong interaction with customers<br>No local lead customer or firm<br>Strong focus on niche markets |
| Market structure | Market dominated by smaller firms , this is a weakness as large lead buyers lack for demand, internationalisation and commercialisation | Market dominated by SMEs<br>Focus internationally<br>Sourcing locally – selling internationally |
| Cluster features | Very strong knowledge 'ecosystem' with spillovers<br>Generous funding of platform | Very high growth rate or nr of firms' turn over (20 percent) and employees (12 percent)<br>Very strong focus and concentration on niches<br>Strong international orientation<br>Strong funding structure for firms (tax incentives as well as funding) |

*Source: TNO compilation.*

### 6.3.4. Factors influencing the future development of photonics

***Factors influencing the future market potential of photonics***

Photonics is a driver for technological innovation and one of the most important key technologies for markets in the 21st century. It has a tremendous leverage for creating products in a broad range of industrial sectors that multiply the value of initial photonic components and technologies many times over. The innovative and competitive capability of many important European industries, such as ICT, lighting, health care and life-sciences, space and defence as well as the transport and automotive sector largely rely on progress and development in photonics (Photonics21, 2006).

***The role of public support***

There are massive efforts taken in the USA and in Asia with respect to research funding (Photonics21, 2006). For example, in Japan research projects in the field of laser technology have received public funding since 1977 (BMBF, 2002b). In Europe, the European Commission treats photonics as a key technology for the economy of the 21st century because it impacts on many important European industries, such as telecommunication, lighting, environment, health care and life sciences, safety and security. In keeping with its greater importance for Europe, Photonics has been given a higher profile in the Seventh Framework Programme (FP7) and Photonics related research and development is supported in different areas of FP7. Political support will particularly be needed in providing the necessary research environment capable of accelerating photonics research, enhancing cooperation, increasing public and private R&D investments and ensuring the mobilisation of the critical mass of resources. The European research policy faces the challenge to effectively link and coordinate the national R&D activities and programs in the Member States of the European Union. Furthermore, at the European level, R&D programs involving optics and photonics are dispersed among various application areas. Projects are carried out widely isolated from each other in a number of different thematic priorities (Photonics21, 2006).

***Contribution of advanced materials to social wealth***

There are manifold contributions of photonics to social wealth. The global warming issue, for instance, requires the development of energy saving technologies. One such example is in the field of lighting where the classical energy intensive light bulb will be replaced by high-efficiency lighting (e.g. LED, OLED). Furthermore, photonics technologies are important in the area of energy production (photovoltaic power generation). Wealth effects are also obvious in completely different sectors like the field of medical technology. New diagnostic technologies allow the examination and manipulation on the cellular, sub-cellular or molecular level. This opens up new possibilities regarding new diagnostic tools and new treatments. Other photonic technologies, like eye and laser surgical procedures, have become standard.

***Importance of sustaining production capabilities***

Photonics production is dominated by Asia, notably Japan, Korea, and Taiwan while China is catching up. Europe accounts for 19 percent of the worldwide production volume and North America host 15 percent. The single regions and countries in Europe are focused on parts of the Photonics product spectrum and several of the Photonics sectors are dominated by a few, large producers. This is true for the sectors of lighting, production technology, communications, and defence photonics (Photonics21, 2007b). Production capabilities allow for an application of newly developed technologies and as a result facilitate experimental learning that can be assumed to be valuable in future technology development efforts.

## 6.4 Conclusions and Policy Implications

***State of technology***

Photonics can be described as a relatively young high technology industry. The number of patent applications started to increase exponentially in the mid-nineties and still has not reached its peak. Photonic markets today mainly refer to lighting, measurement and automated vision, production technology, medical technology and life science, optical communication, optical components and systems, solar energy, and information technology. The current global market size is about €200 billion.

### *Europe's technological position*

Photonic development is concentrated on three global regions, Europe, North America and East Asia. East Asia holds the highest market share, followed by Europe and North America. In terms of patents per GDP, East Asia has a significantly higher photonic patenting intensity than the other two regions. Europe has a comparable patenting intensity as North America. While East Asia was able to improve its technological competitiveness in terms of patent applications, Europe's market share remained stable over the past fifteen years, while North America is slipping down.

The largest subfield in terms of patents is optical devices (more than half of all photonic patents), followed by solar cells, laser, and lighting. Europe has a high market share in solar cells (though decreasing) while Europe's market share in optical devices, laser, and lighting is slightly lower than thirty percent.

Within Europe, most countries show a focus on optical devices while Austria is specialised in solar cells. The Netherlands has the highest proportion of lighting patents and France, the United Kingdom and Sweden in laser patents.

### *Links to disciplines, sectors and other KETs*

At the science side, main links of photonics got to electronics and instruments, but also machinery (especially in the subfield of lighting) have been making important contributions to the development of this KET. Public research plays a subordinate role in patenting and contributes to less than ten percent to total photonic patents.

Photonic patents are technologically linked to electronics, manufacture of instruments, machinery and vehicles, and the chemical industry. In East Asia, most photonic patent applicants from the business enterprise sector belong to the electronics industry while public research is less important. In North America, the optical, cable and solar industry, the telecommunication industry and the chemical industry are the most important groups of photonic applicants. In Europe, the electronics industry, vehicle industry and the telecommunication industry plays an important role.

### *Market prospects and growth impacts*

All existing market forecast for photonics and the various submarkets suggest a strong increase in sales in the next decade. The forecast for total photonics expect global sales in 2015 of more than €400 billion. So far, many of the forecasts have proved to be too optimistic, however. But there is no doubt that demand for photonic products will increase clearly above the total market expansion.

Photonics can, as most other KETs, contribute to economic growth through two ways. On the other hand, photonics applications can help to increase the efficiency of production processes in various industries by enabling more advanced production technologies (e.g. in the fields of measuring and controlling or through a more widespread use of laser technology). On the other hand, photonics has a strong potential to open up new markets not explored yet through product innovation, thus stimulating additional demand and contributing to net growth.

Many new applications in photonics are expected to substitute other technologies. Substantial substitution potentials are seen in the field of microelectronics.

Photonics can raise qualitative growth with new and flexible production methods which for instance enable economically viable production of lot sizes of 1 to 1,000,000 pieces. Furthermore, photonics will play a central part in the development of renewable energy.

***Success factors, market and system failures***

The field of photonics profits from a large and diversified industrial base with a large number of successful enterprises committed to R&D and innovation in photonics. Photonics is also a well-established field of research at universities and public research centres. A main challenge is to better interlink the two groups of actors. As for industry-science links in general, important success factors include a long-term oriented co-operation with clear division of labour between the industrial and the public research part.

Another important issue is standardisation. There is some evidence that in the past, international industry standards were defined by actors outside Europe, resulting in competitive disadvantages for European companies as they often had to adjust to standards set by their competitors (Photonics21, 2007a). More efficient and timely coordination of European standardisation processes could help to strengthen the market position of European companies and and speed up commercialisation. Photonic applications in the areas of ICT, lighting, manufacturing and life sciences are particularly affected by international standardisation issues.

***Policy options***

The European production volume corresponds to 19 percent of the world market in 2005. The European industry has a weak position in the sectors of information technology and flat panel displays (Photonics21, 2007b). Photonics production is already dominated by East Asia and East Asia's significant increase in patent intensity since 1998 continues to strengthen its dominant position. At the same time, photonics are a promising field of technology that is likely to generate a large number of new applications for many different industries, including electronics, automotive, mechanical engineering, energy production and distribution, and medical technologies. In order to feed these and other industries with new technological opportunities from photonics and to sustain sectoral clusters that incorporate new technologies from photonics, a strong photonics industry in Europe is indispensable.

Public policies to strengthen research in and commercialisation of photonics in Europe should particularly take into account the experiences of successful clusters. Though cluster policies tend to be important for any KET, this approach is particularly important for the field of photonics since it requires the combination of a complex set of technologies, involving actors from different industries along the value added chain. For a detailed discussion of how KET clusters can be stimulated and supported, see section 9.2 in the final chapter.

# 7 ADVANCED MATERIALS

## 7.1 Definition and State of Technology

Advancing the properties of materials is one of the most longstanding industrial innovation activities. Throughout human history, substantial efforts have been made to improve the material base of the manufacture of goods, allowing for higher product quality and new product characteristics. In modern times, advancing materials has first focussed on further improving metals by introducing new alloys with superior performance characteristics (particularly in the case of steel) and exploring the industrial applicability of new metals (such as aluminium). In addition, a number of material innovations took place in the field of non-metallic materials such as glass, ceramics and concrete. From the late 19th century onwards, a new main focus on chemical technology emerged. A large number of synthetic materials have been invented, and alternative raw material bases have been explored (coal, petroleum, natural gas). During the 20th century, most efforts in advancing material technology were on building up of so-called "macrostructures" or "superpolymers" by linking together molecular units into super-long chains (e.g. polyethylene, styrene, Teflon) possessing desired physical and chemical properties (Moskowitz, 2009). Since the late 1970s, a new paradigm in material technology has emerged which defines the most recent generation of advanced materials. This paradigm focuses on the customisation of the atomic structure of materials by creating, manipulating and reconfiguring molecular or atomic units within a wide range of material categories. Nevertheless, material innovations still occur along the all the lines mentioned above.

Today, the term “advanced materials” is often used to describe those components which structure and properties have been modified and improved at the mili/micro/nanoscale level. As a result, advanced materials possess new and different types of internal structures and exhibit *avantgard* properties and higher added value, with an unprecedented range of applications (Moskowitz, 2009). A common characteristic of these materials, compared to conventional ones, lies in the improved performance they offer (particularly) in very demanding environments (e.g. in terms of temperature, humidity) or for very demanding processes (e.g. in terms of capacitance, miniaturisation). They also offer additional advantages over conventional materials in terms of physical-chemical properties (e.g. conductivity, weight, durability) which is very often transformed by using industries into (end-) products of higher added value.

The renewed strong interest in the field of advanced materials lies in the fact that the newest advanced materials are believed to have a current application rate nearly three times higher compared to previous generations of materials. It has been estimated that the eight most important materials entering the market in the 1900s-1960s period (e.g. electrometals, synthetic ammonia, nylon, styrene, etc) can claim a total of 24 different applications, that is, an average of 2.7 per material. The 14 newest advanced materials (e.g. nanocrystals, nanocomposites, nanotubes, organic electronic materials, etc) account for 120 different applications, for an average of 8.6 per material (see Moscowitz, 2009, for a full account). It is expected that by 2020, these most advanced materials will generate worldwide direct sales of some hundreds of millions of Euros.

Owing to their "combinatorial" nature, it is difficult to provide a clear-cut classification of advanced materials. Nonetheless it is possible to group "new" advanced materials into five generic categories:

**advanced metals** (e.g. advanced stainless steel, super-alloys, intermetallics, etc),

**advanced polymers** (e.g. synthetic engineering-nonconducting polymers, engineered plastics, conducting polymers or organic-electronic materials OPEs, advanced coatings, advanced/nanofibbers, etc),

**advanced ceramics and superconductors** (e.g. nanoceramics, piezoelectric ceramics, nanocrystals),

**novel composites** (e.g. polymer composites, continuous fibber ceramic composites, metal matrix composites, nanocomposites, nanopowders, metal fullerenes and nanotubes),

**biomaterials** (e.g. bioengineered materials, biosynthetics, nanofibbers, catalyst).

Alternative definitions put more emphasis on combining a structure-based view with application potentials of new materials (see Schumacher et. al., 2007) used for this investigation combines a material-based view with an application oriented view. From such a perspective, one may distinguish **nanomaterials** (e.g. nanoparticles and crystals, nanocomposites, nanofibres and nanorods, nanotubes and nanofullerenes, thin films and spintronic materials; the common characteristic is to scale down materials into a size that results in different material properties; see chapter 3 on nanotechnology), **smart materials** (i.e. complex materials that combine structure characteristics with specific physical and chemical properties, such as shape memory materials, functional fluids and gels, piezoelectrical, ferroelectrical and pyroelectrical materials, magneto, electrostrictive materials, electroactive polymers, electro-, photo- and thermo-chromic materials, tunable dielectrics), **bioconceptual materials** (i.e. materials based on biological technologies such as bioinspired materials, biohybrids, bioactive materials, biodegradable materials and soft matter), and **tailored macroscale materials for high performance applications** (which comprise structural materials for extreme environments, functional materials for extreme environments, energy efficient materials, electromagnetic materials).

Advanced materials are a special kind of **general purpose technology**. Like other general purpose technologies, advanced materials can be applied widely across industries, also emanating into service sectors such as health, software, architecture and construction, telecommunication and engineering services. Advanced materials contribute to more efficient production processes and trigger new product development. In contrast to other general purpose technologies such as ICTs, however, the diffusion of advanced materials exert little network effects among users. The large variety of materials, many tailored to specific application purposes, restrict economies of scale in their production. In addition, both the development and the diffusion of new materials takes particularly long periods, often decades. First, considerable research efforts are needed until new materials comply with the requirements of users in terms of reliability, stability, cost-efficiency, recyclability and safety. Secondly, product regulation typically requires time-consuming procedures for each field of application until new materials are approved for commercial use in the respective application area. Thirdly, using new materials most often requires substantial adaptations in production and distribution processes of users along the value chain, including changes in process technology, product design, delivery mechanisms, recycling etc and may involve high investment by users. The latter fact often delays a rapid diffusion of new materials.

Another peculiarity advanced materials is the broad spectrum of scientific disciplines and research areas that contribute to advanced materials. Material sciences, chemistry, physics, nanosciences and -increasingly- biology have to be combined with in-depth knowledge of process technology and other engineering sciences, information technology and life sciences. As a consequence, cross-disciplinary research is prevalent. Examples for new interdisciplinary fields in materials research include computational materials science and biochemical nanotechnology.

Advanced materials are used in virtually all manufacturing industries, and they drive innovation in many sectors. The most important application areas for new advanced materials are currently semiconductors, automotive and aircraft, energy and environment, medicine and health, construction and housing, and various process technologies. Developing advanced materials often requires a close co-operation between basic research (e.g. public science), material producers (e.g. chemical industry, metals industry), end product producers (e.g. automotive or semiconductor industry), process equipment producers (e.g. machinery industry) and sometimes other users down the value added chain that use products containing advanced materials. Since new materials are often a key component of new products, many producers of end products also engage in R&D on advanced materials.

## 7.2 Technological Competitiveness, Industry Links and Market Potentials

### 7.2.1. Technological Competitiveness

Analysing technological competitiveness in advanced materials based on patent data and using patent classification systems to identify advance in material technology is challenging. While patent classification allows to identify inventions in different areas of substances and basic materials (e.g. certain metals, polymers, non-metallic matters), it is much more difficult to identified whether these inventions comply with the notion of advanced materials given above. In addition, some types of advanced materials such as smart materials or biomaterials are particularly difficult to identify through patent classification systems.

For this study, advanced materials are identified through a set of IPC classes that constitute seven subfields of advanced materials (IPC classes given in parentheses):

Layered materials (B32B 9, B32B 15, B32B 17, B32B 18, B32B 19, B32B 25, B32B 27)

High-performance materials (C01B 31, C04B 35)

Tailored macroscale materials (C08F, C08J 5, C08L)

New alloys (C22C)

Energy-efficient materials (D21H 17, H01B 3)

Magneto and piezo materials (H01F 1, H01F 1/12, H01F 1/34, H01F 1/44)

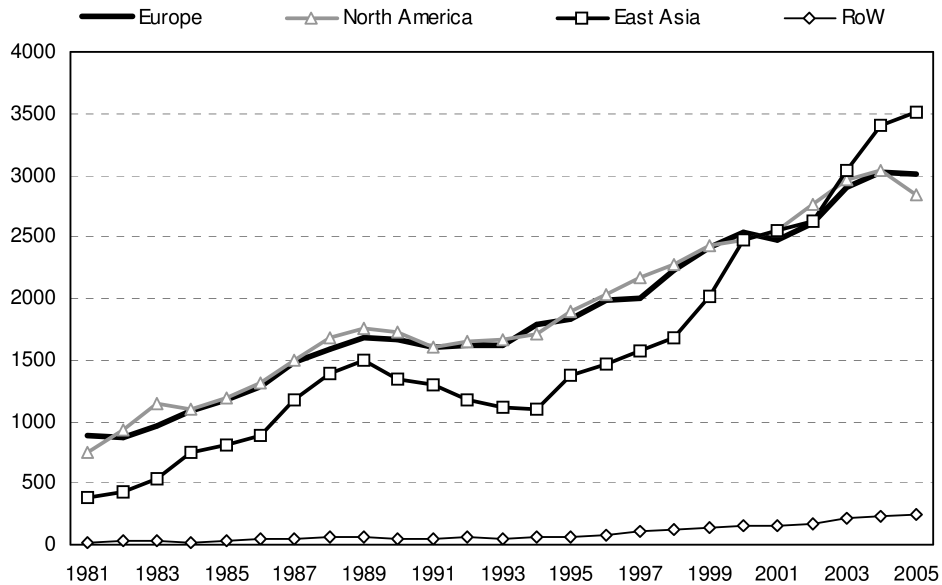
Nanomaterials (Y01N 6)

Note that one and the same patent may be assigned to several subfields of advanced materials owing to the fact that most patents are assigned to many IPC classes.

***Market shares***

Based on this definition of advanced materials, so far about 150,000 patents have been applied either at EPO or based on PCT (EPO/PCT patents) in the field of advanced materials within the past 30 years. The annual number of patent applications by and large followed the general pattern for EPO/PCT patents. Several years of constant annual numbers of patent applications in the early 1990s were followed by a significant increase during the second half of the 1990s. In contrast to the general trend in patenting, the annual numbers of patents further increased after the world economic recession in 2001. In both 2004 and 2005, more than 9,500 advanced materials patents were applied at EPO/PCT (Figure 7-1). The still ongoing upward trend in advanced materials patenting underpins that this KET is still in an expanding phase of generating new knowledge relevant to industrial application.

**Figure 7-1: Number of patents (EPO/PCT) in advanced materials 1981-2005, by region of applicant**

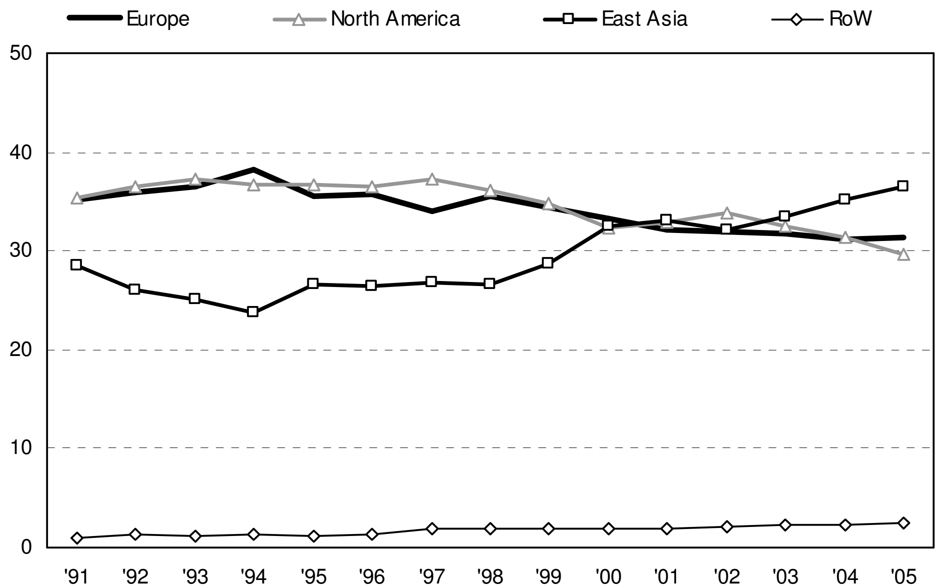



*Source: EPO: Patstat, ZEW calculations.*

In recent years, the number of patent applications by East Asian applicants increased particularly strong. North American and European applicants increased their patent output after 2000 at a more moderate rate. The strong increase of East Asian patents reflects a raise in patenting by Chinese and Korean applicants as well as a stronger world market orientation of advanced materials manufacturers from all East Asian countries.

As a consequence, East Asian applicants were able to gain market shares in the technology market for advanced materials from 2000 onwards. In 2005, 37 percent of all advanced materials patents were applied by East Asian applicants, whereas both North American and European applicants lost market shares (Figure 7-2). The current market share of European applicants is at 31 percent, the one of North American applicants at 30 percent. Applicants from outside these regions do not play any important role in this KET, accounting for a joint market share of just 2 percent.

**Figure 7-2: Market shares for EPO/PCT patents in advanced materials, 1991-2005 (percent)**



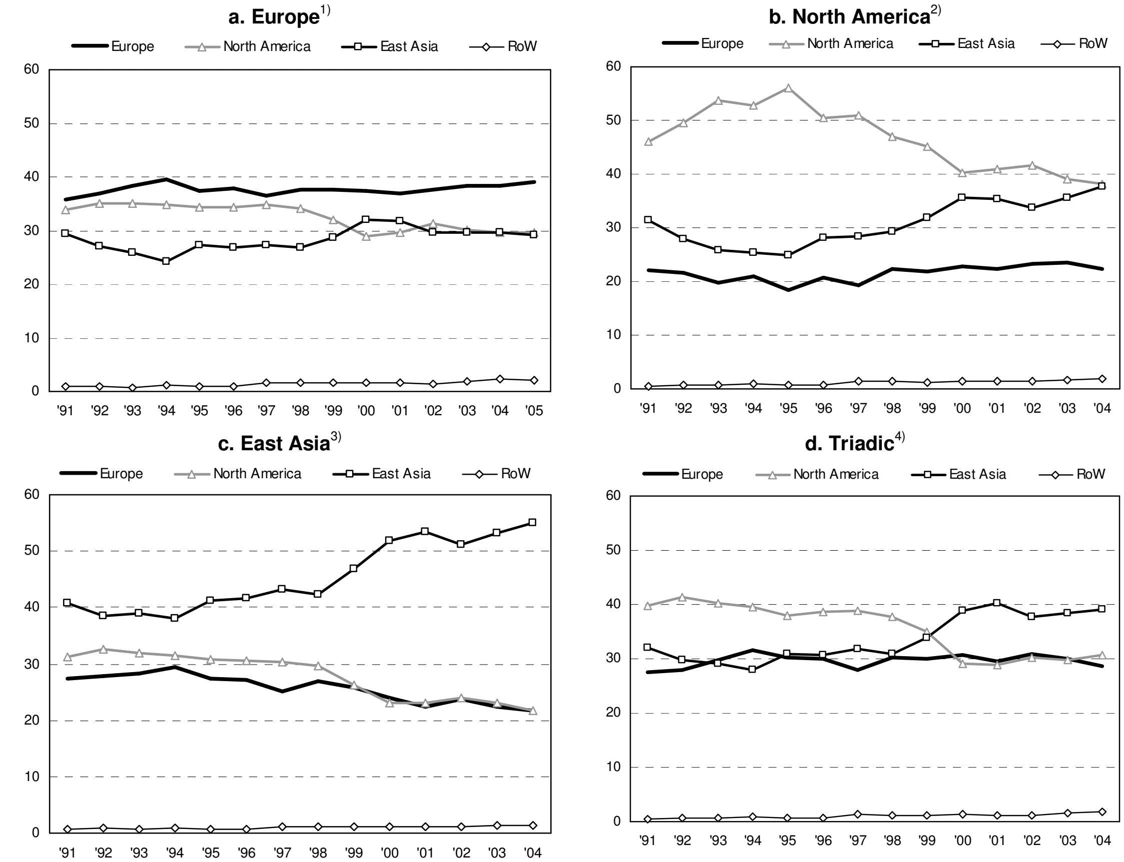

*Source: EPO: Patstat, ZEW calculations.*

The marked increase of market shares of East Asian applicants is revealed by the analysis of market shares at different regional technology markets, based on patent applications at the leading patent office for each regional market (EPO for Europe, USPTO for North America, JPO for East Asia). European applicants still hold a leading position in their home market and were able to maintain a market share of almost 40 percent over the past 15 years (Figure 3-3). East Asian applicants slowly increased their share until the year 2000 at the expense of North American applicants. Since then, market shares remained stable.

With respect to patent applications at the USPTO, East Asian applicants could almost overhaul their North American competitors by 2004, both standing at a market share of 38 percent. European applicants report a stable market share at USPTO of 22 to 23 percent for the past ten years.. Among the patents applied at JPO, market shares of East Asian applicants are constantly increasing while those for European and North American applicants are falling at a similar pace.

When looking a triadic patents, East Asian and North American applicants interchanged their position. While North American applicants held a market share of around 40 percent in the 1990s, this figure felt to about 30 percent in the 2000s. East Asian applicants were able to raise their share in the total number of global advanced materials patents from about 30 to about 40 percent. The contribution of European applicants remained quite stable over the whole period at about 30 percent.

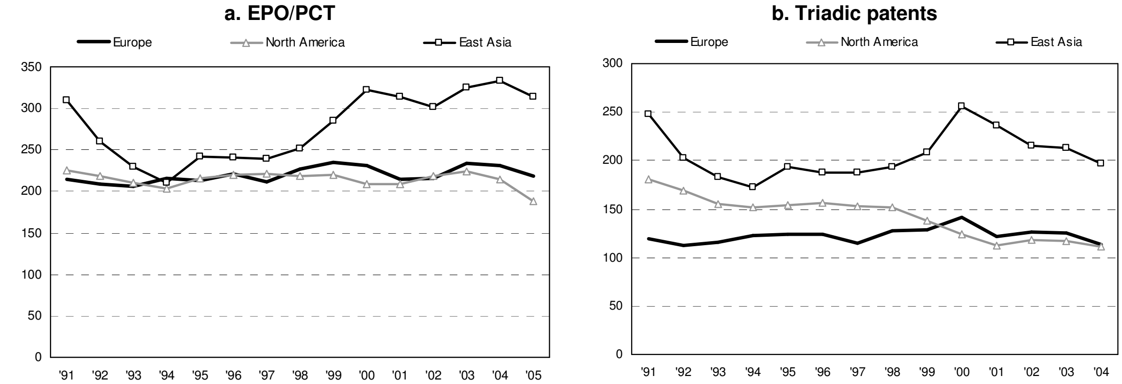
**Figure 7-3: Market shares in advanced materials patents 1991-2005 for national applications and triadic patents (percent)**




*1) EPO applications*
*2) USPTO applications*
*3) JPO applications*
*4) Patents for which 1), 2) and 3) applies*
*Source: EPO: Patstat, ZEW calculations.*

In order to determine the relative importance of advanced material patents for a region, patent intensities can be calculated. The patent intensity relates the number of patents per year from applicants of a certain region to the GDP of that region. This type of specialisation indicator shows that East Asia produces the highest number of advance material patents per GDP, followed by North America and Europe which report a similar intensity level. In 2005, the number of advanced materials EPO/PCT patents per GDP in East Asia is almost 50 percent above the level of Europe and North America. Over time, East Asia has increased its patent intensity in advanced materials as far as EPO/PCT patents are concerned, while North America and Europe report constant figures. A different picture emerges when consulting triadic patents. North America shows a falling trend, Europe reports a constant level and East Asia experienced both downward and upward developments for this indicator (Figure 3-4).

**Figure 7-4: Patent intensity 1991-2005 in advance materials (number of EPO/PCT and triadic patents per 1 trillion of GDP at constant PPP-$)**

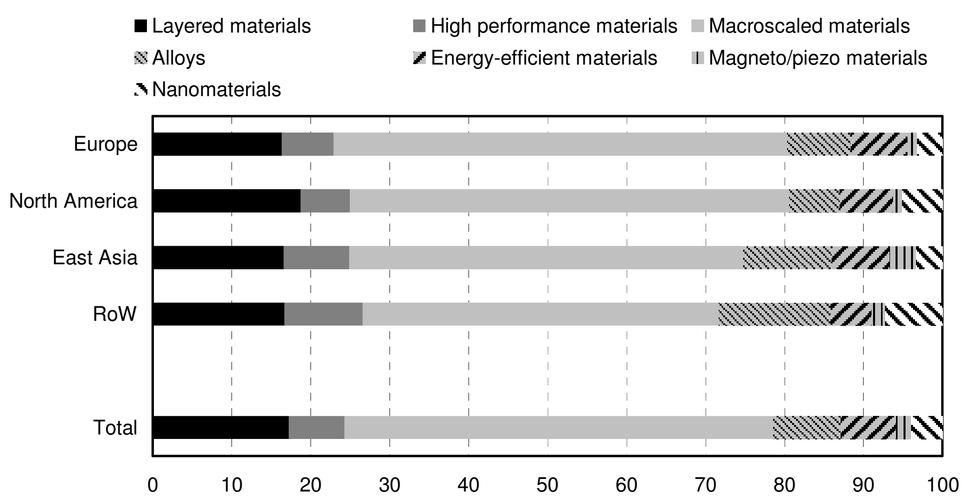



*Source: EPO: Patstat, OECD: MSTI 02/2009. ZEW calculations.*

## *Patenting by subfields*

This study distinguishes seven subfields of advanced materials based on IPC classes. The largest subfield within advanced materials is macroscaled materials tailored to specific applications (Figure 7-5). This rather traditional field of advance in material technologies accounts for 54 percent in total advance materials patenting. Layered materials are the second largest area (17 percent), followed by alloys, high-performance materials and energy-efficient materials. Magneto and piezo materials as well as nanomaterials account for a small fraction of just 2 to 4 percent. East Asian applicants show a higher share for alloys and high-performance materials while Europe is strongly focused on macroscaled materials.

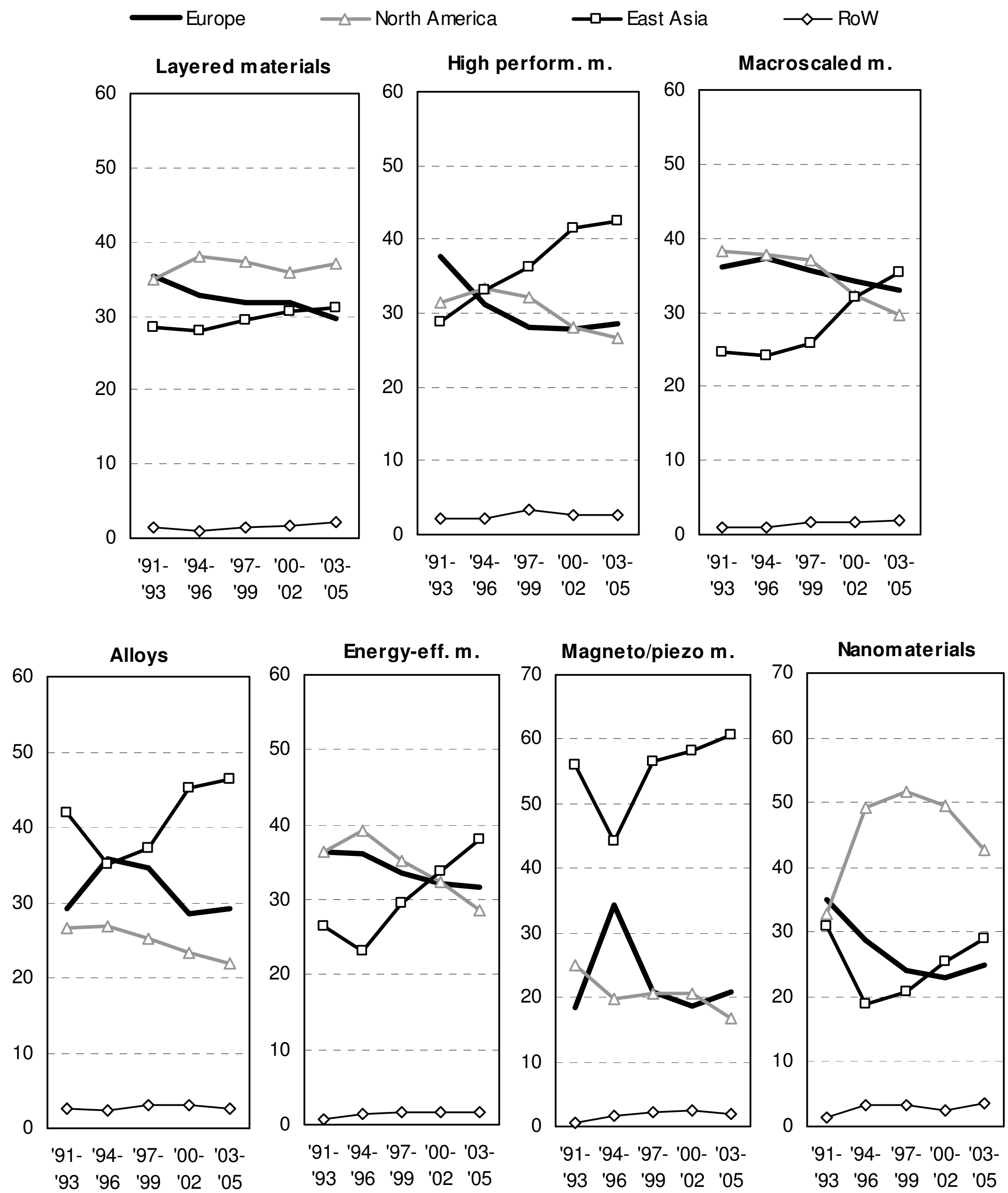
**Figure 7-5: Composition of EPO/PCT advanced materials patents by subfields (percent)**




*Source: EPO: Patstat, ZEW calculations.*

Differentiated by subfields, Europe holds a high market share of 30 percent or more in macroscaled materials, layered materials and energy-efficient materials. Market shares are lower in alloys, high-performance materials and in the two small areas of nanomaterials and magneto/piezo materials. For all seven subfields, market shares of Europe in the most recent subperiod (2003-05) do not exceed the level of 1991-93. This means that the general downward trend of Europe's share in the total number of EPO/PCT patents holds for all subfields. East Asia shows increasing shares in all subfields. Layered materials are the only subfield where East Asian applicants did increase their market share only slightly, and nanomaterials is the only subfield where North American applicants are still ahead of East Asian, though the latter clearly catch up.

**Figure 7-6: Market shares for advance materials patents (EPO/PCT) by subfields 1991-2005 (percent)**

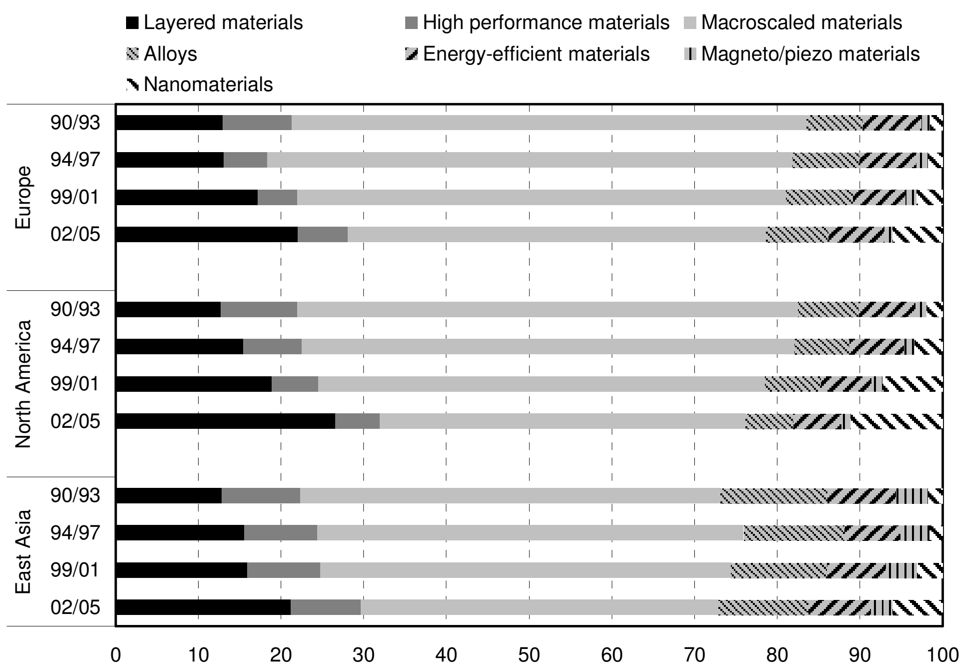



*Source: EPO: Patstat, ZEW calculations.*

When looking at the most recent period, Europe was also able to increase its market shares marginally in alloys, magneto/piezo materials, nanomaterials and high-performance materials. These are all subfields with a below-average market share for Europe. This could be read as a slow improvement of technological output in areas with weaker performance.

Analysing technological dynamics by subfields based on EPO/PCT patents may be biased from varying attractiveness of the European market. For instance, a rise in demand for advanced materials in Europe may stimulate patenting by North American and East Asian applicants at EPO, thus raising the number of EPO/PCT patents. A decreased attractiveness of the European market may result in the opposite effect. In order to avoid such biases from the market environment, we evaluate technological dynamics in advanced materials by looking at patent applications by European, North American and East Asian applicants at their respective home patent office (EPO, USPTO and JPO, respectively). For all three regions we find a trend in patenting toward layered materials and nanomaterials, and decreasing shares of macroscaled materials (Figure 7-7). While macroscaled materials accounted for 62 percent of all advanced materials patents at EPO by European applicants in the period 1990-93, this share felt to 51 percent in 2002-05. In North America the respective share declined from 60 to 44 percent, and in East Asia from 5a to 43 percent. This trend reflects that classical chemical technology plays a decreasing role in advanced materials, though it is still the main source for advances in material technologies in terms of the number of patents.

**Figure 7-7: Composition of advanced materials patents (applications at home patent offices), by region, subfield and period (percent)**

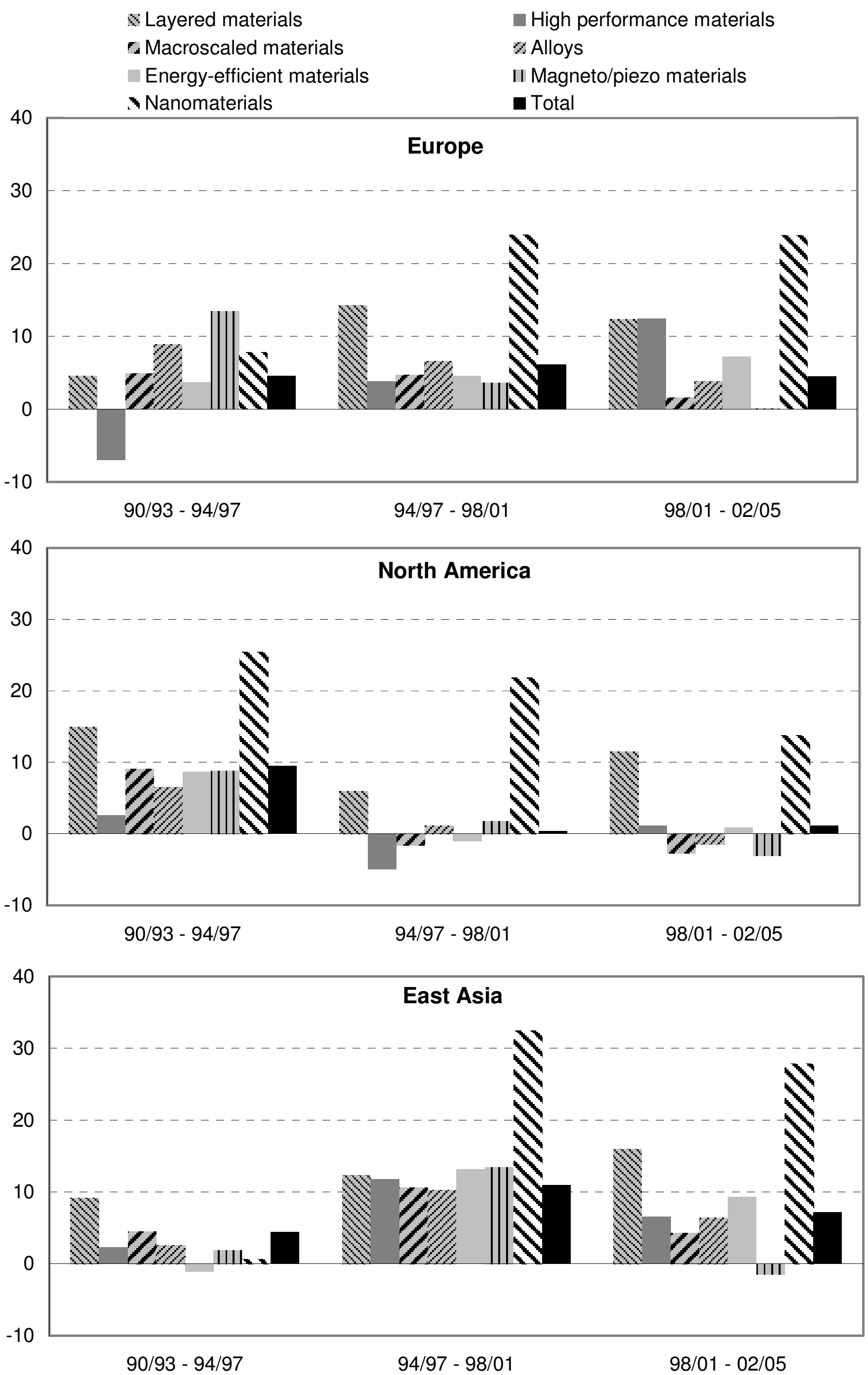



*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

Figure 7-7 also shows specialisation patterns of regions by subfields over time. These differ to some extent from the pattern that emerges when looking at EPO/PCT patents (see Figure 7-5). North America shows particlarly high (and increasing) shares for layered materials and nanomaterials but smaller (and decreasing) shares for high-performance materials, alloys and energy-efficient materials. Europe reports comparably high shares for macroscaled materials and energy-efficient materials. East Asia is specialised on high-performance materials, alloys and magneto/piezo materials. For all three subfields, shares are decreasing over time, indicating that the East Asian specialisation pattern is dispersing.

Analysing the average annual rate of change in the number of advanced materials patents by subfields, regions and subperiods (Figure 7-8) reveals some interesting insights. North American applicants were the first to sharply increase their patent activity in nanomaterials while Europe and East Asia entered this field form the second half of the 1990s on. While Europe was able to maintain a high rate of growth in nanomaterials until the most recent period, growth rates diminished in North America and East Asia in this subfield. In the most recent period, the number of patents in high-performance materials and energy-efficient materials has increased substantially. A similar development can be seen for East Asia. North American applicants did not increase their patent activities in these subfields.

**Figure 7-8: Average annual rate of change in the number of advanced materials patents (applications at home patent offices), by region, subfield and period (percent)**



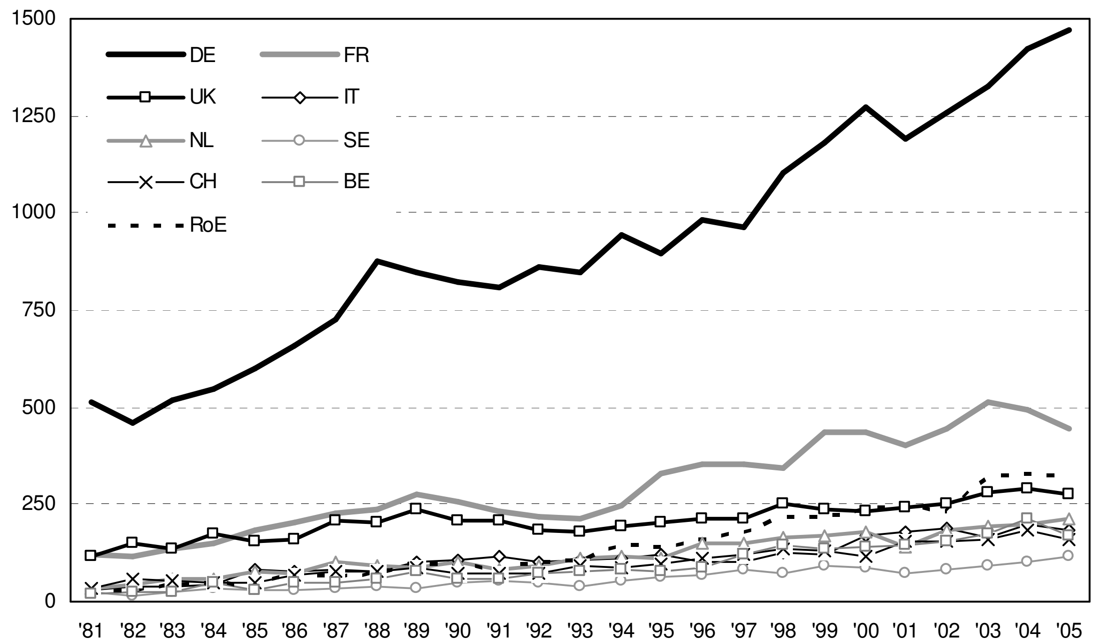

*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

### *Patenting at the country level in Europe*

In order to better assess the potentials and strengths of advanced material patenting in Europe, we analyse the development of patenting over time and by subfield for individual European countries. For this purpose, patents are assigned to countries by the location of the inventors, applying fractional counting in case a patent is applied by inventors from different countries. We only look at EPO/PCT patents.

Within Europe, Germany is by far the largest producer of advanced materials patents, followed by France and the UK (Figure 7-9). Inventors from Germany account for 45 percent of all advanced materials patents applied in the years 2000 to 2005 at EPO or through PCT. French inventors contribute by 14 percent, UK inventors by 10 percent and Dutch inventors by 6 percent. Italy, Switzerland and Belgium each account for 5 percent of total European advanced materials patenting.

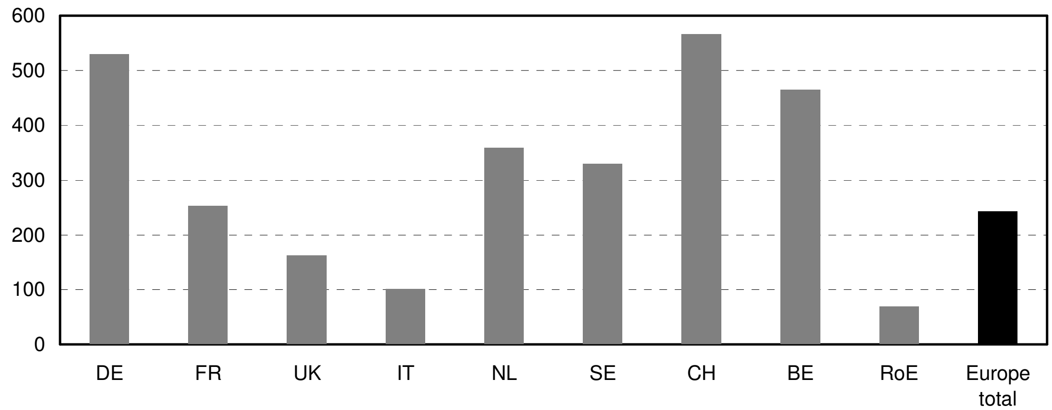
**Figure 7-9: Advanced materials patents (EPO/PCT) in Europe 1981-2005, by country of inventor**




*Source: EPO: Patstat, ZEW calculations.*

The economic significance of advanced materials patenting differs substantially by country (Figure 3-10). Patent intensity -that is the ratio of the number of advanced materials patents to GDP- is highest in Switzerland, Germany and Belgium. The Netherlands and Sweden also report intensities above the European average. France produces as many advanced materials patents per GDP as Europe in total does. Patent intensities are clearly below the European average in the UK, Italy and the group of countries not belonging to the eight largest patent producers in advanced materials in Europe.

**Figure 7-10: Patent intensity in advanced materials 1991-2005 of European countries (EPO/PCT patents)**




*Patent intensity: number of EPO/PCT patents applied between 1991 and 2005 per trillion GDP at constant PPP-$ in the same period.*

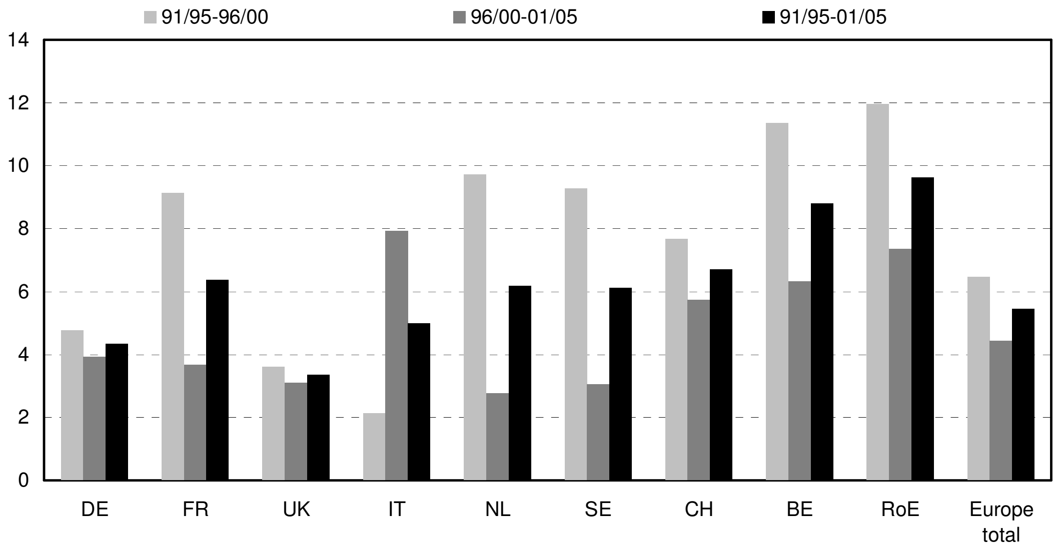
*Eight European countries with the largest number of advanced materials patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The differences in the absolute number of advanced materials patents and in patent intensities have to be kept in mind when looking at patenting dynamics since countries with low patent activities can more easily generate high growth rates. Among the eight countries that produce the largest number of advanced materials patents, Belgium could increase its patent output between first half of the 1990s (1991-95) and the first half of the 2000s (2001-05) at the highest pace (average annual growth of almost 9 percent) which is only exceeded by the "rest of Europe" group which caught up in advanced materials patenting over the past 15 years by increasing patent output at an annual rate of almost 10 percent (Figure 3-11). Growth rates above the European average are reported for France, Switzerland, the Netherlands and Sweden while Germany and Italy increased patent output at more modest rates. The UK is the country among the eight largest advanced materials patents producers with the lowest growth rate (3.5 percent).

In most countries, growth rates were higher during the 1990s (1991/95 to 1996/00) than in the previous period (1996/00to 2001/05). Italy does not follow this pattern as it could achieve a remarkable high growth in the early 2000s. Germany and the UK report similar, though rather low, growth rates in both periods. Advanced materials patenting slowed down in the early 2000s (compared to the 1990s) particularly strongly in the Netherlands, Sweden and France.

**Figure 7-11: Change in the number of advanced materials patents between 1991/95 to 1996/00 and 1996/00 to 2001/05, by country (EPO/PCT patents; compound annual growth rate in percent)**

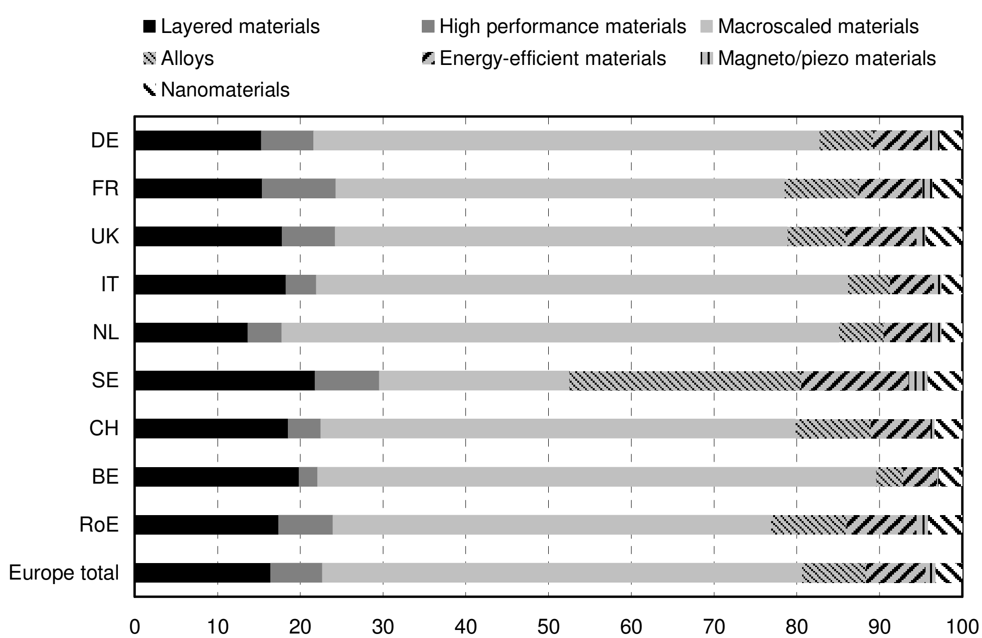



*Eight European countries with the largest number of advanced materials patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The composition of advanced materials patents by subfields does not differ significantly among the eight largest European countries in terms of patent output in this KET (Figure 7-12). The only country with a very specific pattern is Sweden. It has a strong focus on alloys (reflecting Sweden's economic specialisation on metals production) and a comparably low share for macroscaled materials (which mirrors the low importance of the chemical industry in this country).

**Figure 7-12: Composition of advanced materials patents in Europe, by subfield and country (percent)**

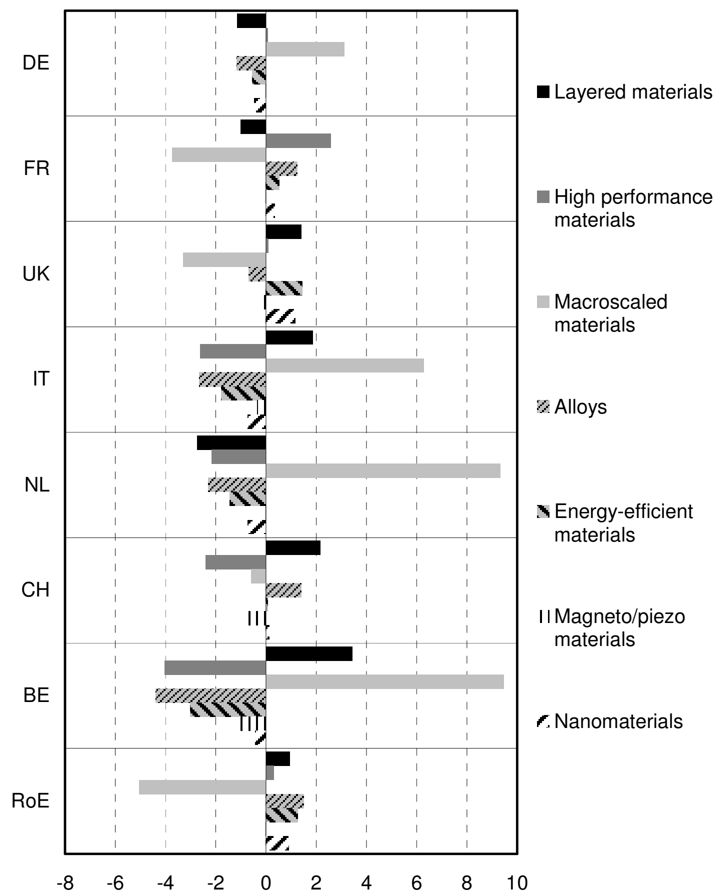


*Eight European countries with the largest number of advanced materials patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Figure 7-13 provides a more detailed picture of country-specific specialisation by subfield within advanced materials. Belgium, the Netherlands, Italy and Germany show particularly high shares in macroscaled materials. Belgium, Switzerland, Italy and the UK are comparatively focused on layered materials. The UK and the "rest of Europe" report somewhat higher shares for nanomaterials compared to the European average. France is specialised on high-performance materials and alloys. Alloys are also a relative strength of Switzerland and the rest of Europe. Energy-efficient materials have a higher share in the advanced materials patent portfolio of France, the UK and the rest of Europe.

**Figure 7-13: Specialisation patterns of advanced materials patenting in Europe, by subfield and country (percent)**




*Difference between the share of a subfield in a country's total advanced materials patents and the respective share for Europe total (excluding the country under consideration).*

*Eight European countries with the largest number of advanced materials patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

European countries show different trends in advanced materials patenting by subfield (Table 7-1). When comparing the growth in the number of patents applied by subfield for the 1990s (i.e. between the number of patents over the 1991-95 and the 1996-2000 periods) and the early 2000s (i.e. between 1996-00 and 2001-05), one can see a strong increase in the field of nanomaterials and layered materials. In both subfields, growth rates were higher in the more recent period. The same is true for high performance materials which show a decline in patent output during the 1990s followed by a sharp increase in the early 2000s. In the four other subfields, patenting dynamics were low in the early 2000s but high in the 1990s.

**Table 7-1: Change in the number of advanced materials patents between 1991/95 to 1996/00 and 1996/00 to 2001/05 by subfield and country (EPO/PCT patents, compound annual growth rate in percent)**

| | DE | | FR | | UK | | IT | | NL | | SE | | CH | | BE | | RoE | | Europe total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Layered materials | 8 | 12 | 7 | 14 | 9 | 10 | 8 | 13 | 17 | 12 | 4 | 15 | 4 | 20 | 16 | 15 | 18 | 14 | 9 | 13 |
| High performance mat. | -3 | 8 | -8 | 14 | -5 | 9 | 0 | 24 | 7 | 3 | -1 | 6 | -8 | 11 | -4 | 13 | 6 | 12 | -3 | 10 |
| Macroscaled materials | 4 | 1 | 12 | 1 | 3 | -1 | 0 | 6 | 9 | -1 | 10 | 2 | 7 | 1 | 10 | 5 | 10 | 3 | 6 | 2 |
| Alloys | 13 | 3 | 8 | 1 | 7 | -4 | 16 | 0 | 13 | 7 | 13 | -1 | 9 | 12 | 16 | 2 | 14 | 10 | 11 | 3 |
| Energy-efficient mater. | 0 | 3 | 4 | 7 | 4 | -5 | 15 | -4 | 14 | 6 | 21 | -10 | 19 | 1 | 19 | 3 | 15 | 1 | 7 | 1 |
| Magneto/piezo mater. | 10 | -3 | 13 | -4 | 17 | -3 | 28 | -11 | -9 | 17 | -9 | 28 | 18 | -3 | ∞ | -13 | -22 | 43 | 8 | 1 |
| Nanomaterials | 8 | 28 | 18 | 25 | 10 | 31 | 7 | 33 | 31 | 37 | 9 | 25 | 49 | 21 | 35 | 27 | 39 | 29 | 15 | 28 |
| Advanced materials tot. | 5 | 4 | 9 | 4 | 4 | 3 | 2 | 8 | 10 | 3 | 9 | 3 | 8 | 6 | 11 | 6 | 12 | 7 | 6 | 4 |

*a: compound annual growth rate of patent applications between 1991/95 to 1996/00*
*b: compound annual growth rate of patent applications between 1996/00 to 2001/05*
*"∞": not available due to zero value in base period.*

*Eight European countries with the largest number of advanced materials patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Most countries show by and large the same pattern. The Netherlands and Belgium deviate from this pattern insofar patenting in layered materials and nanomaterials already increased very strongly during the 1990s. Switzerland shows a strong performance in alloys patenting in the early 2000s and Sweden was able to increase its output in the small field of magneto/piezo materials at a tremendously high rate. France reports the highest growth rate in energy-efficient materials patenting in the early 2000s and Italy increased its patent output in macroscaled materials at a very high rate in the same period.

### 7.2.2. Links to Sectors and other Fields of Technologies

#### *Technological links to sectors*

When linking advanced materials patents to industrial sectors based on the IPC classes a patent was assigned to by Schmoch et al. (2003), we find that technological advance in materials is most relevant for the chemical industry (with a share of 35 percent in all advanced material patents), followed by the glass, ceramics and concrete industry (14 percent), the metals industry (10 percent), the electronics industry (9 percent) and the mechanical engineering industry (9 percent) (Table 7-2). Direct technological links to the manufacture of instruments and vehicles are rather low.

**Table 7-2: Technological sector affiliation of advanced materials patents (EPO/PCT), by region (average of 1981-2007 applications, percent)**

| | Europe | North America | East Asia | **Advanced materials total** |
|---|---|---|---|---|
| Food | 0 | 0 | 0 | **0** |
| Textiles | 2 | 2 | 1 | **2** |
| Wood/Paper | 3 | 3 | 2 | **3** |
| Chemicals | 38 | 37 | 30 | **35** |
| Pharmaceuticals | 5 | 4 | 2 | **4** |
| Rubber/Plastics | 6 | 5 | 5 | **6** |
| Glass/Ceramics/Concrete | 14 | 15 | 14 | **14** |
| Metals | 10 | 9 | 13 | **10** |
| Machinery | 9 | 9 | 9 | **9** |
| Electronics | 6 | 7 | 16 | **9** |
| Instruments | 5 | 6 | 6 | **6** |
| Vehicles | 2 | 1 | 2 | **2** |
| Total | 100 | 100 | 100 | **100** |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

The sector pattern does not differ to a great extent between the three main regions. Europe shows a somewhat higher share for chemicals while the share of European patents that are technologically relevant to the electronics industry is lower. In East Asia a reverse pattern can be observed. 16 percent of all advanced materials patents are technologically linked to the electronics industry and just 30 percent to the chemical industry.

Differentiating by subfields shows the close technological link between macroscaled materials -which is by far the largest subfield in this KET- to the chemical industry (Table 7-3). Patents in the field of alloys are primarily linked to the metals industry, and magneto/piezo materials most often related to electronics. Technological links of high-performance materials and energy-efficient materials are more evenly distributed to different sectors, as is the case of nanomaterials.

**Table 7-3: Technological sector affiliation of advanced materials patents (EPO/PCT), by subfield (average of 1981-2007 applications, percent)**

| | Layered materials | High perform. materials | Macro-scaled materials | Alloys | Energy-efficient materials | Magneto/ piezo materials | Nano-materials | **Total** |
|---|---|---|---|---|---|---|---|---|
| Food | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Textiles | 3 | 1 | 2 | 0 | 2 | 0 | 1 | **2** |
| Wood/Paper | 3 | 0 | 2 | 1 | 13 | 0 | 1 | **3** |
| Chemicals | 17 | 18 | **53** | 5 | **23** | 11 | **37** | **35** |
| Pharma | 1 | 1 | 5 | 1 | 1 | 1 | 7 | **4** |

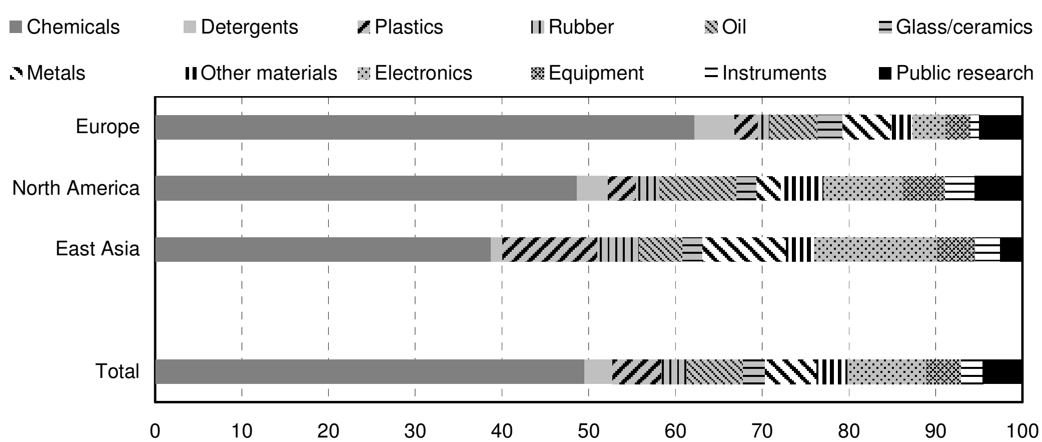
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rubber/Plastics | 10 | 2 | 7 | 1 | 2 | 1 | 1 | **6** |
| Glass/Ceramics | **35** | **34** | 7 | 6 | 10 | 5 | 7 | **14** |
| Metals | 5 | 14 | 3 | **54** | **23** | 24 | 12 | **10** |
| Machinery | 11 | 11 | 6 | 17 | 7 | 7 | 10 | **9** |
| Electronics | 7 | 14 | 6 | 11 | 16 | **45** | 14 | **9** |
| Instruments | 5 | 3 | 7 | 2 | 2 | 3 | 10 | **6** |
| Vehicles | 3 | 2 | 1 | 4 | 0 | 2 | 0 | **2** |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | **100** |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

### *Sector affiliation of applicants*

The sector affiliation of the applicants of advance materials patents the mainly confirms the findings shown above. The largest advanced materials patent producing sector is the chemical industry, having a share of almost 50 percent (Figure 7-14). This result holds for all three regions, though the dominance of this sector is highest in Europe (62 percent) and lowest in East Asia (39 percent). Other important sector sources for advanced materials patenting are the oil industry (particularly in North America), the rubber & plastics industry (particularly in East Asia), the metals industry (Europe and East Asia) and the electronics industry (East Asia). Public research is of little relevance, the highest share is found for North America (6 percent) followed by Europe (5 percent).

**Figure 7-14: Sector affiliation of applicants of advanced materials patents (EPO/PCT), by region (average of 1981-2007 applications, percent)**

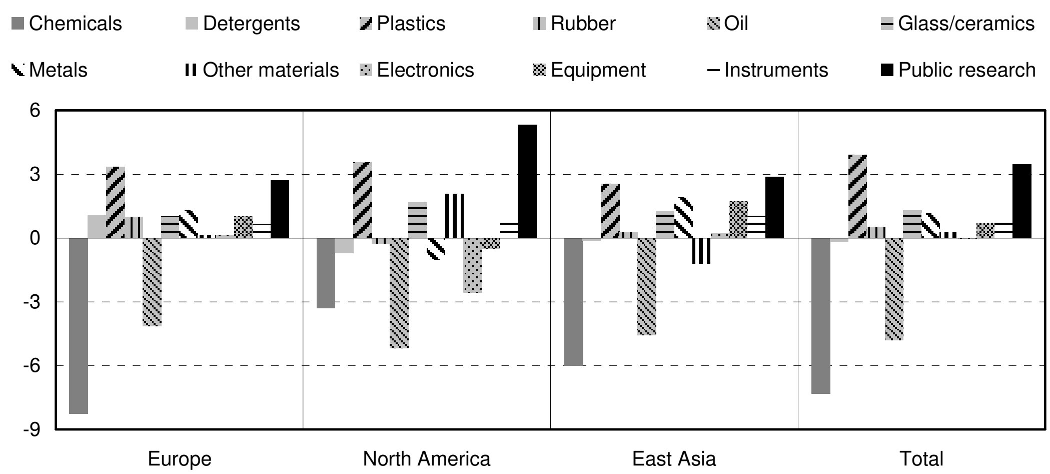



*Note: Patents have been assigned to sectors based on the sector affiliation of the most important patent applicants, who account for 80.2 percent of all advanced materials patents (EPO/PCT) applied from 1981 to 2007.*
*"Public research" includes patents applied by government authorities and by private actors (the number of the latter being of negligible size).*

Source: EPO: Patstat. ZEW calculations.

Comparing the sector affiliation of advanced materials patent applications before and after the end of 1997 - which splits the total sample of advanced materials patents in two subsamples of similar size - reveals a shift of advanced materials patenting away from chemicals and the oil industry (Figure 7-15). This trend holds for all three regions. In North America, the electronics and metals industries also lost in importance, and in East Asia, the group of other materials (e.g. textiles, wood, paper) show a decreasing share in total advance materials patenting.

**Figure 7-15: Change in the sector affiliation of applicants of advanced materials patents before and after the end of 1997 (EPO/PCT), by region (percentage points)**




Source: EPO: Patstat. ZEW calculations.

The plastics industry and public research are the sectors that could substantially increase their shares in total advance materials patenting. All three regions report growing shares for these two sectors by about 3 to 4 percentage points. In North America, patenting by public research could raise its share by more than 5 percentage points. Other sectors that have gained importance in advanced materials patenting are the glass, ceramics and concrete industry, the rubber and the metals industry (both except for North America) and the instruments industry. In Europe, the equipment industry (machinery, vehicles, defence) and the manufacturer of detergents were able to raise their share in total advanced manufacturing patenting, too. North America reports a shift towards other materials (particularly textiles and paper), and East Asia reports increasing shares for manufacturer of machinery and vehicles.

Breaking down the sector affiliation of advanced materials patents by the sector of the applicant (Table 7-4), some important differences to the technological links between advanced material patents and sectors (see Table 7-3 above). The chemical industry is the most important source of patents in the field of layered materials, though the majority of these patents are technologically related to the glass and ceramics industry. Similarly, most patents in the field of energy-efficient materials have been applied by enterprises from the chemical industry while technologically these patents are related to a substantial part to the metals industry. Patents in high-performance materials are primarily applied by the electronics and chemical industry while from a technological point of view they are primarily related to the glass and ceramics industry.

**Table 7-4: Sector affiliation of applicants of advanced materials patents (EPO/PCT), by subfield (average of 1981-2007 applications, percent)**

| | Layered materials | High performance materials | Macro-scaled materials | Alloys | Energy-efficient materials | Magneto/piezo materials | Nano-materials |
|---|---|---|---|---|---|---|---|
| Chemicals | **44** | 25 | **59** | 12 | **49** | 19 | 29 |
| Detergents/cosmetics | 2 | 0 | 4 | 0 | 4 | 1 | 1 |
| Plastics | 7 | 2 | 7 | 1 | 3 | 1 | 2 |
| Rubber | 2 | 0 | 4 | 0 | 1 | 1 | 1 |
| Oil | 5 | 2 | 8 | 1 | 5 | 1 | 1 |
| Glass/ceramics | 7 | 7 | 1 | 1 | 1 | 1 | 2 |
| Metals | 6 | 11 | 1 | **46** | 3 | **32** | 2 |
| Other materials | 7 | 1 | 3 | 1 | 7 | 2 | 2 |
| Electronics | 8 | **29** | 5 | 18 | 19 | 23 | 19 |
| Equipment | 6 | 12 | 2 | 13 | 5 | 9 | 4 |
| Instruments | 3 | 2 | 2 | 2 | 1 | 3 | 6 |
| Public research | 3 | 10 | 3 | 6 | 2 | 8 | **31** |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

Public research is the single most important sector for patenting in nanomaterials (31 percent of all nanomaterials patents originated from public research institutions, including government agencies), followed by the chemical and the electronics industry. Public research is also a relevant source for patenting in high-performance materials (10 percent) and in magneto/piezo materials (8 percent) whil it is of little significance in layered materials, macro-scaled materials and energy-efficient materials.

The list of the 25 largest advanced materials applicants (in terms of the number of EPO/PCT patents applied since 2000) is given in Table 7-5 for information purposes. One should note that patents by subsidiaries are assigned to the parent company. Patents applied by firms that later have be acquired by other companies are assigned to the latter. For patent applications by more than one applicant, fractional accounting applies.

In all three regions, large chemical companies rank first. The world's largest applicant of advanced materials patents in 2000-2007 is BASF (Germany, excluding patents by Ciba which has been acquired in 2009), followed by Du Pont, Dow and 3M (all USA). Important applicants from outside the chemical industry are coming from the electronics industry, the glass industry, the oil industry, the manufacture of detergents and cosmetics, the metals industry, the rubber and plastics industry, the paper industry, the textiles industry and the manufacture of machinery.

**Table 7-5: 25 main patent applicants in advanced materials by region (EPO/PCT patents, 2000 to 2007 applications)**

| Europe | | | | | North America | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | Name | Country | Sector | # pat. | Rank | Name | Country | Sector | # pat. |
| 1 | BASF | DE | chemicals | 1410 | 1 | Du Pont | US | chemicals | 1303 |
| 2 | Evonik Degussa | DE | chemicals | 885 | 2 | Dow | US | chemicals | 1170 |
| 3 | Arkema | FR | chemicals | 796 | 3 | 3M | US | chemicals | 1101 |
| 4 | Bayer | DE | chemicals | 646 | 4 | General Electric | US | electronics | 588 |
| 5 | Sabic Innov. Plastics | NL | plastics | 467 | 5 | ExxonMobil | US | oil | 548 |
| 6 | Clariant | CH | chemicals | 346 | 6 | Rohm and Haas | US | chemicals | 365 |
| 7 | Wacker | DE | chemicals | 325 | 7 | Kimberly-Clark | US | paper | 306 |
| 8 | Borealis | DK | chemicals | 314 | 8 | Procter & Gamble | US | deterg./cosm. | 249 |
| 9 | Lanxess | DE | chemicals | 310 | 9 | Corning | US | glass | 234 |
| 10 | L'Oreal | FR | deterg./cosm. | 304 | 10 | Eastman Kodak | US | instruments | 233 |
| 11 | Saint-Gobain | FR | glass | 302 | 11 | Honeywell | US | machinery | 227 |
| 12 | Henkel | DE | deterg./cosm. | 301 | 12 | Alcan | CA | metals | 223 |
| 13 | Solvay | BE | chemicals | 261 | 13 | PPG | US | chemicals | 220 |
| 14 | Siemens | DE | electronics | 245 | 14 | Goodyear | US | rubber | 210 |
| 15 | Basell Polyolefine | DE | chemicals | 223 | 15 | Eastman Chemical | US | chemicals | 198 |
| 16 | Ciba* | CH | chemicals | 221 | 16 | National Starch | US | chemicals | 186 |
| 17 | Beiersdorf | DE | chemicals | 217 | 17 | ConocoPhillips | US | oil | 171 |
| 18 | DSM | NL | chemicals | 215 | 18 | Ashland | US | chemicals | 163 |
| 19 | Total-Elf | FR | oil | 178 | 19 | Cytec | US | chemicals | 154 |
| 20 | CNRS | FR | research | 176 | 20 | Univ. of California | US | research | 154 |
| 21 | Celanese | DE | chemicals | 167 | 21 | Milliken | US | textiles | 136 |
| 22 | Sandvik | SE | metals | 146 | 22 | United Technologies | US | machinery | 131 |
| 23 | Merck | DE | chemicals | 134 | 23 | Equistar Chemicals | US | chemicals | 128 |
| 24 | Comm. à l'energie atom. | FR | government | 129 | 24 | Hewlett-Packard | US | electronics | 112 |
| 25 | Michelin | FR | rubber | 123 | 25 | Air Products | US | chemicals | 107 |

| East Asia | | | | |
|---|---|---|---|---|
| Rank | Name | Country | Sector | # pat. |
| 1 | Fujifilm | JP | chemicals | 602 |
| 2 | Mitsubishi Chemicals | JP | chemicals | 508 |
| 3 | Sumitomo Chemical | JP | chemicals | 476 |
| 4 | Kaneka | JP | plastics | 467 |
| 5 | Mitsui Chemicals | JP | chemicals | 433 |
| 6 | Shin-Etsu Chemical | JP | chemicals | 412 |
| 7 | Nippon Steel | JP | metals | 398 |
| 8 | JSR | JP | plastics | 394 |
| 9 | Nitto Denko | JP | materials | 379 |
| 10 | Asahi Glass | JP | glass | 362 |
| 11 | Bridgestone | JP | rubber | 350 |
| 12 | Daikin | JP | chemicals | 334 |
| 13 | Idemitsu Kosan | JP | oil | 330 |
| 14 | Sumitomo Metal | JP | metals | 324 |
| 15 | LG Chemicals | KR | chemicals | 316 |
| 16 | Showa Denko | JP | chemicals | 306 |
| 17 | Toray Industries | JP | chemicals | 304 |
| 18 | Nippon Shokubai | JP | plastics | 276 |
| 19 | NGK Insulators | JP | electronics | 267 |
| 20 | Kuraray | JP | plastics | 263 |
| 21 | Matsushita Electric | JP | electronics | 262 |
| 22 | Kobe Steel | JP | metals | 242 |
| 23 | TDK | JP | electronics | 236 |
| 24 | Mitsubishi Polyester Film | JP | chemicals | 229 |
| 25 | Samsung | KR | electronics | 227 |

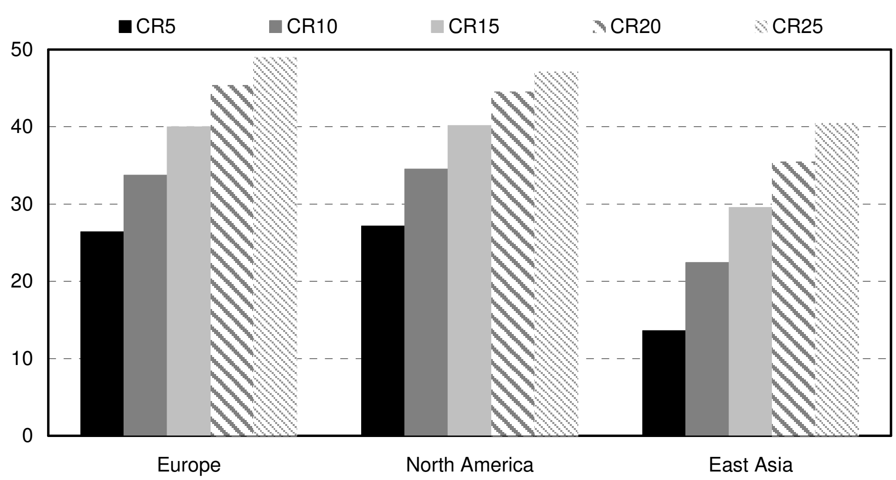
** Acquired by BASF in 2009.*

Source: EPO: Patstat. ZEW calculations.

Public research institutions and government authorities are rather rare among the top 25 patent applicants in advanced materials. In Europe, the CNRS and the Commissariat à l'Energie Atomique (both from France) are the only organisations from this sector that qualify for the top 25 patent applicants. The University of California is the only organisation from North America that is listed among the top 25 patent applicants in this region. In East Asia, no public research organisation is among the top 25. This result clearly deviates from that for most other KETs which show quite high shares of patents that originated from public research. The low share of public research for advanced manufacturing patenting indicates that technological advance in this KET is less driven by completely new scientific findings, and that industry has developed large in-house research capacities.

This result is not surprising since advanced materials are a KET with a very long history and several waves of technical progress (see the introductory section to this chapter). Each wave brought new technological opportunities that have been picked up by existing companies but which also gave room for new entrants. Over time, a manifold group of companies from different industries has emerged that conduct R&D on a significant scale. These companies constantly search for advance in materials technologies and have developed routines to search and adopt relevant findings from scientific research early. Nevertheless, the increasing share of public research organisations in advanced materials patenting that can be observed for the past ten years shows that a new wave of technological advance is about to emerge (particularly based on nanotechnology) that reinforces the role of public research.

**Figure 7-16: Concentration of applicants in advanced materials patenting (EPO/PCT patents) 1981-2007, by region (percent)**




*CR5 is the number of patents applied by the 5 largest patent applicants in the total number of patent applications. CR10, CR15, CR20 and CR25 are calculated accordingly.*

Source: EPO: Patstat. ZEW calculations.

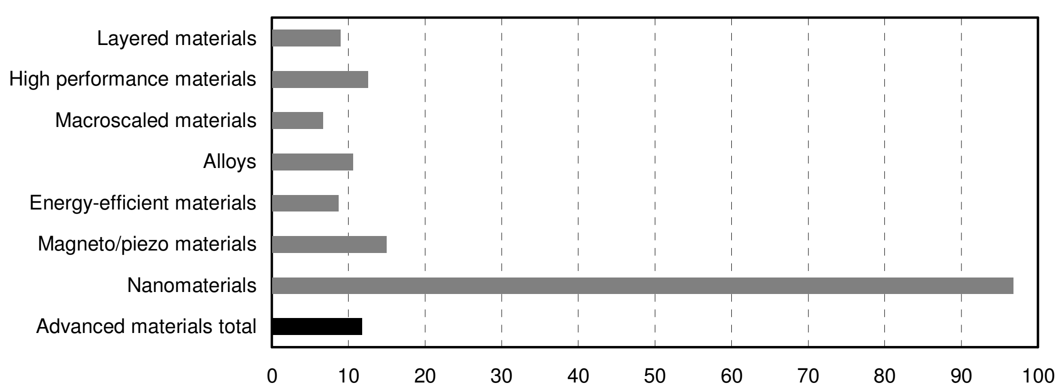
In Europe, the chemical industry is dominating the group of the largest advanced materials applicants particularly strongly (Figure 7-16). The dominance is reinforced if one considers manufacture of detergents, cosmetics, plastics, rubber and oil as technologically closely related to the manufacture of chemicals. Just 5 out of the 25 largest applicants of advanced materials patents are not associated with the chemical industry and its directly forward and backward linked industries. In North America and East Asia, companies from sectors not directly linked to chemicals are more often represented in the list of the top 25 patent applicants.

Advanced materials patenting in Europe and North America is strongly concentrated on a few industrial actors. In both regions, more than one quarter of all patents of the past 27 years has been applied by only 5 companies. In East Asia, concentration is less marked (14 percent of all patents come from the five largest applicants). In Europe, the 25 largest applicants are responsible for almost half of total patent output in advanced materials, compared to 47 percent in North America and 40 percent in East Asia.

### *Links to other KETs*

Related to the issue of sector links is the degree to which advanced materials patents are linked to other KETs. One way to assess likely direct technological relations is to determine the share of advanced materials patents that are also assigned to other KETs (because some IPC classes assigned to a advanced materials patent are classified under other KETs). The degree of overlap of advanced materials patents with other KET patents by subfields is rather low. Just 12 percent of all patents have been co-assigned to other KETs (Figure 7-19). Overlaps are extremely high for nanomaterials (which by and large corresponds to a subfield of nanotechnology) but are very low for macroscaled materials, energy-efficient materials and layered materials.

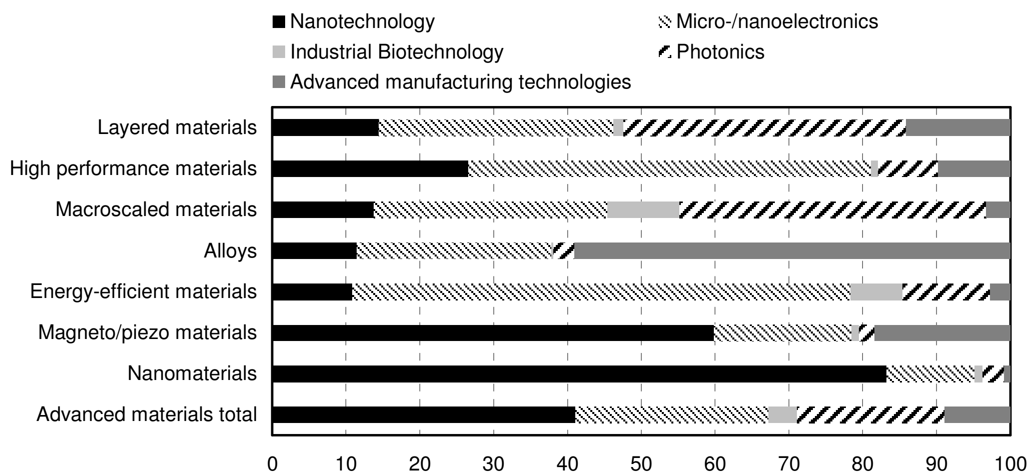
**Figure 7-17: Share of advanced materials patents linked to other KETs by subfield (EPO/PCT patents 1981-2007, percent)**




*Source: EPO: Patstat. ZEW calculations.*

For those advanced materials patents that are linked to other KETs, one can see that overlaps exist to most other KETs. About 40 percent of overlapping advanced materials patents have been co-assigned to nanotechnology (particularly nanomaterials, but also in magneto/piezo materials and high performance materials), about 25 percent are linked to microelectronics (energy-efficient materials, high performance materials is with the field of advanced materials (first of all particularly nanomaterials, nanostructures and nanobiotechnology) and about 20 percent relate to photonics (with high shares for layered materials and macroscaled materials) (Figure 7-18). Less than 10 percent of advanced materials patents with overlaps to other KETs relate to advanced manufacturing technologies (though 60 percent of co-assigned alloys patents are linked to this KET), and only a very few links exist with industrial biotechnology.

**Figure 7-18: Links of advanced materials patents to other KETs by subfields (EPO/PCT patents 1981-2007, only patents with links to other KETs, percent)**




*Source: EPO: Patstat. ZEW calculations.*

### 7.2.3. Market Potentials

Determining market potentials for advanced materials faces similar difficulties as for nanotechnology or industrial biotechnology. The main contribution of advanced materials to innovation and competitiveness is to allow manufacturers in various industries to improve their products and processes. The full economic impact of advanced materials does not occur with the producers of these materials, but in the downward industries where advanced materials are used to manufacture complex products in complex production processes. Evaluating the economic impact of advanced materials would thus require to determining the entire market volume of products based on advanced materials. This would imply, however, to assign a substantial fraction of total manufacturing output to this KET, which is likely to overestimate its real economic contribution since innovative complex products not only rest on advanced materials, but many other innovative inputs from other fields of technology.

Another challenge for determining market sizes of advanced materials is the large variety of different materials that constitute this KET. Market potentials of advanced materials relate to many different submarkets for individual materials (e.g. markets for various metals and alloys, polymers, rubber, ceramics, glass products) as well as for compounds or integrated materials (such as smart materials or layered materials). While many of these submarkets are not related to each other, there is nevertheless a substantial degree of substitution potential among individual advanced materials which makes it difficult to sum up market potentials of individual materials to a total market potential for advanced materials. What is more, advanced materials typically substitute standard materials (which also were advanced materials at the time of their market introduction, but since then have moved forward the product life cycle to maturity stage). Market growth for advanced materials therefore should not be interpreted as a net growth in output but rather indicates the speed at which standard materials are being substituted by new materials. This is in contrast to most of the other KETs analysed in this report for which market potentials can be regarded to a large extent as the potential for additional sales.

The global market for all industrial materials-chemicals, rubber and plastics, metals, glass, ceramics, concrete and other non-metallic materials, textiles, paper, wood and other biologic materials-is estimated to exceed $7 trillion in 2009.[81] Advanced materials constitute only a small fraction of this total volume. Depending on the exact definition of what constitutes an "advanced" material, their global market volume may be around $100 billion (see Moskowith, 2009: 57). When including the large group of advanced polymers, tailored macroscaled materials and new alloys, the global market volume may be about twice this amount. If one applies a more narrow definition of advanced materials that particularly focuses on the application of nanotechnology, market volumes are clearly smaller and do not exceed about $20 billion.

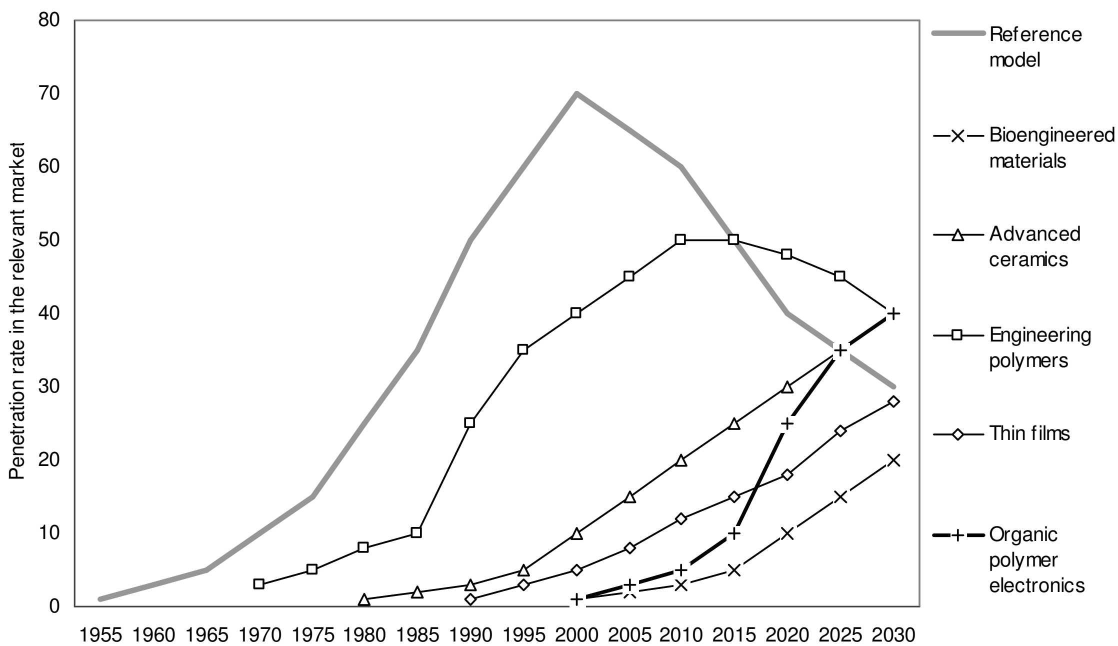
A recent study by Moskowitz (2009) estimates the global market volume for advance materials-following a definition that focuses on material innovation in the fields of biomaterials, alloys, ceramics, polymers and composites, coatings and nanotechnology-based materials-to be $103 billion in 2010. This figure does not take into account the economic crisis from 2008/09 and is therefore likely to be overrated. For 2020, Moskowitz expects a global market volume for these advanced materials of $177 billion, which corresponds to a compound annual nominal growth rate of 5.6 percent. This is somewhat more than the expected mid-term real growth of the world economy (between 4 and 5 percent) which is typically used as a reference for determining the growth of the total market for materials. The

[81] Note that this figure includes some double-counting since some materials such as polymers, fibres or additives are input for other materials such as rubber, plastics or textiles.

higher growth rate for advanced materials indicates that they tend to substitute older materials, though at a rather moderate pace.

One reason for the relatively slow expansion of market volumes in advanced materials are long periods needed for substituting established materials by new ones. In the economics of materials, newly introduced materials often reach their maximum penetration rate only after 40 to 50 years after market introduction (see Moskowitz, 2009). In the first 20 years, the penetration rate -that is the share of total sales in the relevant market- often does not exceed 10 or 15 percent. For most advanced materials that have first been introduced around 2000, including biomaterials, nanocarbon and nanofibers, their share in the relevant market is expected to remain below 10 percent until 2020. On exception is organic polymer electronics which could reach a market share for electronics materials of around 25 percent in 2025 (Figure 7-19).

**Figure 7-19: Expected penetration rates for selected advanced materials (percent)**




Source: adopted from Moskowitz (2009).

The speed of diffusion of new materials depends on several factors. One important determinant is the length of investment and product cycles in the industries that use advanced materials. Long investment and product cycles imply long amortisation periods. In order to avoid canibalisation, new investment and new products tend to be introduced only when past investment and old products have reached their maturity stage. Another determinant for the speed of diffusion is the need for specific investment and adaptation of production facilities in order to use new materials in production. If these are high, fixed costs of introducing new materials will be high and increase opportunity costs of introducing advanced materials.

Another major determinant is the price-cost advantage of new materials over established ones. Price-cost advantages are particularly high if new materials enable the introduction of completely new products or significantly improved production processes which either allow for higher product prices or significantly reduce unit costs. In case advanced materials represent rather incremental improvements in performance characteristics compared to established materials, these price-cost advantages are low and slow down diffusion.

Figure 7-19 shows that biopolymers and other bioengineered materials are expected to diffuse significantly slower than organic polymer electronics. Biomaterials are typically used in the chemical industry which is characterised by long product and investment cycles. Substituting traditional materials such as polymers based on crude oil by biomaterials demands new investment while offering little price-cost advantages. Consequently, diffusion of these advanced materials is expected to take significantly longer than for organic polymer electronics which are used in the electronics industry, an industry with short life cycles. What is more, organic polymer electronics promise significant increases in performance characteristics of electronic products and processes.

Table 7-6 provides a summary of current market size and projected market volumes for a larger number of submarkets in the field of advanced materials. These forecasts are based on analyses of market research institutions that were made between 2007 and 2010. While more recent forecasts already considered the effects of the economic crises in 2008/09, forecasts from 2007 and 2008 tend to be influenced by the very positive global economic climate that was prevalent until the mid of 2008. The table also lists main application areas for each submarket of advanced materials.

Medium-term growth rates for advanced materials range from 4 percent and less (which means a market growth below the average growth of the world market across all types of goods) up to 25 percent and more. Advanced materials with particularly high expected rates of growth are typically those with a very low market volume, while markets with moderate growth rates tend to represent huge market volumes. This indicates a typical pattern of innovation diffusion in advanced materials. New materials substitute existing ones which takes a long time due to high investment needed both by producers of materials and users.

**Table 7-6: Estimates and forecasts of the size of global markets for advanced materials**

| Submarket | Current market size | Reference year | Forecast | Reference year | Cagr* | Main application areas | Source |
|---|---|---|---|---|---|---|---|
| | billion US-$ | | billion US-$ | | percent | | |
| Biocompatible materials | | | | | 10 | health | DTI (2006) |
| Galliumnitrid wafer | 4 | 2006 | | | | semiconductors | WTC Munich (2007) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Biopolymers | 1 | 2007 | | | 25 | chemicals | UBA (2007) |
| Diamont films & coating | 0.53 | 2007 | 1 | 2012 | 14 | machinery, instruments | BCC (2007) |
| Activated carbon (tonnes) | .89 | 2007 | 1.2 | 2012 | 5.2 | environment | Freedonia (2008) |
| Nanomaterials | 1 | 2006 | 4.2 | 2011 | 33 | semiconductors | Freedonia (2007) |
| Nanomaterials | 1 | 2006 | 100 | 2025 | 27 | health, electronics, consumer, construction | Freedonia (2007) |
| Organic & printed electronics | 1.58 | 2008 | | | | semiconductors | IDTechEx (2008) |
| Engineering ceramics | 4 | 2006 | 5.8 | 2011 | 6.5 | machinery, automotive, environment | Materials Technology Publications (2007) |
| Powder metallurgy | 21 | 2006 | 30 | 2012 | 5 | machinery, instruments, automotive | Materials Technology Publications (2007) |
| Thin-film & organic photovoltaics | 0.84 | 2008 | 3.8 | 2015 | 24 | optical/solar | NanoMarkets (2008) |
| Photocatalysts | 0.8 | 2007 | 1.6 | 2014 | 10 | construction, consumer goods | BCC (2010) |
| Thick film devices, processes and applications | 0.027 | 2007 | 0.05 | 2014 | 9 | electronic devices, energy devices, display devices, mechanical/chemical devices | BCC (2010) |
| Aerogels | 0.05 | 2006 | 0.65 | 2013 | 44 | thermal and acoustic insulation applications | BCC (2009) |
| Smart glass | 0.85 | 2006 | 1.85 | 2013 | 12 | transportation, construction | BCC (2009) |
| Metal matrix composites | 4.1 | 2007 | 5.9 | 2013 | 6 | transportation, electronics/thermal management, aerospace, industrial, consumer goods | BCC (2009) |
| Advances structural carbon products: fibers, foams & composites | 1.7 | 2007 | 2.2 | 2013 | 4 | aerospace and defence, industrial applications, energy, sporting goods, automotive & other ground transportation, infrastructure | BCC (2009) |
| Metal and ceramic injection molding | 0.985 | 2009 | 1.9 | 2014 | 14 | powder metal injection molding, ceramic injection molding, Liquid metal molding | BCC (2008) |
| Metamaterials | 0.15 | 2007 | 1.65 | 2018 | 24 | electromagnetic, acoustical, extreme parameter | BCC (2008) |
| Superconductors | 1.4 | 2007 | 2.7 | 2013 | 12 | magnets, electrical equipment, electronics | BCC (2008) |
| Photonic crystals | 0.014 | 2007 | 0.666 | 2013 | 90 | ICT, light emission, energy delivery, energy conversion, sensing | BCC (2007) |
| Specialty fibers | 5 | 2006 | 9.2 | 2012 | 11 | aviation/aerospace, sporting goods, automotive, other industrial | BCC (2007) |
| Electronic chemicals and materials | 22.7 | 2005 | 34.8 | 2010 | 9 | wafers, CMP slurries, gases, polymers, photoresist chemicals, wet chemicals | BCC (2006 |
| Compound semiconductor materials | 14.44 | 2006 | 33.7 | 2012 | 15 | wireless electronic devices, optical data storage, fiber optics communi-cations, illumination, solar cells | BCC (2008) |
| Optical coatings | 5 | 2008 | 5.7 | 2015 | 2 | electronics, defence/security, architecture, solar, medical, telecom, transportation | BCC (2009) |
| Optical coatings | 4.3 | 2005 | 5.6 | 2012 | 4 | telecom, electronics, vehicles, medical, security, architecture | BCC (2006) |
| Total market for advanced materials | 102.7 | 2010 | 177.0 | 2020 | 6 | | Moskowitz (2009) |

** Compound annual growth rate in nominal terms.*
*Source: Compilation of ZEW based on the sources quoted, partially taken from Brand et al. (2009).*

One exemption from this pattern is nanomaterials which are believed to constitute a huge market of around $100 billion in 2025 (Freedonia, 2007). Whether an annual growth rate of almost 30 percent can be sustained over a 20-year period is rather doubtful, however.

The largest sub-market for advanced materials is currently related to electronics (particularly semiconductors) with a market volume of over $20 billion in 2005, which was expected to rise to about 35 billion in 2010. Another large market is optical coatings ($5 billion), powder metals (about $20 billion in 2006) and engineering ceramics ($4 billion in 2006).

The anticipated economic relevance of the advanced materials fields is based on the fact that they represent one of the most significant cost factors of medium and high tech industries. Advanced materials can be used in a wide range of manufacturing and service industries and its science and technology base is deeply related to the chemicals, nanotechnology and biotechnology fields. Materials is consider an area of great potential for enabling innovations in key industries such as energy, electronic and optical equipment (inc. ICT), industrial equipment, aeronautics and space, automotive, engineering, textiles, eco-industry, pulp and paper, agro-food, building, health care, military, and consumer goods (see Table 7-7).

**Table 7-7: Impact of advanced material technology on the ICT, energy and biotechnology sectors (percent of contribution)**

| | 1970 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| ICT | 15 | 25 | 40 | 55 | 65 | 75 | 85 |
| Energy | 10 | 15 | 30 | 45 | 55 | 65 | 70 |
| Biotechnology | 5 | 10 | 20 | 30 | 45 | 55 | 65 |

*Source: Moskowitz (2009: 75).*

An important role of advanced materials as KET is to contribute to reducing resource dependency as well as environmental impacts of production systems. A considerable potential is expected in the areas of energy (mid-term market volume of €19 billion, e.g. catalysts and batteries), environment (mid-term market volume of €12 billion, e.g. polymers and smart packaging), health (e.g. tissue engineering), transport (e.g. lightweight materials) and ICT (e.g. optical fibres and semiconductors) (EC, 2009). However, a recent report from the Europe Innova Sectoral Innovation watch has alerted that advanced materials are an area where Europe has under-invested (in terms of venture capital) compared to mainstream innovation areas (e.g. energy generation and infrastructure) (Europe Innova, 2010).

## 7.3 Success Factors, Barriers and Challenges: Cluster Analysis

Advanced materials clusters can be found all over the globe, but mainly in North America, Europe, Japan, Australia, and BRIC countries. In North America, four US large clusters of advanced materials are worth mentioning: the southwest region (Texas and Oklahoma), the upper New York State region (expanding to the Albany area), California (Silicon Valley and Northern California Nanotechnology initiative) and the mid-West (the nanobelt) (Moskowitz, 2009). It is difficult to provide a detailed account of clusters specifically pertained to the advanced materials sector. In Europe, strong clusters in new materials, for instance advanced polymers are in the Rhein-Main-Neckar region and Cologne region in Germany, the Rhône-Alpes rand Île de France in France, and Denmark.[82] To the previous list we may add recently developed clusters in advanced (chemicals) materials in Wallonia (Plastiwin), and the Polish Kujawsko-Pomorskie plastics cluster and the Slovenian Plasttechnics.

Other countries with advanced materials clusters are Canada (Quebec, Ontario) and China (e.g. Shangai, Wuhan, Changsha), Australia (Melbourne and Sydney), and India (New Delhi).

Although emerging clusters can be identified all over the globe, the cases from Wallonia and Changsha which were chosen for this study can offer an interesting illustration of newly created clusters where public policy intervention and industry self-organisation might be currently playing a distinctive role.

### 7.3.1. Advanced Materials Europe: Wallonia's Plastiwin cluster

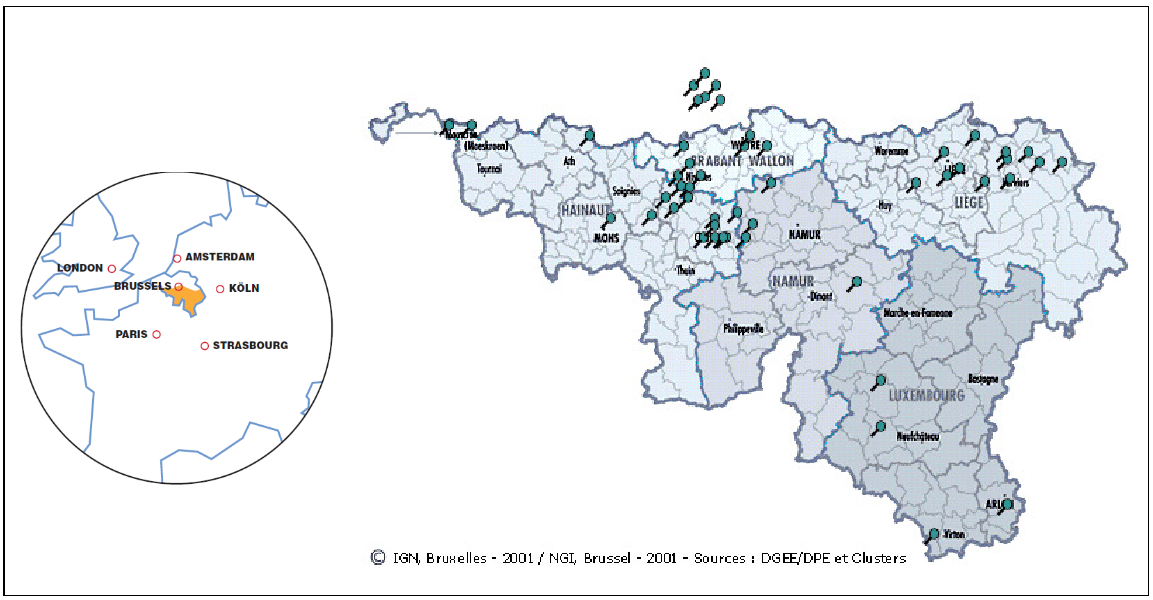
***Introduction***

The manufacturing industry in Wallonia represented 24 percent of the value added of the regional economy in 2006 (the rest corresponds to services) (Biatour et al., 2010). From there, the chemical industry represents a share of about 25 percent in relation to the whole industry in the region (ECRN, 2009b). The chemical industry in Wallonia, which forms the basis on which the new advanced materials clusters is developing, includes 200 companies, 60,000 jobs of which 25,000 direct jobs and a turnover of €10.9 bn. Its export rate is estimated to be around 75 percent (including life sciences). This traditional sector is the second largest industrial employer and an important driver of economic growth in the region (ECRN, 2010).

[82] We only consider those clusters in Europe with high focus and innovativeness level that correspond to both listings: chemicals and plastics clusters. However, this approach has shortcomings when aiming to identify other types of advanced materials clusters, as e.g. the Chestershire-Manchester-Liverpool region in the UK has a considerable specialisation in chemicals and composite materials, which in the ECO data is listed 4th in the chemical clusters category with high level of innovativeness. Another case is the cluster located in the Zuid-Nederland region (Maastricht-Aachen-Liege) which level of innovativeness is not reported, but a number of highly innovative (well established and spin-off) firms in the Chemelot Industrial Park are developing and producing a number of new advanced polymers (e.g. elastomers, coatings, etc), biomaterials and composites.

The Plastiwin initiative aim is to stimulate innovation in the Wallonia region. The number of actors in the cluster is relatively small, and its geography is spread across all the five Walloon provinces with an extended coverage to the Brussels region (see figure below).[83] The regions of Hainaut and Liege account for 70 percent of the activities in the chemical sector and are the provinces with the highest concentration of actors. It is estimated that Plastiwin represents mainly SME's (as 80 percent of Walloon companies account for less than 50 workers), employs around 10,000 people (40 percent of employment of the Walloon chemical industry), and has a common turnover of €5.6 billion(2006) (ECRN, 2009a; Verhoyen and Phillipe, 2009).

**Figure 7-20: Geographical distribution of the Plastiwin Cluster**




*Source: modified from Gouvernement Région wallonne (2008) and Clusters Wallonia*[84]

This cluster brings together three types of chemical-related manufacturers along the plastics value chain (raw materials, casting, engineering, tools manufacturing, R&D, primary and secondary processing), research centres, training centres and industrial associations. Firms in the cluster are active in the fields of: packaging, construction, automotive and transport, compounds and mixes of materials, electrics and electronics, furniture and comfort, technical items, medical and hygiene, household items, office items, agriculture and horticulture, toys and recycling.[85] There are 50 core players, engaging in manufacturing, processing, services, engineering, design, retailing and recycling. In addition, a handful of companies and industry

[83] In a strict sense, Plastiwin would not constitute a geographical cluster (according to Porter). As it is distributed all over the Walloon region but localised in two main areas, these would resemble more an industrial district (according to Marshall). Nonetheless, as the Regional Government has an official policy of industrial development based on clusters and due to the fact that Plastiwin's origins came from intra firm arrangements, we consider this as a suitable case study of clusters of new creation.

[84] http://clusters.wallonie.be/plastiwin/fr/partenaires/index.html

[85] http://clusters.wallonie.be/plastiwin/en/the-cluster/plastiwin-in-two-words/index.html

associations from the Brussels region are also members. Part of the knowledge base is provided by a number of training and research centres.

***Short history of the Plastiwin cluster***

The second industrial revolution (in chemicals) began 1861 in Belgium (Couillet, Wallonia) with the Solvay process for soda ash production, and in 1906, the first composite material of modern history (Bakelite) was there invented and produced. Under the lead of Solvay, the Walloon chemical industry started to diversify and moved to the manufacturing of plastics in the early 1950s. This tendency continued due to the cyclical nature of the chemical and petrochemical industry and the oil crises, and in the early 2000s the development and production of high value speciality polymers (advanced polymers) started. This was the start of the now evolving advanced materials cluster.

The Plastiwin cluster was formally started in 2007 as part of the cluster initiative supported under the Walloon Marshall Plan, with the aim to stimulate innovation. The cluster was then formalised by the Walloon Government's cluster programme in 2008. Hence, whereas the cluster develops upon the foundation of an old developed industry, and strong industry relationships in the area, the cluster itself is emerging out of these 'old structures'. We therefore categorise the cluster as emerging and regeneration at the same time.

***System failures and system drivers for growth***

*Infrastructure*

As is the case in all clusters so far, there is a very strong and well developed knowledge infrastructure in the area. The Walloon region has 9 universities and 13 higher education colleges with courses related to applied sciences. These knowledge institutes have developed relationships with the local industries over time, but will still have to adjust their research to the new developments.

Furthermore, The Walloon region has 220 business parks and 6 science parks. The infrastructure is managed by the economic development agencies. Of particular relevance is the SPoW (Science Parks of Wallonia), which is a network of Belgian science and technology parks which host companies that focus on high tech business-university relationships. These are managed by Universities and local development agencies.

There is also a network of business incubators or shared infrastructures located in Universities and/or Science Parks to facilitate start-up companies. In addition, 3 public training centres and 3 research centres contribute to the knowledge base of the cluster. These are specialised R&D centres related to material science, biotechnology, nanotechnology and polymers.

A special feature of this cluster is that there is also a physical infrastructure in place that warrants cost efficient access to a pipeline distribution network for basic raw materials (olefin, hydrogen, oxygen, nitrogen) and energy fluids (natural gas).

*Institutions*

*Rules and regulations:* As the advanced materials in the Plastiwin cluster are closely related to the chemicals industry, there are a lot of regulations to comply to with regards to hazardous materials and pollution. The REACH regulation (EC 1907/2006) is expected to have impact the innovative efforts of the cluster. A large number of examples can be found in a number of companies' website where statements are being made around the message that "REACH is an important driver for environmental responsibility in our company". As a result, they are actively sourcing alternative "greener" substances and materials. A smaller number of proactive firms are currently assuming an anticipatory position and are engaged into basic and applied R&D for developing advanced eco-materials. The European and Belgium patent Law and fiscal and tax incentives are also important factors hampering or enabling the innovative efforts of firms in advanced materials.

*Norms and values:* In terms of informal rules, values and norms, the long tradition of the Walloon region for chemicals manufacturing and a strong identity and values aligned to sustainability and local development may have created a sense of identity in people working in the industry. This is perhaps one of the reasons why the Walloon workforce is considered of high quality and performance. The education standards (widely recognised university qualifications) and (technical) training might be also contributing to create shared values and behavioural patters. It is estimated that the level of productivity of Wallonia workforce in the chemicals industry (hourly productivity levels) is ranked second at the global level), which can be translated into highly motivated managers and employees and successful mobility and training programmes.

*Public policy*

The Walloon government decided to address the critical situation of international competition and saturation of its old industrial structure by launching, in August 2005, an action plan aiming to reinvigorate the regional economy. The government presented its objectives in a document entitled 'Priority actions for the future of Wallonia' –subsequently called the new 'Marshall Plan Wallon' with a budget of €992,5 m (Gouvernement Région Wallonne, 2005a,b). This plan aims to boost investment in firms by: facilitating access to investment grants; reducing tax for firms; developing industrial research and partnerships between universities and firms; and developing and improving access to vocational training.[86]

As a result of the implementation of the new Walloon industrial policy, there is now a specific promotion of investment package for attracting new firms to the Plastiwin cluster. Among the measures for supporting this policy is the preferential access to risk funding (through SRIW and Sowalfin), a number of fiscal incentives (see next section), tax and social-security incentives (reduced social-security contributions, cash recruitment grants, training subsidies, etc.)[87], support for outstanding scientific research (linkages to Universities), facilitation (if entitled) to European subsidies, and a personalised and speedy following up from public agencies and regional authorities.[88] [89] [90]

*Funding*

The role of public funding has been vital for the development of the Walloon industry since the 1970s, when Belgium experienced the decline of its traditional industries. The Economic Reorientation Act of 1978 led to the creation of the regional development companies, entrusting them with a threefold mission: to finance developing companies, set up new companies, and carry out intervention operations in the industry. The Société Régionale d'Investissement de Wallonie[91], SRIW and Sowalfin[92] are the most prominent regional investment agencies. There is a wide variety of funding opportunities from the European, national and regional agencies aimed at technology development, basic research, and collaborative high tech ventures. In addition, there are a number of local investment companies and there are several sources of private funding, loans and seed capital specially aimed at SMEs.[93] There is a considerable presence of well established angel and venture investors and holding groups in the Walloon region. Walloon and Belgium venture capital firms are represented by the Belgian Venturing Association (BVA). Recent federal legislation introduced PRIVAK (Private Equity Investment Fund - Investment in non-traded companies), which encourages private investors to invest in non-traded venture capital, while benefiting from a tax-free status. Business angels provide start-ups with risk capital and coaching, and Be Angel is an investment structure which includes 25 business angels that help entrepreneurs to develop new businesses.[94]

---

[86] http://www.eurofound.europa.eu/eiro/2009/05/articles/be0905019i.htm
[87] http://www.investinwallonia.be/ofi-belgium/investir-en-wallonie/environnement-des-affaires/acces-aux-capitaux.php
[88] http://www.investinwallonia.be/ofi-belgium/10-reasons-invest-wallonia.php
[89] http://www.investinwallonia.be/ofi-belgium/investir-en-wallonie/opportunites-affaires/chimie-siderurgie-verre-textile.php
[90] http://www.investinwallonia.be/ofi-belgium/investir-en-wallonie/environnement-des-affaires/acces-aux-capitaux.php
[91] http://www.sriw.be/fr/Principes-generaux-9.html
[92] http://www.sowalfin.be/info.php
[93] http://www.investinwallonia.be/ofi-belgium/investir-en-wallonie/environnement-des-affaires/acces-aux-capitaux.php
[94] http://www.walloniatech.org/VentureCapital.html

Fiscal measures are also important for industry and cluster development, and incentives in the region of Walloon include:[95] contribution with up to 20 percent to the cost of setting up a business, lower tax and social cost, support for hiring and staff training and consultancy services, support with export plans, and promotion of renewable energy use and environment initiative. As noted above, the Wallonia government defined economic redevelopment areas (competitiveness hubs) which now receive special tax incentives for existing economic activities in those communities and any future activities such measures may attract. Current investment grants may be increased by 25 percent or even 40 percent for these areas. In addition to fiscal incentives, the Wallonia Government has taken a number of tax-related measures aiming to making Wallonia the least taxed region in both Europe and Belgium, through the suppression of tax on energy, exemption of real estate tax for a maximum of five years during the creation of a company, and exemption of real estate tax for seven years on material and equipment.

*Interactions*

In spite that it has been reported that cooperation between firms and universities in the Walloon innovation system is below the European and Belgium average (Biatour et al., 2010), and that recurrent cooperation problems do exist among Walloon chemical firms (Verhoyen and Phillipe, 2009) there are successful cases within the Plastiwin cluster that highlight the positive interaction between entrepreneurs, Universities, public agencies and private investors in the cluster. In 2002 for instance, Nanocyl was founded as a spin-off from the Universities of Namur and Liège with the support of private investors[96] The firm received seed funding and venture capital to prove the commercial viability of carbon nanotubes and nanopowders for flat screens applications (Eco-innovation Futures TNO, 2010). Nanocyl is one of the few highly innovative SMEs in the cluster.

The cluster platform, which is aimed at stimulating the development of technology, collaboration and international reputation of the cluster, has been formed with an administrator (coordinator) and a board of 8 members. Regular meetings are held, and topics discussed. As the platform is still young, we cannot say much about how it does in facilitating the interaction in the cluster.

*Capabilities*

Wallonia was the cradle of the European chemical industry; and a long story of accumulation of technological, organisational, management, and engineering capabilities which can be found in the regional chemical industry. However, The Walloon region still has only 1.5

[95] http://www.walloniatech.org/FinancialIncentive.html
[96] http://www.nanocyl.com/en/About-Us/History

percent employed people in R&D functions, which is below the Belgium and European (EU15) average (Biatour et al., 2010). Within the large chemical companies there will be a rich source of capabilities in all domains (technology, organisation, marketing). The challenge however lies in the transformation of these capabilities to serve the reorientation of the area towards advanced materials.

***Market failures and drivers for growth***

*Market structure*

The Plastiwin cluster has various large firms in the chemical-plastics-rubber-oil-health such as Solvay, Prayon, Total, Clariant, Nexans, Baxter, and BASF. A number of highly innovative SMEs are also part of the cluster. Some of the firms have in-house R&D facilities (both large and SMEs), nonetheless the number of medium and low innovative firms is rather high. A good feature of the cluster is that it includes, from the start, also complementary service providers and specialists such service providers and specialised recycling and engineering consultancy companies. Finally, a handful (rather small) training centres in plastics and chemistry support competences development of related firms. Hence, there is a good mix of large and small firms, and the cluster is open to a variety of complementary and divers actors

*Market demand*

The chemical sector in Wallonia – in which the Plastiwin cluster is embedded - is highly export-oriented (around 75 percent of exports rate. The chemical sector as a whole in Wallonia can be considered as successful in terms of revenues, confirming high market demand, but the share of advanced materials in this (advanced polymers, biomaterials, and composites) is unknown. There is a number of industries which are lead users of these products, but this is due to the position of the chemicals-plastics-rubber industry in the value chain. No clear role of government as a lead user (e.g. through public procurement), since most of the products of this sector are raw or intermediary materials..

***Conclusion***

The Plastiwin cluster is a young cluster that is emerging as a KET cluster from the strong foundations of the Walloon chemical industry. Here lies a chance, but owing to path dependency also a challenge as the regeneration of the cluster towards new technology applications might prove difficult.

The cluster has a promising combination of firms in the chemicals and plastics value chain, but the road to advanced materials still needs to be further developed. We see that whereas the large leading firms have high capabilities, most smaller firms have moderate innovation capabilities, and only a handful of firms are highly innovative embracing other areas of advanced materials (in particular biomaterials and advanced composites). An important step has been given to facilitate a closer interaction among private and public agents, trust building and sharing a common agenda.

*Public funding*: The role of the public intervention has been decisive, not only in terms of infrastructure, regulation and incentives, but also providing risk capital needed for entrepreneurship and business creation. As a result of the implementation of the new Walloon industrial policy, there is now a specific promotion of investment package for attracting new firms to the Plastiwin cluster. (European and regional) public funding has proven to be effective for the development of highly innovative firms (e.g. Nanocyl), but academic entrepreneurship should be promoted to a higher scale. The chemical-plastics industry traditionally spends a large share of in-house R&D paid with own funding, but the endevours required by the materials revolution require cooperation under a more open innovation model.

*Tax incentives*: The ambitions of the Walloon Government to become a tax-friendly region and the availability of (investment) support measures seems to be creating ideal conditions of tax-related measures aiming to making Wallonia the least taxed region in both Europe and Belgium, through the suppression of tax on energy, exemption of real estate tax for a maximum of five years during the creation of a company, and exemption of real estate tax for seven years on material and equipment.

*Public procurement and lead markets*: Although, like in most clusters we could not specify a particular role for public procurement or lead market, the cluster does get much of its competitive edge through the presence of large lead companies that can and will serve as lead customers (e.g. Solvay). That lead markets are difficult to identify is not surprising as the products sell internationally (75 percent) and almost always are intermediate products.

### 7.3.2. Technology cluster non-Europe: Changsha material cluster

***Introduction***

Changsha, capital of Hunan province, is located in south-central China. The origin of the Changsha cluster as a high-tech base was first developed since 1989 for the machinery sector, with further upgrades in the other related sectors, including advanced materials. Following the implementation of policies from the Central Government of China, the Ministries of Commerce, Industry and Information Technology and Science and Technology jointly announced in December 2007 their ambition to make Changsha the outsourcing services centre of China (KPMG, 2009). In order to encourage the development of the services sector, the Changsha regional government has set up an ad hoc number of outsourcing conglomerations and formulated preferential policies (e.g. financial policies or tax incentives) aiming to promote the development small and medium-sized high-tech companies. The target sectors are related to the creative industry, advanced materials, and university-industry parks (science parks). In addition, Changsha also hosts a number of clusters in the areas of industrial engineering and mechanics, automobile industry, household appliances, electronic and optical equipment, and bio-medicine. Of particular interests is the development of an advanced materials cluster, which has over passed the growth and expectations. The Changsha advanced materials cluster is geographically concentrated, and is mainly located in Changsha Economic & Technological development area and the Changsha new and hi-tech industrial park (see Figure 7-21).

**Figure 7-21: Geographical location of the Changsha Cluster**


*Source: KPMG (2009)*

Changsha saw the naissance of an industry oriented to the internal market in the early 1980s. The Changsha development zone was originally developed (in the early 1990s) as an important cluster for the machinery industry (Li and Ya-Qing. 2006). By mid 2000s the Changsha cluster was considered one of the most important economic and technological development areas, primarily based on the impact of the machinery and the electronic and ICT industries on regional and national industrial development.[97] Nonetheless, and given the quick development pace of the advanced materials industry, Changsha has recently seen a speedy increase of the latter industry which now constitutes its most competitive enabling industry. It is expected that the development the Changsha advanced materials cluster will strengthen the integration of industry, learning and research, at the time it uses and increases the innovation capacity of the Central South University and Hunan University.[98]

[97] http://www.fdi.gov.cn/pub/FDI_EN/StateDevelopmentZone/NewsUpdate/NewsUpdateContent/t20060404_70863.htm
[98] http://www.csinvest.gov.cn/jjcs_cssyscy_6.asp

***Short history of the Changsha Cluster***

The origin of the Luy Valley as a centre for high-tech industrial development of Chansha is dated way before the State Council officially included it as National Economic and Technology Development Zone.[99] A machinery cluster in Changsha burgeoned in early 1990s, when the industrial cluster was formed around the two industrial leaders: Zoomlion Heavy Industry Co., Ltd and Sany Heavy Industry.

Advanced material (and intelligent) manufacturing is one of the eight key areas for economic development for the Chinese government for the modernisation of their economy by 2050. By 2020 the goal is to get breakthrough developments in advanced materials, also contributing to energy saving, low pollution manufacturing, manufacturing technologies of giant and super-giant structural components, and e.g. composite materials. By around 2050 the accurate design and control and the related environmentally sound design of materials structure properties and service properties ought to be accomplished (Lu, 2010).

It is within this framework and within these goals that the Changsa cluster is developing, and its development is going fast. Up to mid 2000s, over 14 small and 6 medium and large engineering machinery manufacture firms were aggregated around Changsha. In 2007, the industrial output value of Changsha advanced materials industries represented 17.37 billion CYN (around €1.85 billion at current prices), representing an increase of 38.3 percent compared to the previous year. Among the main products of this cluster are power, fuel and solar energy batteries, continuous band-shaped nickel foam, cobalt oxide, new construction materials, etc. A number of firms in the Changsha materials cluster are now national and global leader in specific traditional and new advanced materials sectors

Following a low operational cost strategy, the Changsha ETDZ has seen the event of a particularly strong and continuous economic development in recent years. In 2008, the city's economy grew at an annual rate of 15.1 percent and had a GDP per capita of about $6,700. By the end of 2008, over 2,900 foreign firms had been established. including 26 firms in the Fortune 500 list (e.g. Mitsubishi, Cocacola, ArcelorMittal, Bosch and Hitachi) Changsha also ranked 10$^{th}$ most competitive city, according to the “Annual Report on Urban Competitiveness” published by the Beijing International Institute for Urban Development (KPMG, 2009). In 2007, the Changsha city government reported improvements in the regional innovation system, by actively promoting the transformation of science and technology achievements and industrialisation.

[99] It is important to note that what High Technology means for the Chinese government may differ from what most Western countries.

***System failures and system drivers for growth***

*Infrastructure*

The Changsha city government has set up a long practical strategic partnership with the region's universities and other scientific research institutes to effectively promote the technology breakthrough. The constructions of several platforms (information, technology, services and financing) have achieved remarkable results. The number of professional technology intermediary agents has increased as well as the number of science and technology business incubators (Liu, 2007).

Changsha is one of the key higher education and research bases in China. There are many new and well established universities. The universities are expected to function as anchor entities for cluster and regional (innovation) development. Changsha universities also promote entrepreneurship and new business development (through incubators), assist in technology transfer, and spin-off companies which are established in the university industrial parks. One example is the firm Boyun New Material Co as a spin-off firm for the manufacturing of high-performance composite material.[100]

Furthermore, there are 45 higher education institutions, 76 special training agencies, over 120 research institutions, 47 national and provincial key labs, 46 academies and 340,000 technological staff.[101] In terms of specialised equipment available to firms in the cluster, the two high-tech zones of Changsha account with about 44 highly specialised large-scale instruments/equipments that can be used by any firm established in the area upon payment of a fixed/negotiated fee. The list of equipment ranges from spectrophotometers and chromatographers to laser and plasma devices, often located at (one of) the University's facilities.

There is also a number of business development and business incubation centres (both public and private). Among these centres are the Changsha Technical Assessment and Demonstration Centre, their High-tech Business Incubation Service Centre (governed by the Changsha administration of Science and Technology and with more than 300 success cases which represented the creation of 27,000 jobs), the Business Incubation Service Centre of the Changsha High-tech Industrial Development Zone (specialised in supporting academic entrepreneurship of returning students, young PhDs and post-docs, with more than 100 SMEs created by around 250 young talents), the Hunan Xinjinrong Technical Incubator and the Oak Garden Enterprise Business Incubation Service. In addition, the cluster also has intermediary

[100] http://www.cshtz.gov.cn/webkey/index.do?templet=Eindustrystructure&id=3483
[101] http://www.csinvest.gov.cn/jjcs_fwwb.asp

organisations for (intangible) assets evaluations, auditing processes and a number of quality & productivity testing/inspection.

Changsha provides sound infrastructure and facilities to companies at comparatively low rates. The region and the city have a sizeable workforce (around 190,000 people enter the regional job market every year) and maintains cost advantages over other inland cities (KPMG, 2009).

*Public policy and funding*

*Public policy:* China's policy framework for industrial development, high tech zones and the support of specific technology areas is considered to be very supportive of the cluster (Ding, 2007). It has been suggested that the success of regional development model based on a combination of science and technology and industrial policies have had three major institutional drivers: the Central government provides infrastructure and resources needed for supporting innovation and business development (e.g. science parks, industrial parks, and incubators). Secondly, it has enabled foreign direct investment at the time it has promoted closer and more effective industrial and technological links with neighbouring countries for supporting technology transfer, capabilities and skills development and access to global markets. Thirdly, an explicit policy of industrial development through clusters (Sigurson, 2004). The local government in Chinese provinces and cities has been seen as the key enabler for the success of regional and local industrial development of modern China, as the operation of the funds and all the aspects for new business development are carried out at the local level, in close cooperation with entrepreneurs, regulators, cluster management, and financing bodies (Ding, 2007)

*Funding:* Both the Central and Local government have played a key role in the provision of public funding for cluster development. At the Central Government level, the Central Council dictates where money should be invested, and a number of plans and funds have been created. Privately-owned banks also respond to these ambitions by facilitating loans to those projects that the central Government favours.[102] The largest financial institutions, e.g. China development Bank, China construction bank, ICBC, and China Merchants Bank, have a leading role in providing financial support to those projects. Other entities of the financial system include the China Investment Corporation (CIC) and the China International Capital Corporation (whose seed capital was provided by Morgan Stanley back in 1995), the latter providing additional funding. The role of large Banks is particularly relevant, since around

[102] Albeit these Banks are not explicitly run by the Government, regulators often attend board meetings and senior management often includes a senior manager known as 'Head of discipline' who represents the Communist party (Economist, 2010).

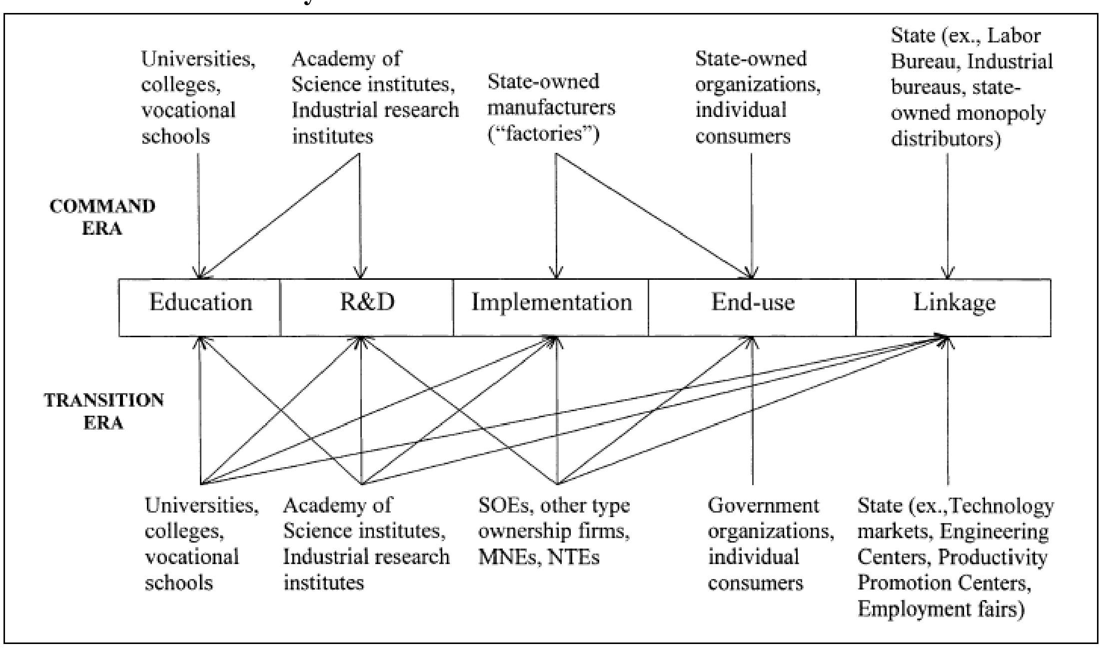
fourth fifths of the assets in the Chinese banking system is controlled by 17 institutions (from a total of 70 State-owned banking institutions) (EIU, 2010).

At the local and provincial level, the regional and local administration of the high tech and economic and technology development zones has set up funds of over 50 million Yuan for supporting new business development and restructuring of existing ones. Private equity capital is provided by firms and at the local level there are also Venture capital providers. Large leading machinery firms had no finance difficulties for its continuous development, also thanks to close links with the government supportive of the cluster's development. But as to the whole cluster, some other firms are short of capital because of inadequate finance channels (Li and Ya-Qing, 2006).

*Interactions*

Relationships in China are of a specific nature due to the many changes the country has gone through over the past hundred years from a centrally planned economy (until 1978), the reform period (1978-2000) and after that the opening of the economy (Liu and White, 2001). The differences in the type of interaction in the command era versus in the transition era are depicted in Figure 7-22.

**Figure 7-22: Interactions within the different actors in the Chinese national and regional innovation system**




*Source: Liu and White (2001)*

Following the experience of leading examples of high-tech cluster development in the USA, Chinese universities and research institutes have been encouraged to play a leading role for scientific and technological development linked to economic development through collaborative relationships between industry and science (Chen and Kenney, 2007). Interactions between well trained graduates, returning graduates (from abroad), academic entrepreneurs, firm employees, government representatives and strategic investors have become more effective throughout time. An example of this is the evolution of the Hunan Taijia New Material Science and Technology Co. Funded by returning graduates from abroad it is now a Sino-China joint venture specialised in the manufacturing of composite materials with annual sales of 500 million Yuan. At the international level, Changsha Universities and research institutions have established ambitious cooperation programmes with top centres in the industrialised and industrialising world (e.g. MIT in the USA, Cambridge, etc.).

*Capabilities*

China has advanced its innovation capabilities from imitation to innovation in the last 20 years (Altenburg et al., 2008; Dobson and Safarian, 2008). For the Changsha's cluster, however, little information is available for the advanced materials cluster. What can be said, however, is that the central role of the two major Universities and a number of research centres and large advanced material firms very probably warrants a very high level of capabilities.

***Market failures and drivers for growth***

*Market structure*

A total of 136 companies are established in the cluster (Changsha Commerce Bureau 2010b).[103] There are many large companies that play a dominant role. That, combined with the lesser access to resources for smaller firms, makes that the market will be less dynamic and less accessible for new entrants.

*Market demand*

The advanced materials cluster is oriented to the development and production of new materials related to advanced batteries. For example, the Changsha Liyuan New Materials firm has now exceeded the previous national leader Sumitomo Company in making material for batteries. Another example is Hunan Reshine New Material Co. which is now the domestic leader in lithium ion cathode material production. All in all, the cluster has got companies that are leading in the growing international markets for both batteries and other advanced materials.

[103] http://www.csinvest.gov.cn/jjcs_cssyscy_6.asp

***Conclusion***

Changsa is a fast growing cluster in advanced materials that serves a fast growing international market, e.g. batteries. The cluster has been strongly stimulated by the government, both financially and by other guiding policies.

Strengths of the cluster are the strong knowledge infrastructure and the presence of large companies that play a leading role in the cluster. The collaboration between government, universities and industry, and the strong government guidance in these processes (e.g. by deciding who will get funding) is a strength for the Chinese example but is a strength that will not be easily transferable to other countries as they have different cultures and industry policy traditions.

A weakness of the cluster can possibly be the relative weak position of smaller and supplier firms to the large companies. As they have a lesser position in the system, the collaboration between these parties will be more prone to distrust which will be detrimental for collaboration and innovation. Their restricted access to funding on top of that means that the dynamism and accessibility of the cluster can be restricted which can be harmful for the healthy mix of actors in the cluster, and hence hinder the further growth of the cluster.

However, all needs to be considered in the light of international competition as well. The growth and the development of cluster will also largely be determined by the relative production costs of China versus other parts of the world.

*Public procurement and lead markets*

Like in the Canadian Ontario microelectronics cluster, the Chinese government uses public procurement policies: they source materials within the region. Like in the Canadian example though, we have no further information on how this policy is implemented and what the results of it are. Like in most other clusters, lead firms play an important role in the cluster. They are important actors for the growth, critical mass and internationalisation of the cluster.

### 7.3.3. Conclusion on Advanced Materials Cluster Comparison

*Strengths and weaknesses*

The advanced materials clusters in Wallonia and Changsha are in some ways comparable. The completely different cultures and structures of both countries make a real comparison hard to make though.

Similarities include that they are young clusters, but growing on the foundations of a long industrial tradition, and that both clusters are embedded in a strong knowledge infrastructure.

Also, both clusters have relative large firms in them, which increase the likeliness of critical mass and internalisation of the clusters.

The role of SMEs should be considered more favourable in Belgium though as the smaller firms in China have a lesser position in the economy, giving them less power and hence less freedom to innovate and creatively contribute to the dynamism and growth of the cluster. The problem with the smaller firms in the Walloon cluster is that they have less developed capabilities and are hence less likely to come with ground breaking new technologies.

Both clusters do facilitate the development of start-up companies though through a network of business incubators and shared infrastructures. In addition to this, both countries provide a large number of different tax incentives for start-ups, regional development and technology development. Finally, there is a considerable presence of well established angel and venture investors in both locations.

*Public policy, funding and tax incentives*

From a geographical point of view, the Walloon cluster is highly spread over five provinces, in comparison to the Changsha cluster, which is highly concentrated. But the largest differences are related to government involvement. While the Walloon advanced materials cluster was created to support and develop the existing traditional chemical industry, Changsha decided to give advanced materials more priority and thus planned its cluster from scratch. The dominant role of the Chinese government is also visible in many other occasions, such as setting up strategic partnerships with local universities and business, providing most of the research funding, acting as a lead customer, and promoting the creation of high-tech SMEs within the Changsha cluster. In the Walloon cluster on the other hand, the Plastiwin initiative as a separate cluster organisation is in charge of cluster coordination, internal and external relationships and building collaboration opportunities. Furthermore, the Belgian government plays no major role, except of providing public funding for research and development. Another difference is that in Changsha, universities act as anchor entities for cluster and regional (innovation) development, while in Wallonia large firms execute this function.

*Lead markets: The role of lead actors / anchor firms*

In both clusters large firms play an important role. They are not explicitly mentioned as playing a role as anchor firm though, nor as lead customers. The reason why we do not earmark the firms as anchor firms is because there is no evidence that they create dynamism in the cluster by for example spin-offs, nor is it their knowledge base that is intensively shared with smaller firms in the cluster leading to a dynamic innovation milieu.

The companies do serve as lead customers though. They are large buyers with high quality demands that will increase the level of quality and capacities of its supplying firms. This will be beneficial for the clusters' development.

**Table 7-8: Summary of findings from advanced materials cluster comparison**

| | Plastiwin cluster, Belgium | Changsha material cluster, China |
|---|---|---|
| History | Dates back to establishment Solvay 1861<br>2007 establishment of cluster platform by group of firms | Dates back to 1990 as machinery cluster<br>Officially established as development/ cluster region around 2000 |
| Size | 44 firms (70 percent SMEs)<br>10,000 employees<br>€5.6 billion annual sales | 136 companies<br>340,000 technical staff |
| Classification | Emerging new cluster / revitalisation of old cluster | Fast growing |
| Infra-structure | Strong knowledge infrastructure with many universities and colleges for applied science.<br>Wallonia has 6 science parks, SPoW (Science Parks of Wallonia is network of high tech business parks<br>Provided are physical and internet infrastructure as well as shared research facilities<br>Pipeline for raw materials transport (e.g. hydrogen) and energy supply (e.g. gas) | Strong knowledge infrastructure with many higer education institutes and training facilities, research institutes and labs |
| Institutions | Highly regulated industry as chemicals play a large part in new materials | Centrally planned society, making direct planning more possible |
| Public policy / funding / tax | Cluster platform initiated by group of firms<br>Cluster platform is part of larger cluster initiative Plan Marshall Wallon to stimulate innovation by access to funding, reducing tax for firms, developing industry-science collaboration, training<br>Regional development agencies provide infrastructure and start-up support through incubators and shared infrastructure (e.g. labs)<br>Active regional development agencies<br>Finance<br>Financial support from European, national and regional funds<br>Tax, financial and social security incentives for existing firms<br>Tax incentives and grants to attract new firms to the cluster (up to 20 percent of set up costs) | Strong support of national and regional government providing funding, stimulating industry-university collaboration, stimulating private and providing public funding for research, development and commercialisation |
| Interactions | Not much known on interactions | Interaction hindered by old culture and relative distrust between larger and smaller actors in the cluster |
| Capabilities | Building upon long history in industry<br>Smaller companies have relative weaker innovation skills | Large companies, in collaboration with universities, represent strong innovation skills |
| Market demand | 75 percent of output is for export | Fast growing cluster with strong export |

| | | |
|---|---|---|
| | Large companies can serve as lead users<br>Not clear what is percentage of advanced material in total output cluster | product such as advanced batteries<br>International demand through relative low production and labour costs in China |
| Market structure | 70 percent SME's<br>Large firms are e.g. Solvay, Total, BASF, Prayon, Nexans and Baxter. | Cluster originated around 2 anchor firms in 1990s<br>Smaller firms and new entrants are disadvantaged compared to well connected large firms |

*Source: TNO compilation.*

### 7.3.4. Factors influencing the future development of advanced materials

***Factors influencing the future market potential of advanced materials***

Radical developments in advanced materials technology are viewed as trigger for further innovations with the potential for major economic impact across a broad range of industries and applications (MTC and NSTI, 2004). Advanced materials are attracting both government interest and new entrants. Because of their general purpose character companies and research facilities developing advanced materials need access to financing and the establishment of effective alliance partners. These are required in order to demonstrate value in specific market applications, a necessary intermediate step for an advanced materials venture to create and capture value (Maine and Garnsey, 2006). Cooperation networks will arise in order to realise these values.

Preferences of the society will influence the future development of research in new materials and their application. Society's demand of advanced materials included in new technologies, products and services is affected by a variety of factors and is influenced by development s in many other technologies (especially other KETs) and industries, as mentioned before. Evaluating foresight studies of the EU the priorities regarding new and advanced materials are directed firstly to "Better Life" which includes materials used in medicine, security and convenience (Schumacher et.al., 2007). High tech textile materials and smart materials belong to this category as well as implant and new surface materials, and regenerative medicine. The second highest priority for advanced material applications is "Security", which mainly includes nano and smart materials for non-stop protection, identity proof systems and alarm systems included in surfaces. The foresight studies indicate at the third place of priorities within advanced material research and development, the problem of "Energy Saving". To this group belong solar materials, fuel cells and materials for energy efficiency. Sustainable solutions improving environmental saving technologies is expected to be a powerful demand of advanced materials.

***Contribution of advanced materials to social wealth***

Wealth effects are obvious in the application of new products for life style, medicine and environmental techniques. Shape memory alloys (e.g. Nickel-titanium alloy) open many opportunities to improve the convenience and to extend the durability of implants, stents and prostheses. In combination with new diagnostic technologies which are strongly driven by other KETs -such as nanoelectronics, biotechnology and photonics- the opportunities for new applications will rise. Additionally, it is evident, that the appropriation of new and advanced materials focuses on central needs of the society, such as sustainable environmental technologies and energy efficiency goals. The awareness of the special characteristics of certain advanced materials opens a huge range of appropriation of material to diverse wealth enhancing purposes.

***The role of public support***

There are complementary effects obvious in two directions. First, advanced technologies in energy production and storage (e.g. fuel cells), or in medicine (e.g. new organic materials) call for new materials which are applicable to high temperatures and high pressures. Secondly, production technologies for those advanced materials are necessary to produce those materials with reasonable costs. Substitution effects exist in cases where old materials are replaced by new, smart and highly advanced ones, such as of aluminium and other materials with high-energy-consuming production technologies. In order to realise those complementary and substitution effects in a desirable way, public programmes should support collaboration between research institutions and companies. National programmes at the federal level as well as EU programmes are shaped to improve such collaboration.

In Germany, the Federal Ministry of Education and Research, BMBF supports certain fields of material technology and selected main areas of chemical technology in differently oriented programmes, “MaTech – New Materials for Key Technologies of the 21st Century” and “Chemical Technologies. MaTech induced with a funding of €530 million a total mount of investment of almost €1 billion within the time period 1994 to 2003. A long term framework programme for funding and supporting research and development of new materials and their application in diverse implementations in technologies WING integrates these programmes (see BMBF, 2003). This has a particularly pronounced effect on cooperation between universities and small and medium-sized companies. The latter often do not have the human or financial resources for intensive materials research. Publicly funded collaborative projects can close this gap and enable education and further training on a project-specific level (see Schumacher et.al., 2007).

In Great Britain the Associate Programme of the Institute of Materials (IoM) was launched in 1999 with the objective of consulting and engaging the materials community in the

FORESIGHT process. In all cases, the process involved end-users, manufacturers and suppliers from different value added chains. The following areas were selected for action: Crime Prevention, Sustainable Development, Finance and Innovation Technical Textiles, Packaging, Process Modelling and Simulation. Education and collaboration between research institutions and companies play a key role within the action of this programme (see Foresight Panel UK, 2000).

The 7$^{th}$ framework programme of the EU directs in their activity in similar areas. Research will focus on developing new multifunctional surfaces and materials with tailored properties and predictable performance for new products and processes as well as for their repair.[104] Huge efforts have been made to trigger a fruitful and economic relevant amount of cooperation between research institutions and companies which appropriate the results in material research. However it is not clear how these will influence the market potentials and production capacities of advanced materials within the EU.

## 7.4 Conclusions and Policy Implications

***State of technology***

Innovation in material technology has a long history. Several waves of technological advance have emerged during the past centuries. The past two decades saw a new surge in technological developments in new materials, driven by different factors. On the one hand, further progress was made in traditional areas of material technology, including innovation in advanced metals, advanced polymers and advance ceramics. On the other hand, some new fields of material technologies developed rapidly, opening up entirely new areas of material innovation. One driving force is **nanotechnology** which allows to scaling down materials into a size that result in different material properties. Another driving force is **smart materials**, i.e. complex materials that combine structure characteristics with specific physical and chemical properties. A further new development in materials technology refers to **bioconceptual** materials, i.e. materials based on biological technologies.

Advances in materials primarily attempt to improve critical performance characteristics of materials compared to conventional materials. Such improvements can result in a wider applicability of materials in very demanding environments (e.g. in terms of temperature and humidity), in allowing more demanding processing of materials (e.g. in terms of capacitance, miniaturisation) and in utilising better physical-chemical properties (e.g. conductivity, weight, durability). Research in new materials currently focuses on the biomaterials, super alloys,

[104] http://ec.europa.eu/research/fp7

advanced ceramics, engineering polymers and advance composites, organic polymer electronics and other advanced electronic materials, advanced coatings, nanopowders, nanocarbon and nanofibers, thin films, and technical textiles.

Current major trends in advanced materials cover both improvements of traditional material technology such as layered materials, high-performance materials, tailored macroscaled materials, new alloys and energy-efficient materials as well as the application of nanotechnology in various fields of material sciences. Improvements of traditional material technology follow a steady path of rather incremental, though still significant technical progress that gradually substitutes older materials by new materials with higher performance characteristics. Nanotechnology represents a more disruptive technological change. Advanced materials based on nanotechnology are expected to change the material world quite radically, opening up entirely new fields of application.

***Europe's technological position***

Europe's share in the global production of new technological knowledge in advanced materials -as revealed by patent statistics- has fallen from more than 35 percent in the 1990s to 31 percent in 2005. While North America lost market shares at a similar pace, East Asia could significantly strengthen its position in advanced material technology, raising its market share from 25 percent in the mid 1990s to 37 percent in 2005. Patent intensity in advanced materials -that is the number of patent applications per GDP- is more than 50 percent higher in East Asia compared to Europe and North America. While patent output per GDP shows an increasing trend in East Asia, patent intensity is stable over time in Europe and North America. It is thus fair to say that the main geographical focus of technological advance in materials has shifted towards East Asia over the past two decades.

Europe has lost market shares in all subfields of advanced materials, though it still holds a strong position in macroscaled materials and layered materials. Both subfields are closely related to traditional chemical technology. Europe's position is weaker -in terms of its share in total patent output- in nanomaterials, magneto/piezo materials and high-performance materials. In recent years, Europe could increase its output in nanomaterials and high-performance materials at a higher rate than North America and East Asia, reflecting a slow catching-up in these two fields. Within Europe, Germany is the single most important location for producing new materials technology (42 percent of all inventors of advanced materials patents) though smaller European economies were able to increase their patent output in recent years substantially.

***Links to disciplines, sectors and other KETs***

Advanced materials are used in virtually all manufacturing industries. They drive both product and process innovation in many sectors. The most important application areas for new advanced materials are currently semiconductors, automotive and aircraft, energy and environment, medicine and health, construction and housing, and various process technologies (including mechanical engineering and automation, packaging and logistics, textiles and clothing). Another major application area is defence and security.

The chemical industry is the most important source of advanced materials patents (about 50 percent), followed by electronics, the oil industry and metal production. In Europe, the chemical industry has a particularly high share in total patent output (62 percent) which is directly linked to Europe's focus on macroscaled materials and layered materials. Over time, the role of the chemical industry as most important patent applicant has diminished in all three main world regions while the plastics industry and public research have gained in significance.

Although R&D in advanced materials rests on a broad spectrum of scientific disciplines, including material sciences, chemistry, physics, nanosciences and biology, the role of public research as a direct source of technological advance in materials is rather limited. In the past ten years, just 6 percent of all advanced material patents originated from public research institutions. The growing share of public research basically relates to the field of nanomaterials where public research institutions are the single most important group of applicants. Public research is particularly important as producer of nanomaterial patents in North America and less in East Asia while its share in Europe is 26 percent.

The particular importance of advanced materials as a KET is that they are essential for many other KETs. For example, innovation in micro- and nanoelectronics heavily depend on materials with improved performance characteristics (both for end products and manufacturing processes) to further miniaturise electronic devices. New materials are also essential in advanced manufacturing technologies and photonics. Increasing energy efficiency is particularly depending on progress in material technologies, including new ways of producing and storing energy (e.g. fuel cells, wind energy, solar energy, batteries) and reducing energy consumption in housing and transportation (see Schumacher et al., 2007). Direct technological overlaps in the way that advanced material patents are at the same time assigned to other KETs are rare, however. Only 11 percent of all advanced material patents overlap with other KETs, particularly with nanotechnology, microelectronics and photonics.

### *Market prospects and growth impacts*

The world market for materials is huge with annual sales of several trillion US-$. Advanced materials constitute only a small fraction of this market. Depending on the exact definition of advanced materials, current market volumes are likely to be between $100 and 200 billion. Most advanced materials are substitutes for established materials, offering better performance characteristics and widening the scope of application. Nanotechnology based advanced materials, which can be regarded as the subgroup of advanced materials that is likely to open-up new markets and has the potential to generate net growth, are currently sold at annual figures of around $20 billion.

For most advanced materials, market growth is expected to be slightly above the average growth of the world market for goods, which can be used as a reference for the likely market growth for the entire materials market. Expected average annual growth rates of 5 to 6 percent are rather low compared to other KETs and reflect that most advanced materials are diffuse slowly because of high opportunity costs in substituting established by new materials and often rather low price-cost advantages of more advanced materials. The situation is different for advanced materials based on nanotechnology. Most market forecasts expect compound annual growth rates of 20 to 30 percent over the next 10 to 20 years.

Growth impacts of advanced materials are twofold. For most advanced materials, net growth effects tend to occur in the user industries as long as new materials help to increase productivity or enable new products with superior characteristics that generate additional demand. These user industries include electronics, medical instruments and health services, automotive, energy production and distribution, construction, textiles and clothing, and various material processing industries. The manufacturers of these advanced materials are less likely to experience net growth as new materials typically substitute established ones. A second source for net growth is certainly nanomaterials. The expected strong growth in demand for nanomaterials will most likely give ground for new producers and additional production facilities. Nanomaterials can contribute to net growth in the material producing sector since their value added tends to be higher than for traditional materials resulting in a higher share of material input in total production value.

### *Success factors, market and system failures*

Advance materials are a special kind of general purpose technology. Advanced materials can be applied widely across all manufacturing industries, but also emanating into service sectors such as health, software, architecture and construction, telecommunication and engineering services, contributing to both product and process innovation. Like other general purpose technologies, the diffusion of advanced materials generates network and learning effects among users. As a consequence, diffusion of new materials is accelerated when a certain level of diffusion is reached. However, if users are reluctant to adopt new materials it can take long time until new materials reach sale figures that allow for profitable production. Securing a broad adoption of advanced materials early after introduction can thus be vital for advanced materials producer, and the lack of it can hinder further advance.

New application areas of advanced materials often emerge during their use and may developed by actors other than those who have originally developed a certain advanced material (e.g. by users, competitors or other material suppliers). A rapid diffusion of advanced materials is thus likely to result in opening-up more and more fields of application, generating a positive feedback in the demand for the respective material.

Advanced materials are characterised by an extreme variety of individual products and material solutions. The large variety of advanced materials, many tailored to specific application purposes, restrict economies of scale in their production. In order to achieve cost-efficient production volumes, producers of advanced materials have to go beyond geographical market borders early and serve global markets. Furthermore, specialisation and concentration among advanced materials producers is likely to occur. This can complicate the development of new application areas and advances in material technologies at the crossroad of different approaches in material sciences (e.g. for smart materials) and calls for co-operation among producers with different sector and material technology background. Clusters of actors engaged in R&D, production and the use of advanced materials can be helpful in this respect.

Both the development and the diffusion of new materials takes particularly long periods, often decades. Considerable research efforts are needed until new materials comply with the requirements of users in terms of reliability, stability, cost-efficiency, recyclability and safety. Product regulation typically demands time-consuming procedures for each field of application until new materials are approved for commercial use in the respective application area. Using new materials most often requires substantial adaptations in production and distribution processes of users along the value chain, including changes in process technology, product design, delivery mechanisms, recycling etc. and may involve high investment by users.

***Policy options***

Developing and commercialising advances in material technology is by and large the business of a large number ob enterprises engaged in various sectors of processing raw materials and producing more complex materials as inputs for other manufacturing industries. Since material development is one of the most longstanding industrial activities and most critical to all manufacturing sectors, a large materials industry and a well-developed network between producers and users of materials -including advanced materials- has emerged over time. Since new materials are often a key component of new products, many producers of end products also engage in R&D on advanced materials.

At the same time, developing advanced materials is challenging as it typically requires to integrate findings from basic research (public science), in-depth knowledge of specialised material producers (e.g. from the chemical, metals, glass/ceramics or textile industry), requirements of end product producers and other users down the value added (e.g. automotive or semiconductor industry), process technology knowledge from equipment producers (e.g. machinery and instruments industry) and demands of regulatory bodies and other public authorities which have to guarantee that new materials do not harm health or the environment.

In this situation, public policy can support the advance in material technologies through various activities:

Linking public research and industry is critical for this KET, as it is for all other KETs. In contrast to other KETs, public research is less important as producer of knowledge that can be commercialised directly but rather focuses on basic research, preparing the scientific ground for future material technologies. Linking industry and science should thus focus on a smooth exchange of knowledge through personal networks (including mobility of researchers between science and industry) and long-term co-operative projects that combine basic and applied research. Both cluster initiatives and established R&D programmes (such as the EU FP) are important instruments in this respect. Research mobility programmes can offer further incentives to knowledge exchange.

Promoting a rapid diffusion of advanced materials through early and flexible regulation of new materials and the process of manufacturing them. While regulations have to be strict in terms of protection negative impacts on safety, health and environment, they should specify technical requirements to materials and processes early and with a long-term view in order to reduce uncertainty at the side of producers and users of advanced materials. At the same time, regulations should be flexible, i.e. reviewed regularly with respect to changes in material technologies, allowing for innovative advance in new materials and their use.

R&D in advanced materials is associated with high costs and risks and long amortisation times for new materials. As a consequence, business R&D in advanced materials is concentrated on large companies which can afford the high investment needed. For upcoming fields in material technologies, young firms could play an important role, too. This is particularly true for nanomaterials. Providing funding for start-ups and SMEs either through grants for R&D projects or venture capital is critical for a vital small business sector in this KET. So far, start-ups and SMEs rarely appear among the more important producer of new technological knowledge. This is in sharp contrast to the situation in nanotechnology and industrial biotechnology, but also the field of photonics.

More emphasis on funding research-based start-ups and incorporating R&D performing SMEs in clusters and co-operations could help in this respect.

Policy intervention should generally focus on those subfields of advanced materials that are in their early stages since links to science are particularly important in this stage, and costs and risks of R&D are high while returns from sales of new products may be still out of sight. This is currently true nanomaterials and biomaterials as well as energy-efficient materials and high-performance materials. Traditional areas of advance in material technology such as macroscaled materials, alloys and layered materials tend to require less support from governments as markets have already been established.

# 8 ADVANCED MANUFACTURING TECHNOLOGIES

The chapter on advanced manufacturing technologies differs from the other five chapters on KETs. It was agreed to refrain from conducting analyses of successful clusters in this KET but solely focus on quantitative analyses based on patent data. This decision reflects the specific nature of this KET (see the following section for more detail) which implies different mode of generating and diffusing technologies and less significance of clusters for technological advance in this KET. As a consequence, analysis of success factors, barriers, market and system failures are missing. The final chapter of this section still makes an attempt to summarise some of the main issues on drivers and barriers for developing and commercialising advanced manufacturing technologies and what the role of public policy could be.

## 8.1 Definition and State of Technology

Advanced manufacturing technologies (AMT) comprise all technologies that significantly increase speed, decrease costs or materials consumption, and improve operating precision as well as environmental aspects like waste and pollution of manufacturing processes. In contrast to the five other fields of technology considered in this study, advanced manufacturing technologies are not a single field of technology, but rather a combination of different technologies and practices that aim at improving processes of manufacturing goods. These technologies comprise, among others, material engineering technologies (e.g. cutting, knitting, turning; forming, pressing, chipping), electronic and computing technologies, measuring technologies (including optical and chemical technologies), transportation technologies and other logistic technologies. A major trend in AMT for more than four decades has been the integration of numerically controlled, i.e. computer-integrated, technologies into manufacturing processes that allow for a vertical integration of planning, engineering design, control, production and distribution processes. A further major trend is automation that allows to performing increasingly complex manufacturing processes without manual intervention. Robotics, automation technologies and computer-integrated manufacturing are the keywords for AMT.

Industries in which AMT are important can thus be characterised as capital intensive with complex assembly methods. In this respect, AMT enable an intelligent control of processes as well as automation for modelling and production which eventually brings down the costs associated with production and increases the quality of products. Today, AMT are responsible for 10.5 percent of the EU’s industrial production and associated 2.2 million jobs. They account for 19 percent of EU exports and over 40 percent of EU private sector R&D expenditure (Manufuture, 2010).

Innovation in AMT is rather based on incremental technological progress than on radical change, though the latter occurs from time to time when general purpose manufacturing technologies emerge (e.g. steam engine, electrical motor, computing). In this respect, AMT can be characterised as the oldest key enabling technology in human history. Furthermore, innovations in AMT are not only developed by specialised technology producers (e.g. mechanical engineering firms), but also by users (i.e. any type of manufacturing firm). As a consequence, the market for AMT is restricted due to the need for user-specific design. This limits the opportunities to deploy identical technology in many different companies. For some manufacturing industries, no external AMT providers exist, which forces manufacturing firms to advance manufacturing methods on their own. Smaller firms typically rely on external AMT providers since they do not have the necessary technology competencies for developing AMT themselves.

There are several barriers to the diffusion of AMT. First of all, investment costs are high, and they are combined with uncertainty over the advantages of new generations of manufacturing technologies (i.e. degree of cost savings and other efficiency gains unclear at the time of investment). Moreover, there is considerable need for tailor-made adjustments, which are costly. Adjusting and using AMT also requires in-house capabilities for dealing with new technologies (skills of workers, coordination among departments, integration of suppliers and customers). Adjustments to AMT may as a result lead to adjustments to the product produced which may result in complex changes in a firm's internal and external organisation (involving marketing and users).

The future development of AMT receives considerable policy support, for example in the form of the European Robotics Technology Platform (EUROP) which is an industry-driven platform comprising the main stakeholders in robotics in Europe. EUROP was established in 2004 and aims at strengthening Europe's competitiveness in robotics R&D and global markets. Since October 2005, EUROP has become a European Technology Platform (ETP). The use of robots is in fact dramatically increasing, from 6.5 million robots in operation in 2007 to an estimated number of 18 million robots in 2011 (World Robotics, 2009). Over the next few years, robots are expected to become much more flexible and easy to use, laying the ground for a new era which is characterised by robots as ubiquitous helpers improving the quality of life by delivering efficient services. In the industrial application, robots are expected to combat the expected shortage of 6 million skilled labourers by 2020. Moreover, there is a pressing requirement for increasing productivity through robot usage as labour costs are and will remain high in Europe. In this respect, important trends are the miniaturisation of robotic technologies and the development of sophisticated sensing capabilities. This will for example enable the use of robots in small-batch production facilities. Furthermore, new developments in robotic technologies mean that they can assist in operations under hazardous conditions, for example in space, deep sea, or mining and mineral extraction (EUROP, 2009).

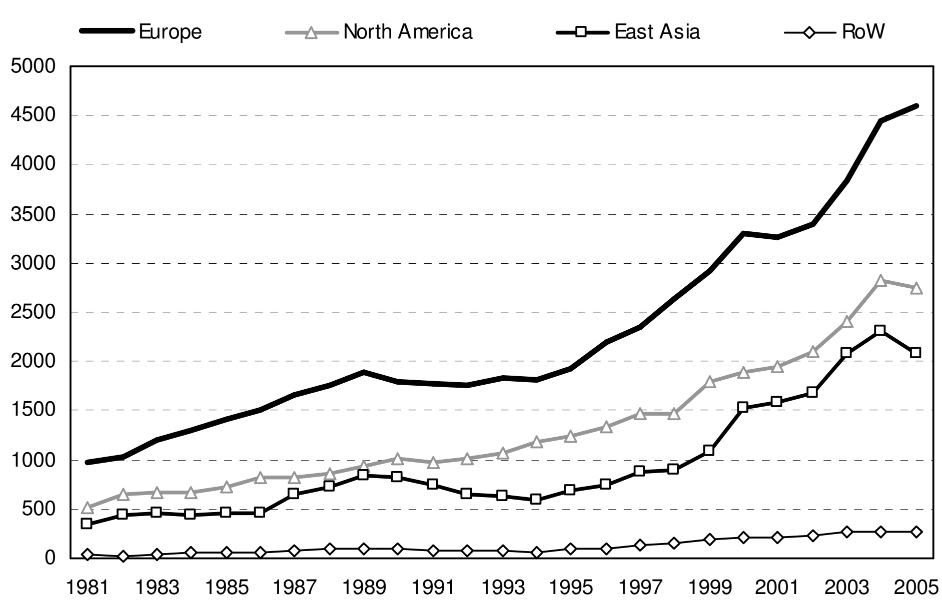
## 8.2 Technological Competitiveness, Industry Links and Market Potentials

### 8.2.1. Technological Competitiveness

*Market shares*

We analyse technological competitiveness of advanced manufacturing technologies (AMT) based on patent data. AMT patents are identified through a combination of IPC classes (see section 2.2). Measured in terms of patents applied at EPO or through the PCT procedure (EPO/PCT patents), the number of AMT patents applied for per year by European applicants increased markedly since the mid 1990s, exceeding almost 3,000 patents per year in 1999 (Figure 8-1). Over the entire period from 1981 to 2005, more than 131,000 AMT EPO/PCT patents were applied for. Europe exhibits a significantly higher number of patent applications compared to North American and East Asian applicants which applied for a rather similar number of patents each year. Applicants from other regions than Europe, North America and East Asia are of little significance.

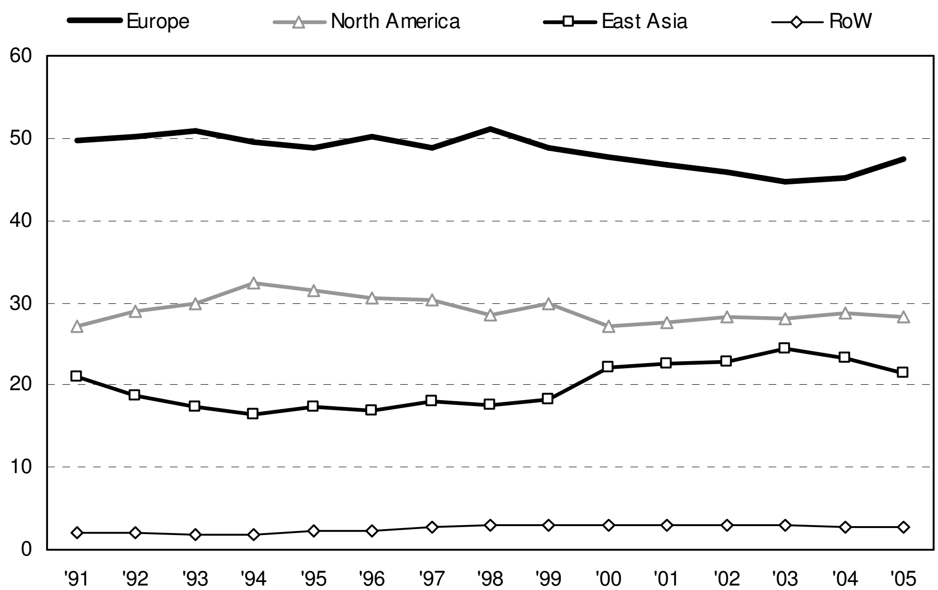
**Figure 8-1: Number of AMT patents (EPO/PCT) 1981-2005 by region of applicant**




*Source: EPO: Patstat, ZEW calculations.*

In 2005, European applicants had a share of almost 50 percent in total AMT patent applications at the EPO/PCT, compared to below 30 percent for North American and slightly more than 20 percent for East Asian applicants (see Figure 8-2). Over the past 15 years, market shares have remained relatively constant but Europe's share has moderately increased in recent years.

**Figure 8-2: Market shares of AMT patents (EPO/PCT) 1991-2005, by regions (percent)**

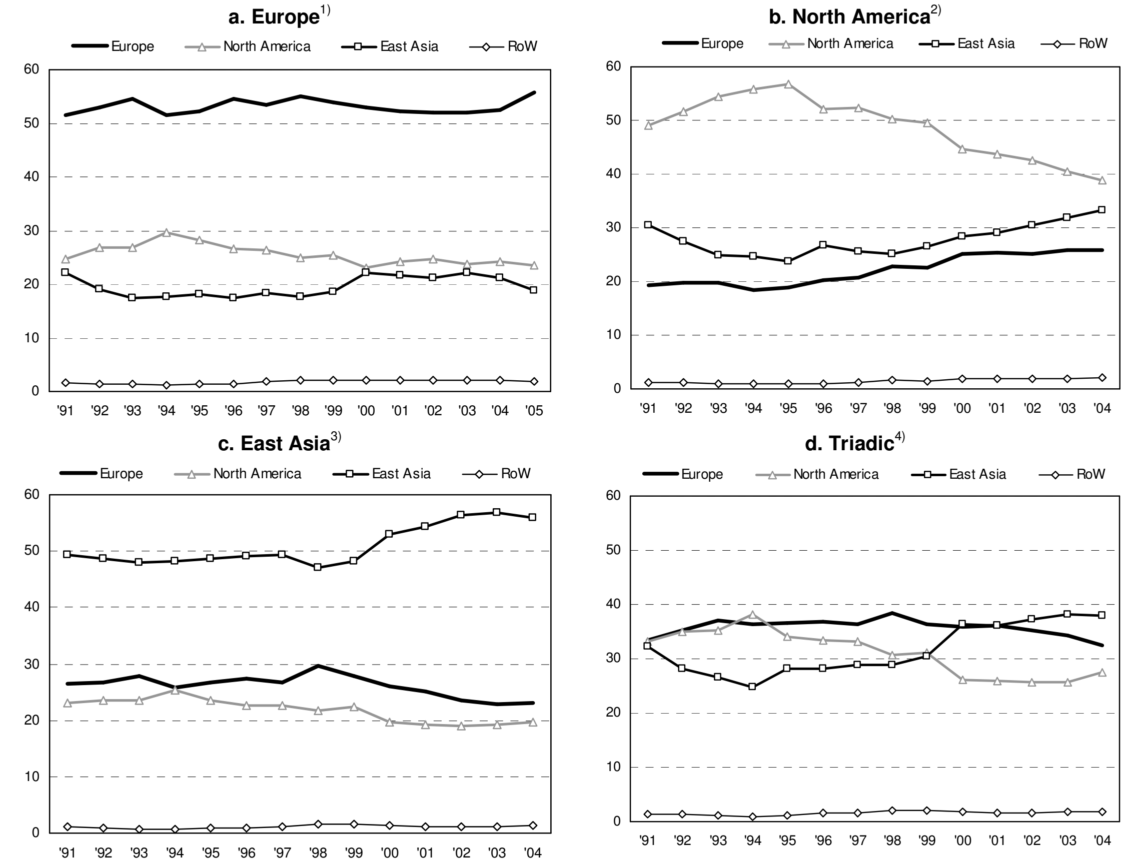



*Source: EPO: Patstat, ZEW calculations.*

Market shares differ significantly when looking at regional patents (Figure 8-3). When only looking at EPO patents, European applicants show a huge head start over applicants from North America and East Asia. For USPTO patents, North American applicants outperform those from Europe and East Asia. However, this advantage has considerably decreased in recent years and has almost disappeared in 2005. Among the patents applied at JPO, East Asian applicants are clearly ahead of European and North American applicants When looking at triadic patents, i.e. patents applied at patent offices in all three regions, market shares for European, North American and East Asian applicants are at a similar level. While Europe shows a constant share, East Asian applicants could raise their share in all triadic AMT patents significantly, while North American applicants lost shares.

The very different pictures for national patent applications compared to triadic applications reveals that AMT patenting is less global than in other KETs. Most AMT patents remain in the applicant's home region and only a small fraction is patented in other world regions.

**Figure 8-3: Market shares in AMT patents 1991-2005 for national applications and triadic patents (percent)**




*1) EPO applications*

*2) USPTO applications*

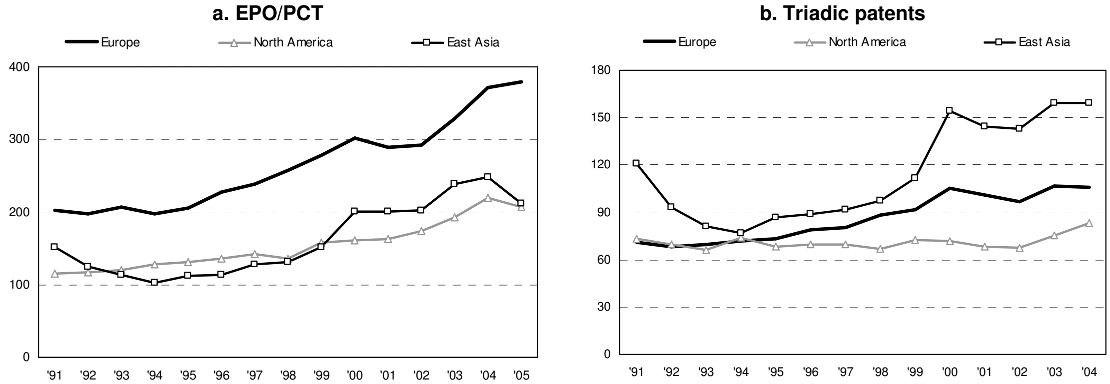
*3) JPO applications*

*4) Patents for which 1), 2) and 3) applies*

*Source: EPO: Patstat, ZEW calculations.*

In order to determine the relative importance of AMT patents for a region, patent intensities can be calculated. These relate the number of patents per year form applicants of a certain region to the GDP of that region (Figure 8-4). This type of specialisation indicator shows that regarding EPO/PCT patent applications, Europe clearly produces more AMT patents per GDP than North America and East Asia. This situation is somewhat different when triadic patents are considered. It turns out that East Asian applicants exhibit the highest patent intensity, followed by European and North American applicants. While both East Asia and Europe increased patent intensities in AMT over time, patent intensities of North America remained constant (though they grew slightly in most recent years).

**Figure 8-4: AMT patent intensity 1991-2005 for EPO/PCT and triadic patents (number of patents per 1 trillion of GDP at constant PPP-$)**




*Source: EPO: Patstat, OECD: MSTI 02/2009. ZEW calculations.*

### *Patenting by subfields*

The further analysis is structured by distinguishing six subfields of AMT which are defined by IPC classes or a combination of these:

robotics (B25J)

measuring of industrial processes (G01D, G01F, G01H, G01L, G01M, G01P, G01Q)

controlling industrial processes (G05B, G05D, G05G, G08C)

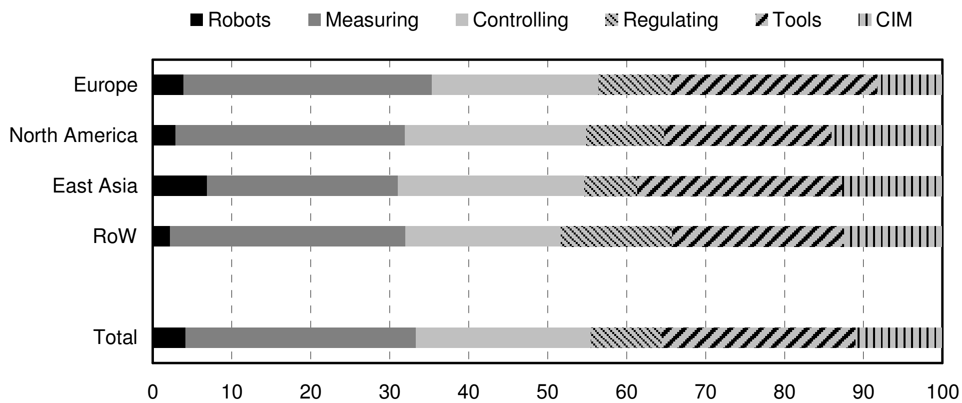
regulating industrial processes (B03C, B06B, B07C, G05F, G06M, G07C)

machine tools (B23H, B23K, ,B23P, B23Q)

computer integrated manufacturing (G06 and at least one of the following classes: A21C, A22B, A22C, A23N, A24C, A41H, A42C, A43D, B01F, B02B, B02C, B03B, B03D, B05C, B05D, B07B, B08B, B21B, B21D, B21F, B21H, B21J, B22C, B23B, B23C, B23D, B23G, B24B, B24C, B25D, B26D, B26F, B27B, B27C, B27F, B27J, B28D, B30B, B31B, B31C, B31D, B31F, B41B, B41C, B41D, B41F, B41G, B41L, B41N, B42B, B42C, B44B, B65B, B65C, B65H, B67B, B67C, B68F, C13C, C13D, C13G, C13H, C14B, C23C, D01B, D01D, D01G, D01H, D02G, D02H, D02J, D03C, D03D, D03J, D04B, D04C, D05B, D05C, D06B, D06G, D06H, D21B, D21D, D21F, D21G, E01C, E02D, E02F, E21B, E21C, E21D, E21F, F04F, F16N, F26B, G01K, H05H)

The largest subfield is measurement, followed by tools and controlling (Figure 8-5), each account for 22 percent to 29 percent of all patent applications. Generally speaking, there appears to be only little specialisation as all subfields are almost equally distributed among the world regions. Some of the slight differences include a rather high share of robots in East Asia and a high share of measurement in Europe. North American applicants are particularly strong in CIM.

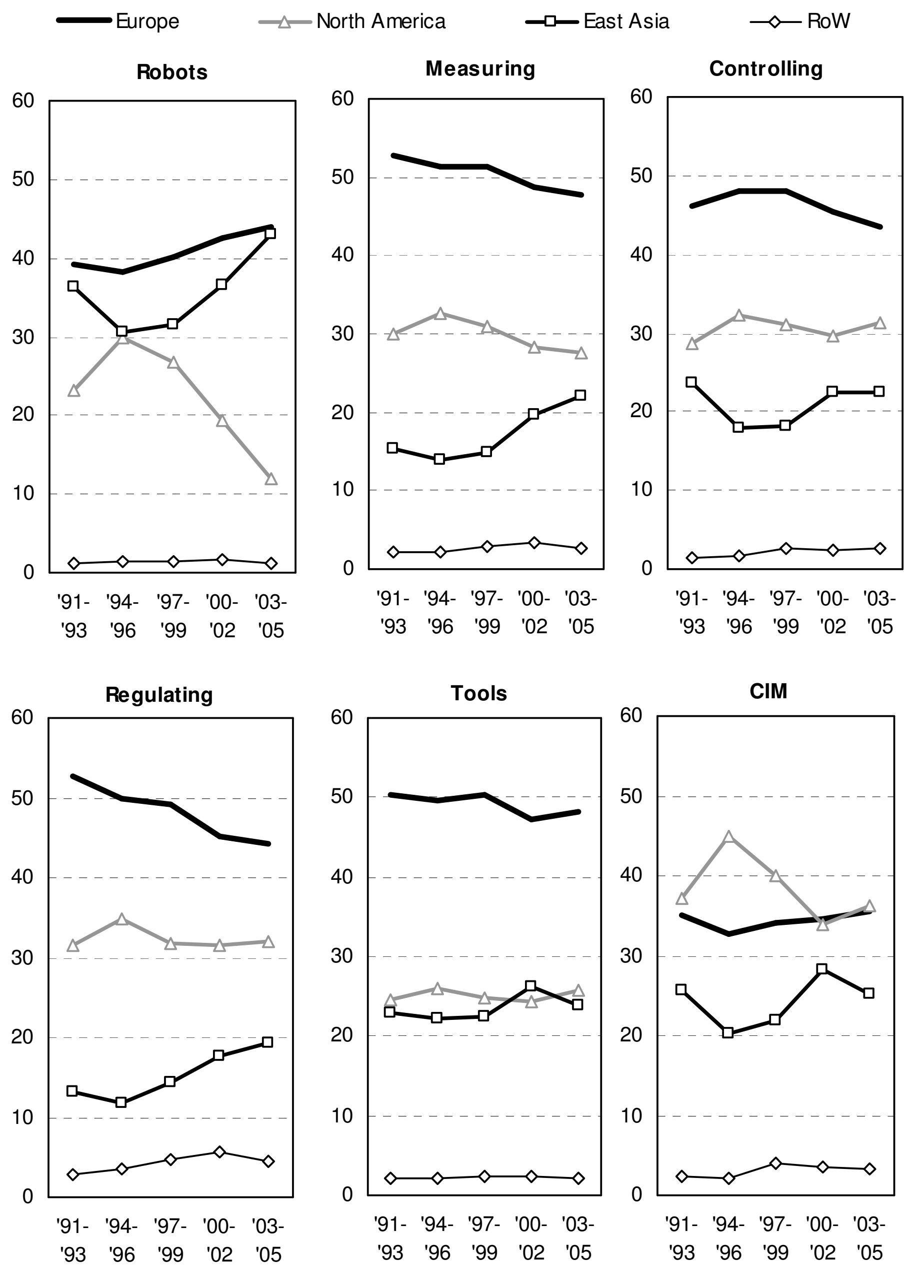
**Figure 8-5: Composition of AMT patents (EPO/PCT) by subfields (per cent)**




*Source: EPO: Patstat. ZEW calculations.*

When looking at the technology market shares by subfield over time (Figure 8-6), Europe shows rather high, though in all subfields except for robots and CIM falling market shares. Europe's market shares are highest in measuring, controlling, regulating and tools with around 50 percent each. North American applicants are particularly strong in CIM while East Asian applications show a rather high market share in robots.

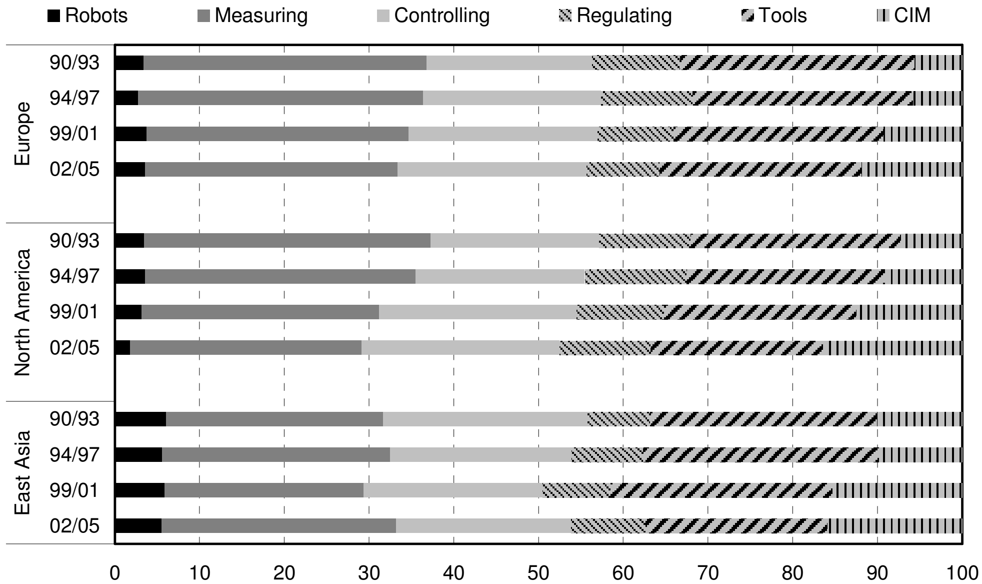
**Figure 8-6: Market shares for AMT patents (EPO/PCT) 1991-2005, by subfields (percent)**




*Source: EPO: Patstat, ZEW calculations.*

When the development of the composition of patent applications in AMT are analysed over time, no significant differences can be observed between the three world regions (Figure 8-7). Europe and North America turn out to have focused less on measuring, while the specialisation of East Asia did not change in a clear direction. All three regions have considerably expanded their patenting activity in CIM.

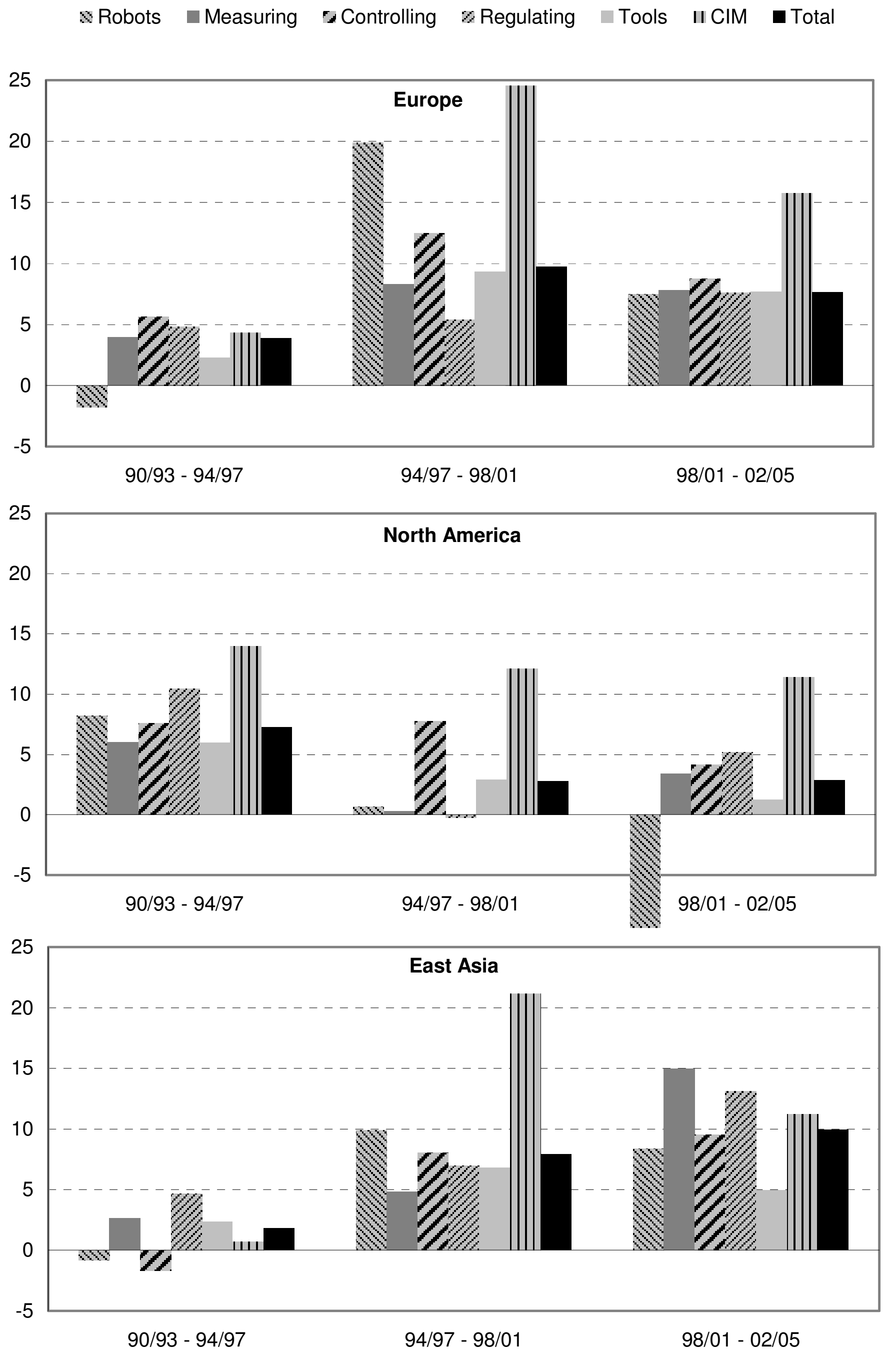
**Figure 8-7: Composition of AMT patents (applications at home patent offices), by region, subfield and period (percent)**




*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*
*Source: EPO: Patstat, ZEW calculations.*

Dynamics in AMT patent applications at the regional home offices differ by subfield and region. In the most recent period (1998/01 to 2002/05), East Asia increased the number of annual patents in measurement at a high pace while Europe and North America have been lagging behind (Figure 8-8). All three regions show high growth in CIM and, to a somewhat lesser extent, in controlling.

**Figure 8-8: Average annual rate of change in the number of AMT patents (applications at home patent offices), by region, subfield and period (percent)**



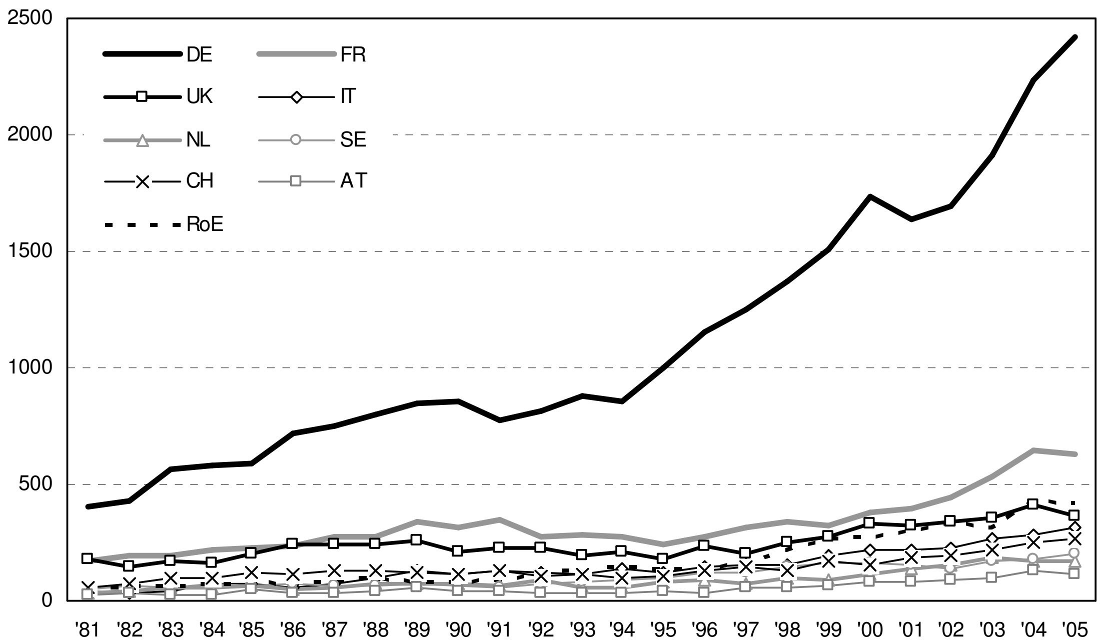

*90/93: average of the four year period from 1990 to 1993.*
*94/97: average of the four year period from 1994 to 1997.*
*98/01: average of the four year period from 1998 to 2001.*
*02/05: average of the four year period from 2002 to 2005.*

*Source: EPO: Patstat, ZEW calculations.*

***Patenting at the country level in Europe***

Shedding light on the AMT patenting within Europe, applicants from Germany represent by far the largest group of AMT patentees (Figure 8-9). From 1981 to 2005, 47 percent of all AMT patents at the EPO stem from German applicants, followed by France (14 percent), the United Kingdom (10 percent) and Italy (6 percent). There has been a particularly fast growth of German patent applications from 1993 to 2005 with a short pause between 2000 and 2002.

**Figure 8-9: Number of AMT patent applications (EPO and PCT) 1979-2005 by European applicants, by country**

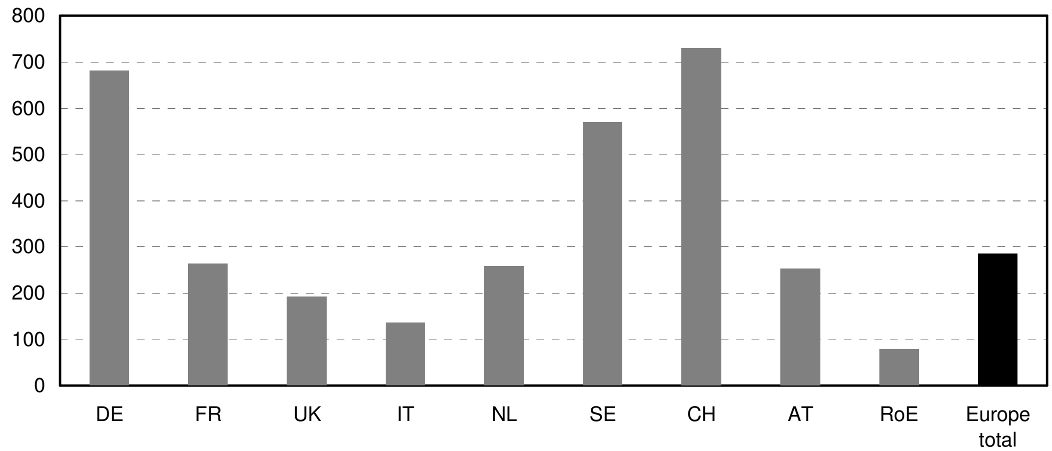



*Eight European countries with the largest number of AMT patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The economic significance of AMT patenting differs substantially by country (Figure 8-10). AMT patent intensity -that is the ratio of the number of AMT patents to GDP- is highest in Switzerland and Germany, but also Sweden reports a high patent output per GDP. All other European countries clearly fall behind and show AMT patent intensities below the European average (which is strongly driven by Germany as the largest AMT patent producer). AMT patent intensity in France, the Netherlands and Austria is close to the European average while the UK, Italy and the group of countries not belonging to the eight largest AMT patent producers in Europe show low patent intensities.

**Figure 8-10: Patent intensity in AMT 1991-2005 of European countries (EPO/PCT patents)**




*Patent intensity: number of EPO/PCT patents applied between 1991 and 2005 per trillion GDP at constant PPP-$ in the same period.*

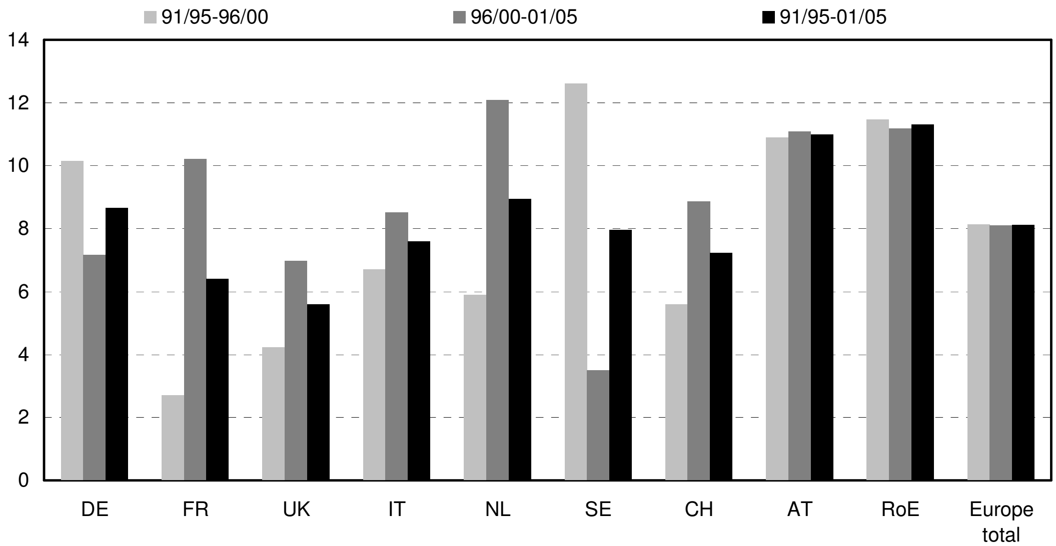
*Eight European countries with the largest number of AMT patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

The differences in the absolute number of AMT patents and in patent intensities have to be kept in mind when looking at patenting dynamics since countries with low patent activities can more easily generate high growth rates. Among the eight countries that produce the largest number of AMT patents, Austria could increase its patent output at an annual growth rate of 11 percent between the first half of the 1990s (1991-95) and the first half of the 2000s (2001-05) followed by the Netherlands and Germany (9 percent) (Figure 8-11). The highest growth rate was experienced by the group of European countries not qualifying for the eight largest patent producers in AMT. Sweden, Italy and Switzerland report growth rates close the European average whereas AMT patent dynamics in France and the UK were rather modest.

AMT patent output in Europe grew at an annual rate of 8 percent both in the 1990s (1991/95 to 1996/00) and in the early 2000s (1996/00 to 2001/05). Sweden, Austria and Germany show high growth rates in the former period while the Netherlands, Austria and France report the highest growth rates for the latter period.

**Figure 8-11: Change in the number of AMT patents between 1991/95 to 1996/00 and 1996/00 to 2001/05, by country (EPO/PCT patents; compound annual growth rate in percent)**

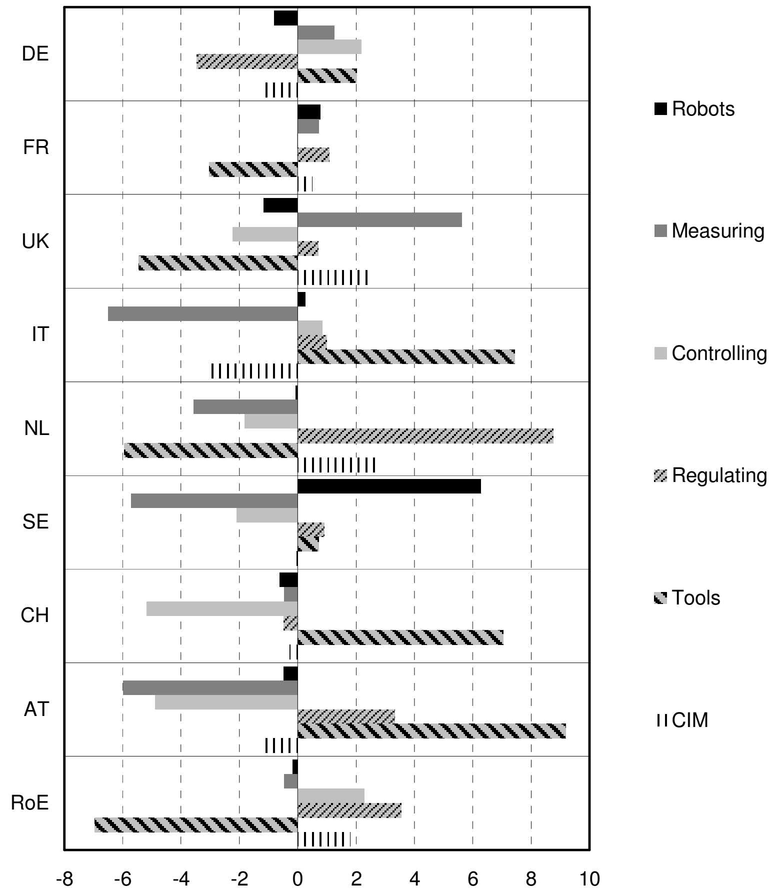



*Eight European countries with the largest number of AMT patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Figure 8-12 provides a more detailed picture of country-specific specialisation by subfield within AMT. Considerable differences become apparent. Germany is specialised on patenting in measuring, controlling and machine tools whereas AMT patenting in France by subfields is quite similar to the European average, except a lower share for machine tools. The UK is strongly specialised on measuring and CIM while Italy has a clear priority in machine tools. The Netherlands are very strong in the field of regulating, and Sweden has a pronounced specialisation on robots. Switzerland and Austria are both specialised on machine tools, and Austria has also a priority in the field of regulating.

**Figure 8-12: Specialisation patterns of AMT patenting in Europe, by subfield and country (percent)**




*Difference between the share of a subfield in a country's total AMT patents and the respective share for Europe total.*

*Eight European countries with the largest number of AMT patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

Trends in AMT patenting by country and subfield differ considerably (Table 8-1). When comparing the growth in the number of patents applied by subfield for the 1990s (i.e. between the number of patents over the 1991-95 and the 1996-2000 periods) and the early 2000s (i.e. between 1996-00 and 2001-05), one can see a high growth in the field of CIM. Patent output in this subfield increased in the early 2000s at a higher pace than during the 1990s. This trend can be seen for all countries except Italy and the "rest of Europe". Patenting in the subfield of regulating also shows a higher growth rate for the more recent period, driven by increased patenting in Germany, France, the UK, Italy and the Netherlands. France, the UK, the Netherlands as well as Switzerland were also able to achieve a higher growth rate in the field of machine tools in the more recent period while Sweden and Austria report declining growth rates. France, Italy, the Netherlands, Switzerland and Austria show higher growth rates in the subfields of robots, measuring and controlling in the early 2000s compared to the 1990s.

**Table 8-1: Change in the number of AMT patents between 1991/95 to 1996/00 and 1996/00 to 2001/05 by subfield and country (EPO/PCT patents, compound annual growth rate in percent)**

| | DE | | FR | | UK | | IT | | NL | | SE | | CH | | AT | | RoE | | Europe total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b | a | b |
| Robots | 15 | 11 | 3 | 13 | 9 | 3 | -3 | 12 | 1 | 9 | 25 | 9 | 6 | 10 | 0 | 26 | 7 | 21 | 11 | 11 |
| Measuring | 11 | 6 | 0 | 11 | 4 | 6 | 9 | 9 | 4 | 14 | 9 | 5 | 8 | 10 | 5 | 11 | 12 | 10 | 8 | 8 |
| Controlling | 12 | 8 | 8 | 13 | 10 | 8 | 8 | 11 | 5 | 13 | 12 | 8 | 4 | 15 | 13 | 14 | 15 | 13 | 11 | 10 |
| Regulating | 4 | 6 | 0 | 11 | -1 | 10 | -3 | 8 | 7 | 14 | 13 | -2 | 6 | 3 | 9 | 8 | 8 | 13 | 4 | 8 |
| Tools | 9 | 9 | 4 | 7 | 3 | 6 | 8 | 8 | 5 | 7 | 13 | 0 | 3 | 7 | 18 | 9 | 8 | 10 | 7 | 8 |
| CIM | 17 | 18 | 7 | 24 | 7 | 20 | 22 | 16 | 8 | 22 | 15 | 21 | 23 | 15 | 0 | 25 | 24 | 18 | 14 | 19 |
| AMT total | 10 | 7 | 3 | 10 | 4 | 7 | 7 | 9 | 6 | 12 | 13 | 4 | 6 | 9 | 11 | 11 | 11 | 11 | 8 | 8 |

*a: compound annual growth rate of patent applications between 1991/95 to 1996/00*
*b: compound annual growth rate of patent applications between 1996/00 to 2001/05*
*Eight European countries with the largest number of AMT patents (based on inventors' locations) from 1981-2005. "RoE": all other European countries.*

*Source: EPO: Patstat, ZEW calculations.*

### 8.2.2. Links to Sectors and Fields of Technologies

#### *Technological links to sectors*

When linking AMT patents to industrial sectors based on the IPC classes to which a patent was assigned (so-called "technological sector links"), we find a rather focused sector relevance of AMT (Table 8-2). 28 percent of all AMT patents are linked to the instruments sector, followed by machinery (26 percent), electronics (21 percent) and vehicles (14 percent). The remaining sectors are only of minor importance. Moreover, patents from East Asian applicants show a significantly higher association with the electronics sector than North America and Europe. In contrast to this, European applicants' AMT patents are more frequently associated with the machinery sector than patents from North American and East Asian applicants.

**Table 8-2: Technological sector affiliation of AMT patents (EPO/PCT), by region (average of 1981-2007 applications, percent)**

| | Europe | North America | East Asia | **AMT total** |
|---|---|---|---|---|
| Food | 0 | 0 | 0 | **0** |
| Textiles | 0 | 0 | 0 | **0** |
| Wood/Paper | 1 | 1 | 1 | **1** |
| Chemicals | 2 | 2 | 2 | **2** |
| Pharmaceuticals | 0 | 0 | 0 | **0** |
| Rubber/Plastics | 3 | 2 | 2 | **2** |
| Glass/Ceramics/Concrete | 1 | 1 | 1 | **1** |
| Metals | 5 | 4 | 4 | **4** |
| Machinery | 28 | 25 | 24 | **26** |
| Electronics | 17 | 22 | 28 | **21** |
| Instruments | 28 | 28 | 25 | **28** |
| Vehicles | 15 | 14 | 15 | **14** |
| Total | 100 | 100 | 100 | **100** |

*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

Patents in the field of robots are primarily linked to the machinery industry as well as to electronics and instruments (Table 8-3). Measuring has strong technological links to the instruments industry important ones to the electronics and vehicles industry. Controlling patents are most important for the instruments industry, followed by electronics, vehicles and machinery. Regulating and CIM patents are strongly linked to the electronics industry, followed by machinery, instruments and vehicles, while patents on tools are important for the machinery industry, followed by metals and electronics.

**Table 8-3: Technological sector affiliation of AMZ patents (EPO/PCT), by subfield (average of 1981-2007 applications, percent)**

| Sector | Robots | Measuring | Controlling | Regulating | Tools | CIM | **AMT total** |
|---|---|---|---|---|---|---|---|
| Food | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Textiles | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wood/Paper | 2 | 1 | 1 | 2 | 1 | 2 | 1 |
| Chemicals | 1 | 2 | 2 | 4 | 2 | 1 | 2 |
| Pharmaceuticals | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Rubber/plastics | 2 | 3 | 2 | 1 | 3 | 1 | 2 |
| Glass/ceramics | 0 | 0 | 0 | 0 | 3 | 0 | 1 |
| Metals | 3 | 2 | 2 | 1 | 12 | 1 | 4 |
| Machinery | **51** | 9 | 16 | 27 | **54** | 12 | 26 |
| Electronics | 15 | 15 | 23 | **40** | 12 | **48** | 21 |
| Instruments | 18 | **50** | **32** | 13 | 8 | 25 | **28** |
| Vehicles | 8 | 17 | 22 | 10 | 5 | 9 | 14 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

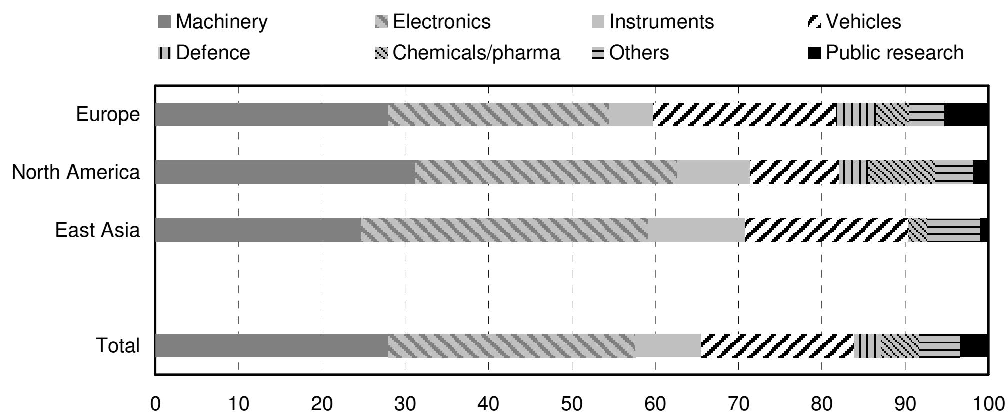
*Source: EPO: Patstat. Schmoch et al. (2003). ZEW calculations.*

### *Sector affiliation of applicants*

Regarding the sector affiliation of AMT patent applicants, it turns out that almost 80 percent of AMT patenting takes place in three sectors: machinery, electronics and vehicles (Figure 8-13). While a high share for machinery firms is straightforward and simply reflects that developing AMT is at the core of this industry, the high shares for vehicle and electronics manufacturer are more interesting. In the vehicles industry (particularly in automobile manufacturing), firms have to combine high quality and a high degree of product novelty (owing to short life cycles) with high cost efficiency. This situation requires continuous updating of process technologies. Since achieving high quality and low unit costs is a key competitive factor in both industries, most manufacturers are keen to develop in-house competencies in these technologies in order to avoid a too strong dependence upon external technology suppliers.

A similar situation is with the electronics industry. The high share of AMT patenting in this industry is also associated with the production of electronic components for AMT, particularly sensors for measuring, controlling and regulating processes, as well as for computer-integrated manufacturing and robotics. What is more, a number of large electronics companies have important automation businesses (e.g. Siemens, ABB, General Electrics).

**Figure 8-13: Sector affiliation of AMT patent applicants (EPO/PCT), by region (average of 1981-2007 applications, percent)**

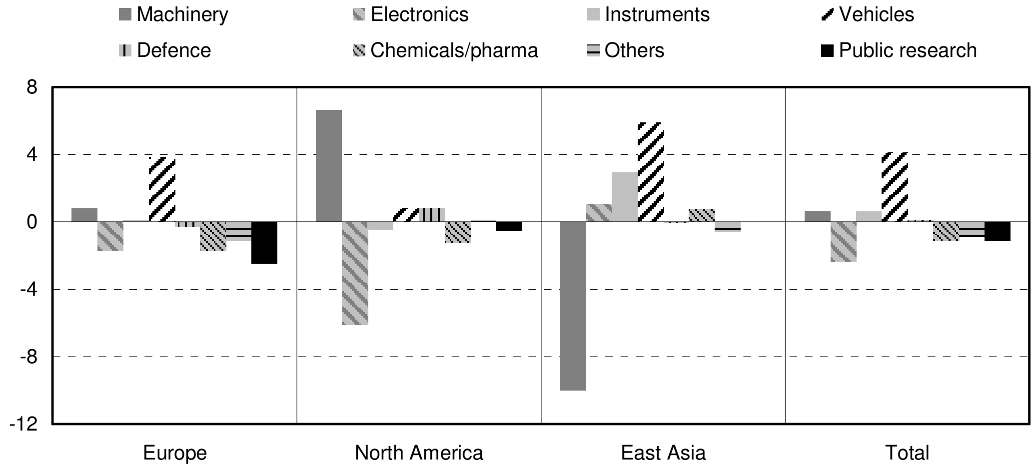



*Source: EPO: Patstat, ZEW calculations.*

The sector composition of AMT patents does not differ a lot across the three regions. In Europe, public research has a somewhat more important role than in North America and East Asia, though its share is still very low compared to other KETs. This reinforces the special character of this KET compared to the five other analysed in this report.

Current sector dynamics in AMT patenting show increasing shares for the vehicles industry in all three regions and declining shares for the electronics industry (Figure 8-14). Machinery has strongly gained in relative importance in North America, but lost in East Asia (at the expense of the electronics industry). Public research shows a declining share in AMT patenting particularly in Europe when the situation before and after the year 1999 is compared.

**Figure 8-14: Change in the sector affiliation of AMT applicants before and after the end of 1999 (EPO/PCT), by region (percentage points)**




*Source: EPO: Patstat. ZEW calculations.*

The electronics industry is the most important applicant sector for most subfields in AMT. 55 percent of patents in the field of regulating and 44 percent of all CIM patents were filed by companies from this industry (Table 8-4). Electronics is also a main source for patents in the fields of robots and controlling. The majority of measruing and machine tools patents is produced by companies from the machinery industry which is also a main sourdce for patents in the field of controlling and CIM. The vehicles industry (automotive, aircraft, railway vehicles, ships) is an important AMT patent producer in the fields of measuring, controlling, tools and robots. Another important AMT patents producing sector is the instruments industry, particularly for the field of measuring. Public research is of limited significant for AMT patenting.

**Table 8-4: Sector affiliation of applicants of AMT patents (EPO/PCT), by subfield (average of 1981-2007 applications, percent)**

| | Robots | Measuring | Controlling | Regulating | Tools | CIM |
|---|---|---|---|---|---|---|
| Machinery | **36** | **25** | 31 | 15 | **35** | 23 |
| Electronics | **36** | 24 | **34** | **55** | 22 | **44** |
| Instruments | 4 | 11 | 6 | 7 | 7 | 7 |
| Vehicles | 12 | 24 | 19 | 7 | 15 | 13 |
| Defence | 2 | 3 | 3 | 3 | 3 | 4 |
| Chemicals/pharma | 1 | 4 | 4 | 5 | 5 | 4 |
| Others | 2 | 4 | 2 | 5 | 8 | 3 |
| Public research | 6 | 4 | 2 | 4 | 4 | 2 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |

*Source: EPO: Patstat. ZEW calculations.*

The list of the 25 largest AMT patent applicants (in terms of the number of patents applied since 2000) is given in Table 8-5 for information purposes. Applications by subsidiaries are assigned to the parent company. Patents applied by firms that later have been acquired by other companies are assigned to the latter. For patent applications by more than one applicant fractional accounting applies. The list for Europe is led by three German companies: Siemens, Robert Bosch and Continental. In North America, Honeywell occupies the top position while in East Asia Fanuc applied for most patents.

**Table 8-5: 25 main patent applicants in AMT by region (EPO/PCT patents, 2000-2007 applications)**

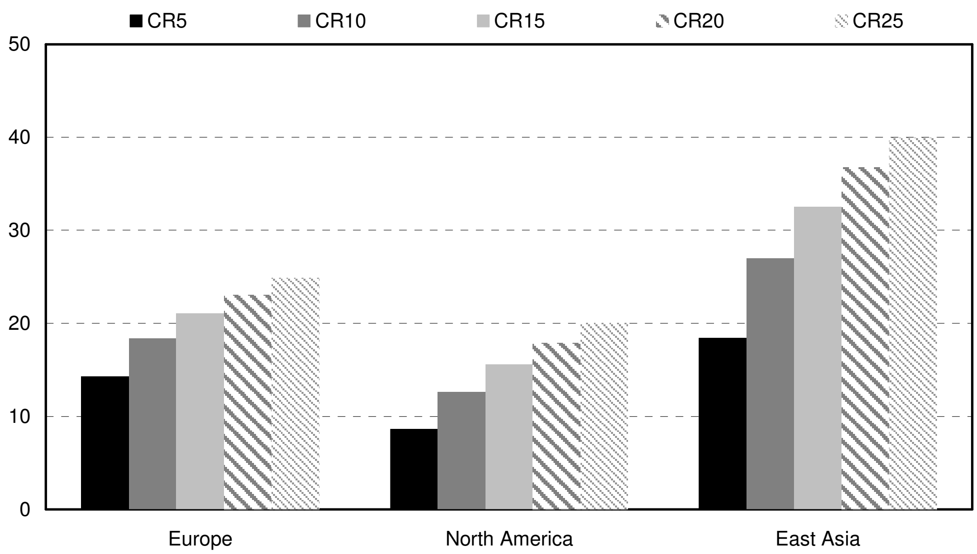
| Europe | | | | | North America | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Rank | Name | Country | Sector | No. of patents | Rank | Name | Country | Sector | No. of patents |
| 1 | Siemens | DE | electronics | 1847 | 1 | Honeywell | US | machinery | 573 |
| 2 | Robert Bosch | DE | vehicles | 1348 | 2 | General Electric | US | electronics | 515 |
| 3 | Continental | DE | vehicles | 635 | 3 | Delphi | US | vehicles | 250 |
| 4 | Endress + Hauser | CH | machinery | 589 | 4 | United Technolog | US | machinery | 201 |
| 5 | ABB | CH | electronics | 555 | 5 | Rosemount | US | machinery | 157 |
| 6 | EADS | FR | defence | 274 | 6 | Boeing | US | defence | 141 |
| 7 | Daimler | DE | vehicles | 270 | 7 | Rockwell Automa | US | machinery | 140 |
| 8 | Philips | NL | electronics | 254 | 8 | Illinois Tool Work | US | machinery | 126 |
| 9 | STMicroelectronics | IT | electronics | 189 | 9 | Agilent Technolo | US | machinery | 126 |
| 10 | Heidenhain | DE | machinery | 171 | 10 | 3M | US | chemicals | 108 |
| 11 | Thales | FR | defence | 169 | 11 | Lincoln Global | US | electronics | 99 |
| 12 | Fraunhofer | DE | research | 164 | 12 | Hewlett-Packard | US | electronics | 93 |
| 13 | Comm. a l'energie atom. | FR | government | 164 | 13 | Ford | US | vehicles | 88 |
| 14 | Trumpf | DE | machinery | 159 | 14 | Black & Decker | US | machinery | 79 |
| 15 | Rolls-Royce | GB | machinery | 140 | 15 | Johnson Controls | US | vehicles | 71 |
| 16 | Valeo | FR | vehicles | 139 | 16 | Micro Motion | US | machinery | 71 |
| 17 | ZF Friedrichshafen | DE | vehicles | 134 | 17 | John Deere | US | machinery | 69 |
| 18 | Renault | FR | vehicles | 124 | 18 | Newfrey | US | machinery | 67 |
| 19 | KUKA | DE | machinery | 124 | 19 | Xerox | US | instruments | 66 |
| 20 | Carl Zeiss | DE | instruments | 123 | 20 | Pitney Bowes | US | machinery | 60 |
| 21 | SNECMA | FR | defence | 122 | 21 | Texas Instrument | US | instruments | 60 |
| 22 | BMW | DE | vehicles | 121 | 22 | Microsoft | US | software | 60 |
| 23 | Alstom | FR | electronics | 121 | 23 | Motorola | US | electronics | 59 |
| 24 | Infineon | DE | electronics | 121 | 24 | Eaton | US | machinery | 58 |
| 25 | VEGA Grieshaber | DE | instruments | 121 | 25 | General Motors | US | vehicles | 53 |

| East Asia | | | | |
|---|---|---|---|---|
| Rank | Name | Country | Sector | No. of patents |
| 1 | Fanuc | JP | machinery | 574 |
| 2 | Matsushita Electric | JP | electronics | 504 |
| 3 | Honda | JP | vehicles | 344 |
| 4 | Hitachi | JP | electronics | 338 |
| 5 | Samsung | KR | electronics | 294 |
| 6 | Toyota | JP | vehicles | 262 |
| 7 | Sony | JP | electronics | 243 |
| 8 | JTEK | JP | vehicles | 215 |
| 9 | Fujitsu | JP | electronics | 177 |
| 10 | Alps Electric | JP | electronics | 168 |
| 11 | Seiko | JP | instruments | 165 |
| 12 | Canon | JP | instruments | 163 |
| 13 | Nissan | JP | vehicles | 159 |
| 14 | LG Electronics | KR | electronics | 159 |
| 15 | Omron | JP | machinery | 155 |
| 16 | Denso | JP | vehicles | 145 |
| 17 | Toshiba | JP | electronics | 125 |
| 18 | Mitsubishi Motor | JP | vehicles | 125 |
| 19 | Fujifilm | JP | chemicals | 101 |
| 20 | Mitutoyo | JP | instruments | 100 |
| 21 | Sumitomo Rubber | JP | materials | 83 |
| 22 | Yamaha | JP | vehicles | 81 |
| 23 | NEC | JP | electronics | 77 |
| 24 | Yamazaki Mazak | JP | machinery | 75 |
| 25 | NGK Insulators | JP | instruments | 75 |

*Source: EPO: Patstat. ZEW calculations.*

The concentration of patent applications on a few applicants can be quantified by using concentration measures. Figure 8-15 shows the concentration of patenting activity in AMT on the basis of five concentration measures indicating the share of patents for which the 5 percent (CR5), 10 percent (CR10), 15 percent (CR15), 20 percent (CR20), and 25 percent (CR25) most patenting active firms account for.

**Figure 8-15: Concentration of patenting activity in AMT (EPO/PCT patents, 1981-2007 applications; percent)**

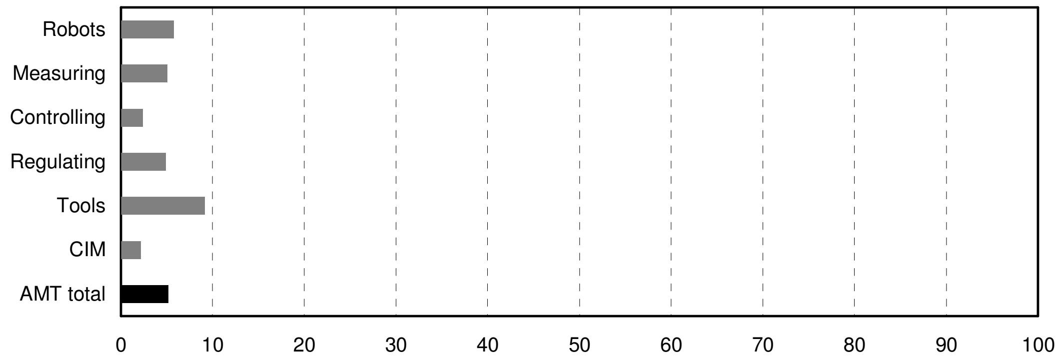



*Source: EPO: Patstat. ZEW calculations.*

### *Links to other KETs*

Related to the issue of sector links is the degree to which AMT patents are linked to other KETs. One way to assess likely direct technological relations is to determine the share of AMT patents that are also assigned to other KETs (because some IPC classes assigned to a AMT patent are classified under other KETs). The degree of overlap of AMT patents with other KET patents is very low (Figure 8-16). Only 5 percent of all AMT patents have been co-assigned to other KETs. This share is highest in the subfield of machine tools (almost 10 percent) and very low in CIM and controlling. This result indicates that patents in the other five KETs are not directly related to process technology, though they have great potentials to affect technological advance in AMT, e.g. by providing better materials, new approaches to measuring through new photonics applications or more efficient microelectronics for controlling and regulating.

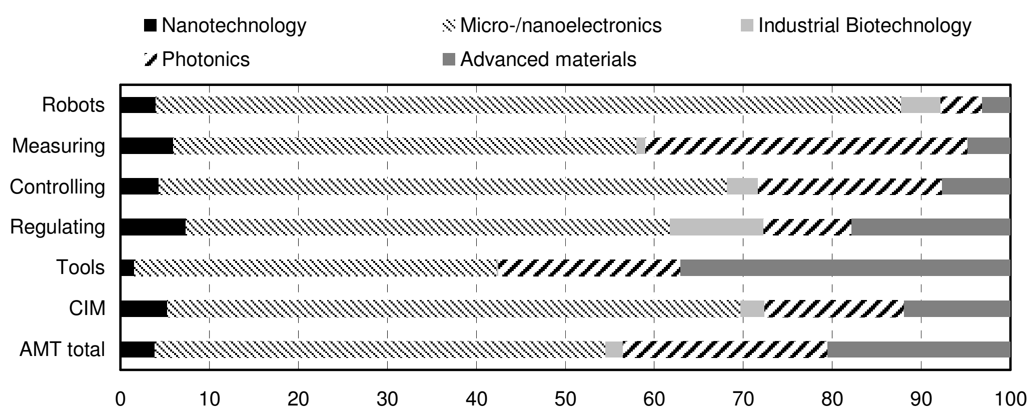
**Figure 8-16: Share of AMT patents linked to other KETs by subfield (EPO/PCT patents 1981-2007, percent)**




*Source: EPO: Patstat. ZEW calculations.*

For those AMT patents that are linked to other KETs, one can see that the largest overlap is with the field of microelectronics (more than 50 percent, with particularly high shares in the fields of robots, controlling, CIM, measuring and regulating) (Figure 8-17). Almost 25 percent of AMT patents with co-assignment to other KETs are linked to photonics, and about 20 percent related to advanced materials. Overlapping with industrial biotechnology is negligible. Out of the 10 percent of machine tools patents that overlap with other KETs, many are linked to microelectronics and advanced materials.

**Figure 8-17: Links of AMT patents to other KETs by subfields (EPO/PCT patents 1981-2007, only patents with links to other KETs, percent)**




*Source: EPO: Patstat. ZEW calculations.*

### 8.2.3. Market Potentials

Market forecasts are available for different subfields of the AMT market. Common to all these forecasts is the methodological challenge of how to delineate the market for AMT. AMT are an integral part of manufacturing processes in a multitude of industries which considerably complicates the delineation of a market. Table 8-6 follows a different approach and lists market sizes and forecasts for a number of subfields in AMT, including chemical process monitoring devices, continuous monitoring, non-destructive testing, machine vision, pharmacy automation, automotive sensor technologies, and robotics.

**Table 8-6: Estimates and forecasts for the size of the global AMT market (billion US-$)**

| Subfield | Source | 2005/06 | 2007/08 | 2010/11 | 2012/13 | ~2015 | Cagr* |
|---|---|---|---|---|---|---|---|
| Chemical process monitoring devices | BCC (2005) | 49.1 | | 61.8 | | | 3.9 |
| Continuous monitoring | BCC (2005) | 21.0 | | 32.4 | | | 9.1 |
| Nondestructive testing | BCC (2005) | 2.2 | | 3.1 | | | 5.9 |
| Machine vision | BCC (2006) | 8.1 | | | 15.0 | | 10.8 |
| Pharmacy automation | BCC (2006) | 2.1 | | | 3.6 | | 9.4 |
| Automotive sensor technologies | BCC (2008) | | 12.0 | | | 19.0 | 5.9 |
| Robotics | BCC (2008) | | 17.3 | | | 21.4 | 3.6 |
| Machine tools | VDW | | 77.2 | | | | |

** Compound annual growth rate in nominal terms (percent).*

*Source: Compilation by ZEW based on the references quoted.*

The collection of market estimates and forecasts can only highlight the expected development in a selected number of subfields. Nevertheless, several interesting insights can be derived. In this respect, it turns out that the average CAGR is estimated with about 7 percent which signals an overall highly interesting market in terms of growth opportunities. The highest growth rate is found in the machine vision subfield, followed by pharmacy automation and continuous monitoring. The relatively low growth rate in robotics can be explained by the already substantial use of robotics in modern manufacturing and the correspondingly high level of the market size.

Owing to the cross-cutting nature of AMT, it is not possible to aggregate the numbers presented in Table 8-6 in order to arrive at a consolidate figure of the market in AMT. In addition, in Table 8-6 does not include market figures for all submarkets of advanced manufacturing technologies. Nevertheless, one may estimate that the global market volume of AMT in 2006/08 exceeded $150 billion. In 2015 one may expect this market to have risen to more than $200 billion, assuming a rapid recovery of the market after the sharp downturn in 2009 and an average annual rate of growth of about 5 percent.

### 8.2.4. Factors influencing the future development of AMT

***Factors influencing the future market potential of AMT***

The previous chapters have made clear that AMT are a cross-sectional technology that is important for a large number of manufacturing sectors. The future market development will therefore depend on the market development in the sectors in which AMT are of central importance. Innovation in AMT is typically characterised as incremental and it is immediately connected to the specific needs of the firm applying AMT. This customisation of AMT reduces at the same time the risk that manufacturing technologies are easily copied by competitors or substituted by competing technologies. At the same time, technology adoption can be expected to increase in the future because of the need to produce even more cost efficiently and in an environment friendly way.

***The role of public support***

Public support of AMT should particularly be centred on three policy fields. First, access to technological information is important. Providers of highly advanced technological information can typically be found among the universities and public research organisations (PRO). As a result, it is important to facilitate the exchange between universities, PRO and industry, for example by encouraging the creation of technology transfer offices at the research institutes. Moreover, the functionality of markets for technology can be expected to increase when intellectual property rights (IPR) are well-defined and assigned to the research institutes such that technology transfer offices can engage in IPR sale or licensing negotiations with interested industrial firms.

Second, AMT are largely dependent on a highly skilled workforce as they require a complex set of flexible skills that include high technology as well as interdisciplinary skills that allow for collaborative working. In this respect, public support will be particularly helpful in launching measures that encourage young people to catch an interest in science, technology, engineering and mathematics subjects. At the same time, additional places for students need to be provided in these subject areas.

Third, AMT are characterised by the emergence of several new platform technologies that are multifunctional and that have a range of manufacturing applications. These platform technologies include for example plastic electronics, silicon design, renewable chemicals and carbon fibre composites that may replace various metals. Despite their early stage of technological development, these platform technologies potentially offer substantial economic opportunities. Public support can specifically facilitate the further development and adoption of these platform technologies through initiatives like grants for collaborative R&D, support for knowledge transfer networks as well as for collaboration between small and medium sized enterprises and large enterprises.

***Contribution of AMT to social wealth***

There are several potential contributions of AMT to social wealth. First of all, environmental friendly manufacturing is hardly possible without an extensive use of AMT, which can be assumed to increase the efficiency of the entire manufacturing process. By increasing efficiency, AMT may limit the consumption of raw materials and energy as well as decrease the waste resulting from the manufacturing process.

AMT may also incur manufacturing processes to become more user-friendly as they reduce the amount of hard labour that is needed in the manufacturing process and that is taken over for example by robots. As a result, health of the employees can be expected to improve as work-related accidents go down.

***Importance of sustaining production capabilities***

AMT have been characterised as requiring a solution tailored to a specific customer's needs. In this regard, production capabilities allow for an application of newly developed AMT and facilitate experimental learning that can be assumed to be valuable in future technology development efforts. Sustaining production capabilities can therefore be considered as utmost important for R&D activities in AMT.

## 8.3 Conclusions and Policy Implications

Advanced manufacturing technologies can be characterised as all technologies that significantly increase speed, decrease costs or materials consumption, and improve operating precision as well as environmental aspects like waste and pollution of manufacturing processes. They are a combination of different technologies and practices that aim at improving processes of manufacturing goods. AMT are responsible for 10.5 percent of the EU's industrial production and associated 2.2 million jobs. They account for 19 percent of EU exports and over 40 percent of EU private sector R&D expenditure.

Costs for investment into AMT are high, and they are combined with uncertainty over the advantages of new generations of manufacturing technologies (i.e. degree of cost savings and other efficiency gains unclear at the time of investment). Moreover, costly tailor-made adjustments are necessary. Adjusting and using AMT also requires in-house capabilities for dealing with new technologies (skills of workers, coordination among departments, integration of suppliers and customers).

***Europe's technological position***

Developing AMT is highly concentrated on the three global regions Europe, North America and East Asia. European patent applicants dominate with a market share of almost 50 percent, followed by North American (around 30 percent) and East Asia (around 20 percent). Market shares have remained rather stable over the last decades. With respect to patents per GDP, it turns out that Europe has a significantly higher patent intensity than East Asia and North America.

The largest subfield in AMT is measuring, followed by tools and controlling. The composition of subfields does not differ considerably by region. European applicants tend to have a higher share in tools while North American and East Asian applicants have higher shares in CIM. However, Europe has improved its market share over time particularly in CIM. When looking at the technology market shares by subfield over time, Europe shows rather high market shares, though market shares are decreasing in all subfields except for robots and CIM. Europe's market shares are highest in measuring, controlling, regulating and tools with around 50 percent each. North American applicants are particularly strong in CIM while East Asian applications show a rather high market share in robots.

***Links to disciplines and sectors***

AMT is particularly relevant to the instruments, machinery, electronics and vehicles sectors. Regarding the subfields, patents in the field of robots are primarily linked to the machinery industry as well as to electronics and instruments. Measuring has strong technological links to the instruments industry important ones to the electronics and vehicles industry. Controlling patents are most important for the instruments industry, followed by electronics, vehicles and machinery. Regulating and CIM patents are strongly linked to the electronics industry, followed by machinery, instruments and vehicles, while patents on tools are important for the machinery industry, followed by metals and electronics.

Current sector dynamics in AMT patenting show increasing shares for the vehicles industry in all three regions and declining shares for the electronics industry. Machinery has strongly gained in relative importance in North America, but lost in East Asia (at the expense of the electronics industry). Public research shows a declining share in AMT patenting particularly in Europe when the situation before and after the year 1999 is compared.

Regarding the concentration of AMT patenting among a few patent applicants, it turns out that concentration is highest in East Asia, followed by Europe and North America. However, East Asia shows a higher number of firms with substantial patenting activity than Europe. Concentration in North America is generally lower.

***Market prospects and growth impacts***

Market forecasts are available for different subfields of the AMT market. Because of the cross-cutting nature of AMT, it is not possible to simply aggregate the numbers in order to arrive at a consolidate figure of the market in AMT. Moreover, delineating "advanced" from less "advanced" manufacturing technologies is extremely difficult and highly subjective in nature. By and large, any producer of manufacturing technology attempts to further advance the state of technology by developing new equipment that enables more complex and higher quality processing of materials and tools. Tentative estimates for the total market of AMT arrive at global sales (prior to the economic crisis of 2009) of more than 150 billion.

When growth in the different subfields is analysed, the compound annual growth rate ranges between 4 percent and 11 percent which signals an overall interesting market in terms of growth opportunities. The highest growth rate is found in the machine vision subfield, followed by pharmacy automation and continuous monitoring. The relatively low growth rate in robotics can be explained by the already substantial use of robotics in modern manufacturing and the correspondingly high level of the market size.

Because of the cross-cutting nature of AMT, their future market development critically depends on how other sectors where AMT are relevant develop and grow. It seems therefore reasonable to assume that market prospects in AMT are pretty much tied to GDP growth in general plus an additional factor that reflects the dynamics of AMT.

***Success factors, market and system failures***

AMT is a field of technology with a huge number of industrial companies engaged in various subfields. Though AMT is perhaps the oldest KET in human history and is a key industrial sector since the emergence of modern industry, the AMT industry did not undergo a concentration process as many other high-technology industries did. Manufacturers of AMT are mainly medium-sized firms, typically highly specialised on specific fields of application. Research in AMT takes place in many different companies while public research plays a rather small role compared to other KETs. A key success factor for technological advance in manufacturing technologies is to combine new technological opportunities emerging from different fields of technology (including most other KETs covered in this report, particularly microelectronics, photonics and advanced materials, but also including software) with the specific needs of users in specific industry. Developing AMT thus means to have a deep understanding of the industry in which this technology will be applied, and which factors dirve competitiveness in the user industries. Another main success factor is to balance user-specific requirements with new technological opportunities yet out of sight of users.

A main barrier for commercialising AMT is potential users that hesitate to adopt new manufacturing technologies. The reasons may be manifold:

Information asymmetries over the expected returns of AMT compared to established technologies can result in low adoption rates (i.e. degree of cost savings and other efficiency gains unclear at the time of investment);

high investment cost may exceed the available internal funds of users, particularly for SMEs, while external financing through loans can be difficult if the technology is completely new and no experience over the likely returns are available to banks;

many AMT require tailor-made adjustments, which are costly and time-consuming;

in-house capabilities for dealing with new technologies -skills of workers, coordination among departments, integration of suppliers and customers- may be missing and cannot be built up in short term;

introducing AMT may need adjustments to the product produced which may result in complex changes in a firm's internal and external organisation (involving marketing and users).

Developing AMT can be hampered by small market volumes for certain new applications, particularly if user-specific designs are required. This limits the possibilities to employ the identical technology in many different companies and reduces economies of scale both in R&D and production of AMT.

Another peculiarity in AMT is the fact that AMT is not only developed by specialised technology producers (e.g. mechanical engineering firms), but also to a great extent by users (i.e. any type of manufacturing firm). The main reason for manufacturing firms to refrain from purchasing AMT from external producers is their outstanding importance as competitive factor in many industries. Sectors where production efficiency (i.e. unit prices) are the key driver for commercial success, companies will attempt to control critical production technologies and develop technological advantages over competitors.

***Policy options***

Policy intervention in favour of developing and commercialising AMT should not focus primarily on the side of developing these technologies (which is the task of specialised firms), but put equal emphasis on diffusing them. Supporting the development of AMT could rest on a set of proven policy tools such as public-private partnerships in developing new technologies (e.g. public co-funding of R&D) and programmes that bring together public research and companies. In some countries, co-operative sectoral research initiatives have been successful in this respect tool.

Innovation policy has also gained extensive experience in promoting the rapid and broad diffusion of AMT. In the 1980s and 1990s several countries run programmes that supported the diffusion of computer-integrated manufacturing technologies and other types of flexible manufacturing (see Link and Kapur, 1994). Many of these programmes proved to be successful (see Polt and Pointner, 2005; Arvanitis and Hollenstein, 1997, 1999; Arvanitis et al., 1998; Shapira and Youtie, 1998). Common findings of evaluations include the role of consulting, skills and training, to combine access to external funding (loans), to stress the critical role of human capital in upgrading technology successfully and to stimulate co-operation and mutual learning among SMEs. Typically, programmes that focus on smaller firms tend to be more effective than support of larger firms since barriers to adoption increase as firm size decreases.

# 9 SUMMARY AND CONCLUSIONS

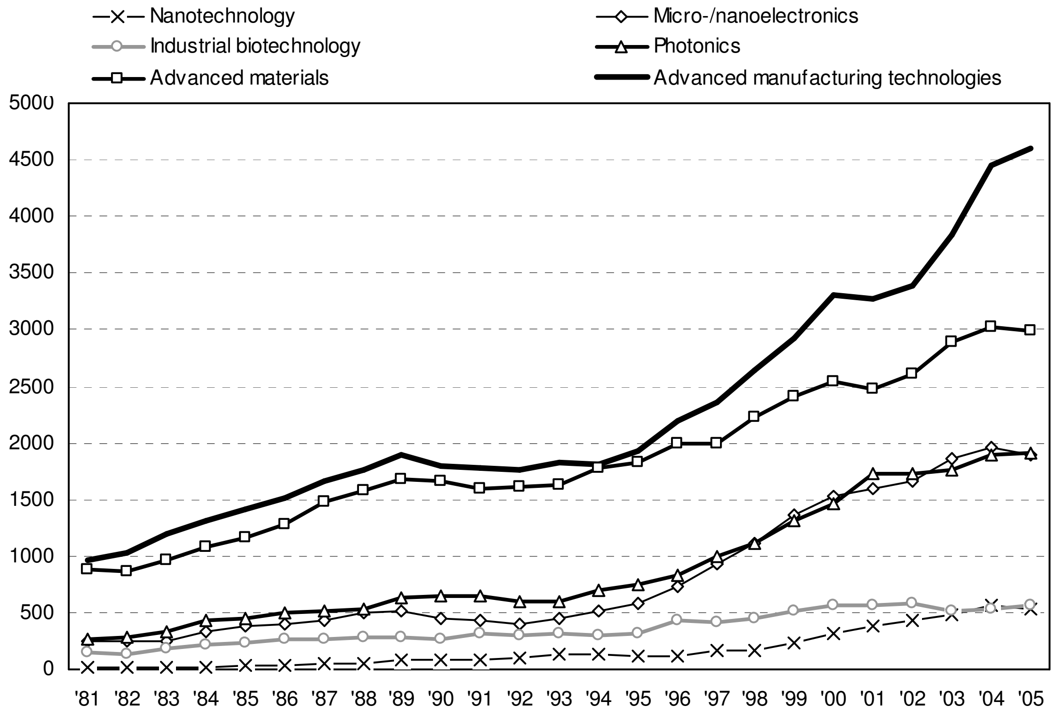
This report made an attempt to assess the technological competitiveness of Europe in six fields of key enabling technologies (KETs): nanotechnology, micro- and nanoelectronics, industrial biotechnology, photonics, advanced materials and advanced manufacturing technologies. The main purpose of the study was to apply a uniform methodology that allows for quantitative and qualitative analyses of technological performance as well as the strengths and weaknesses of each KET in Europe. For quantitative analysis, patent data were employed. Qualitative analysis of success factors, barriers and market and system failures rest on detailed analysis of ten selected clusters (five from Europe, five from overseas). This chapter summarises main findings of the report in a comparative way.

## 9.1 Technological performance

*Dynamics in Patenting*

The number of patent applications (EPO/PCT patents) by European applicants considerably increased in all six KETs over the past ten years (Figure 9-1). While the number of patents cannot be directly compared across KETs because of different definition criteria of patent classes that are used to delineate a certain KET as well as because of different patenting strategies, technology content and inventive HÖHE, one still can see that KETs differ significantly in the amount of new technology that is generated within each KET. Advanced manufacturing technologies and advanced materials tend to be rather large fields with several thousands new patents applied by European applicants every year, while photonics and microelectronics are smaller in size. In nanotechnology and industrial biotechnology, European applicants generate only about 500 patents per year.

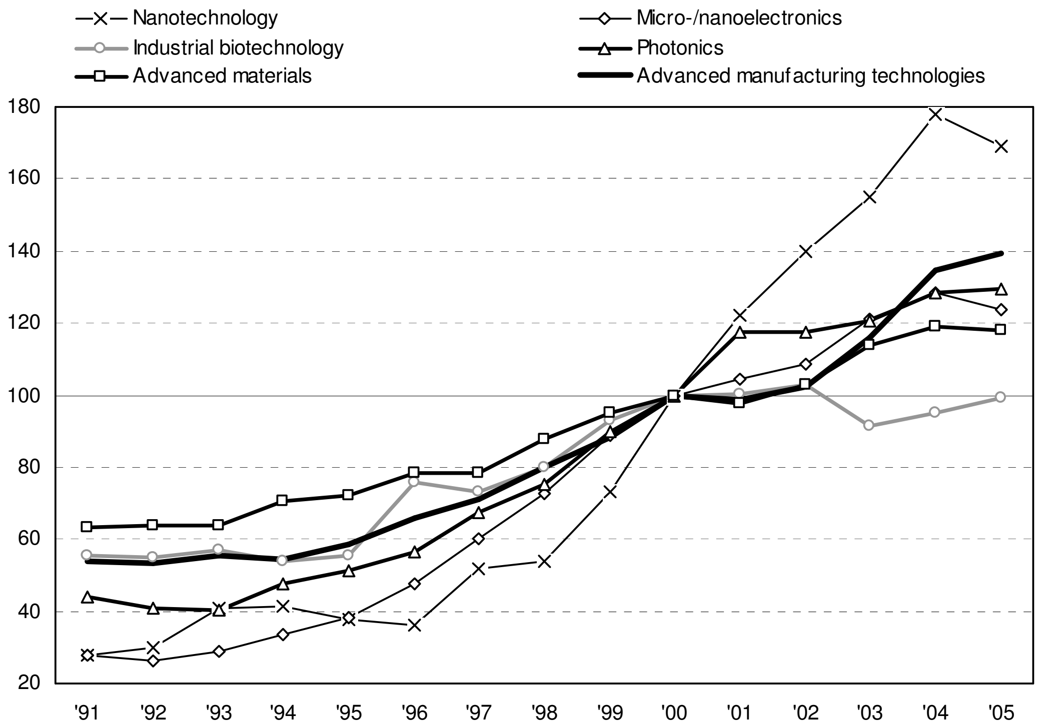
**Figure 9-1: Number of patents by European applicants 1981-2005 (EPO/PCT patents), by KET**




*Source: EPO: Patstat. ZEW calculations.*

Nanotechnology shows the largest increase in patenting over the past 15 years (Figure 9-2). All other KETs except industrial biotechnology also show a continuous upwards trend in the number of yearly patent applications, though at a more moderate pace. Advanced manufacturing technologies reports a quite significant increase recent years while patenting in microelectronics grew strongly until 2000 but less rapidly afterwards. Photonics shows a strong growth until 2001, followed by only modest growth rates. The annual number of patents in advanced materials rose steadily, though at a modest rate. Patenting in industrial biotechnology grew until 2000. After that year, the annual number of patent applications by European applicants remained stable.

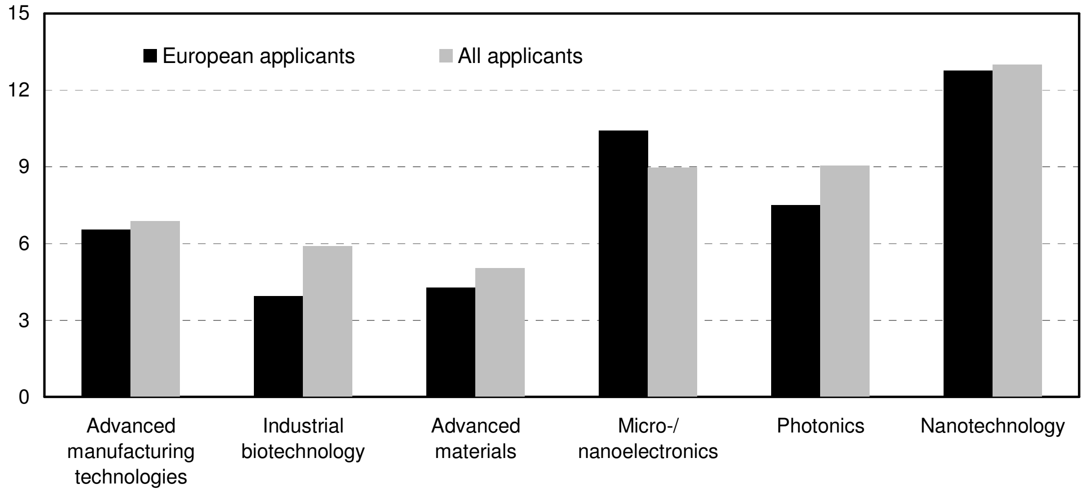
**Figure 9-2: Dynamics of patent applications in KETs by European applicants 1991-2005 (EPO/PCT patents; 2000=100)**




*Source: EPO: Patstat. ZEW calculations.*

When looking at the entire period 1991-2005, compound annual growth rates of the number of EPO/PCT patent applications by European applicants were highest in nanotechnology (13 percent), followed by microelectronics (10 percent) and photonics (8 percent) (Figure 9-3). Patenting in advanced manufacturing technologies grew by 7 percent, while growth rates were lower in advanced materials and industrial biotechnology (4 percent). Growth rates in Europe were above the world average only in microelectronics. The number of patents increased at the global growth rate in nanotechnology and advanced manufacturing technologies. The other three KETs (advanced materials, photonics, industrial biotechnology) show below average growth rates for Europe.

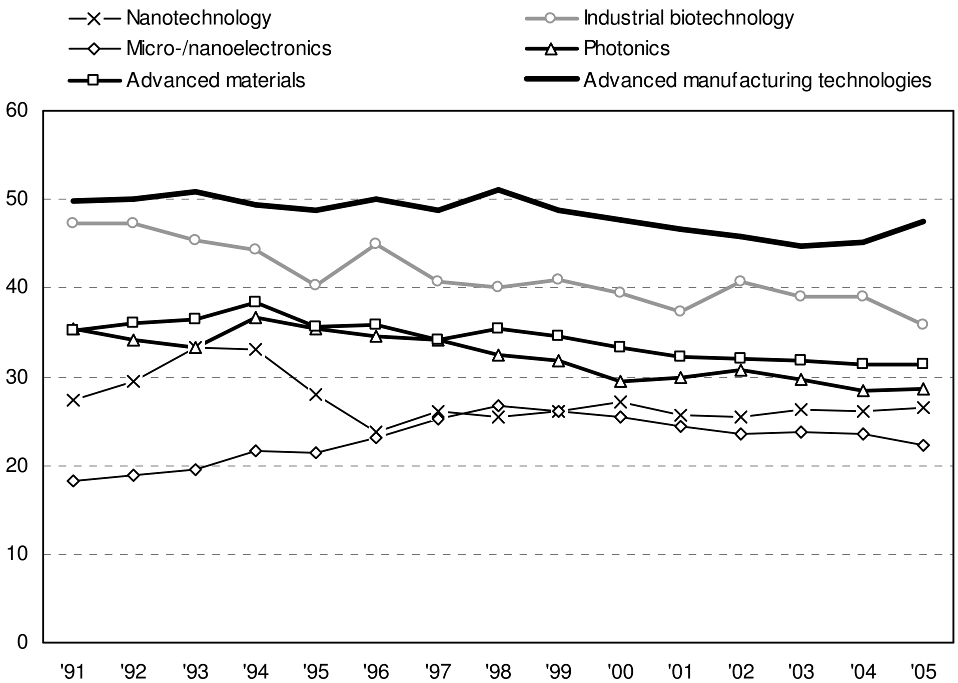
**Figure 9-3: Compound annual growth rate of the number of patents 1991-2005 (EPO/PCT patents; percent), by KET**




*Source: EPO: Patstat. ZEW calculations.*

Europe's share in the global production of new technological knowledge in KETs varies considerably by field of technology (Figure 9-4). Market shares are high in advanced manufacturing technologies (48 percent in 2005) and industrial biotechnology (36 percent). In both KETs, Europe produces more patents than North America or East Asia. While Europe could sustain its high market share in advanced manufacturing technologies over the past 15 years, Europe's share in the total output of industrial biotechnology patents felt significantly (from 48 percent down to 36 percent).

**Figure 9-4: Market share of Europe in KETs 1991-2005 (EPO/PCT patents; percent)**



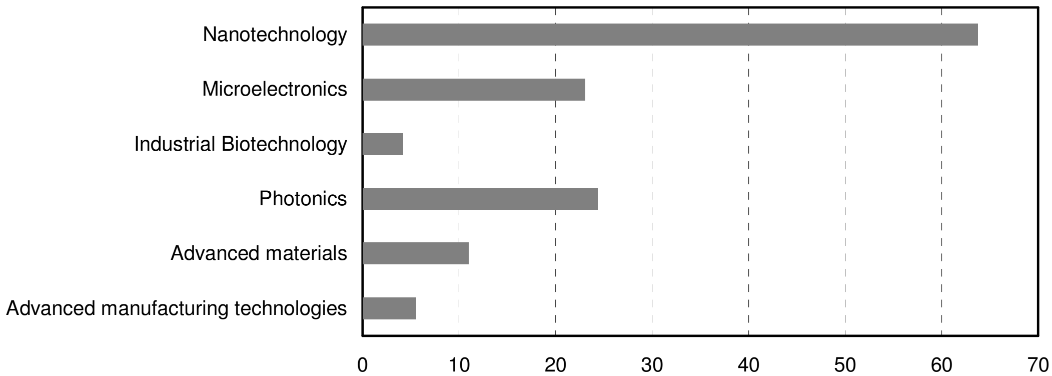

*Source: EPO: Patstat. ZEW calculations.*

Lower market shares are reported for advanced materials (32 percent) and photonics (29 percent). Both KETs show slightly decreasing shares for Europe over time. Europe's market share in nanotechnology is rather low (27 percent) though slowly increasing since 1996. In microelectronics, Europe could raise its share in global patenting from 1991 to 1998 but experienced a decreasing market share since then, falling to 22 percent in 2005.

*Overlap between KETs*

The six KETs are technologically linked to each other to some extent. One may determine the degree of overlap by identifying the share of patents from one KET which are at the same time classified as patents of another KET. Such overlap results from the fact that one patent may be assigned to many different IPC classes, some define one KET, others another. Figure 9-5 shows that nanotechnology strongly overlaps with other KETs. 64 percent of all patents assigned to nanotechnology have also been assigned to another KET: For photonics and microelectronics, this share is 24 and 23 percent, respectively. Less overlap occurs with advanced materials (11 percent) and almost none with advanced manufacturing technologies (6 percent) and industrial biotechnology (4 percent).

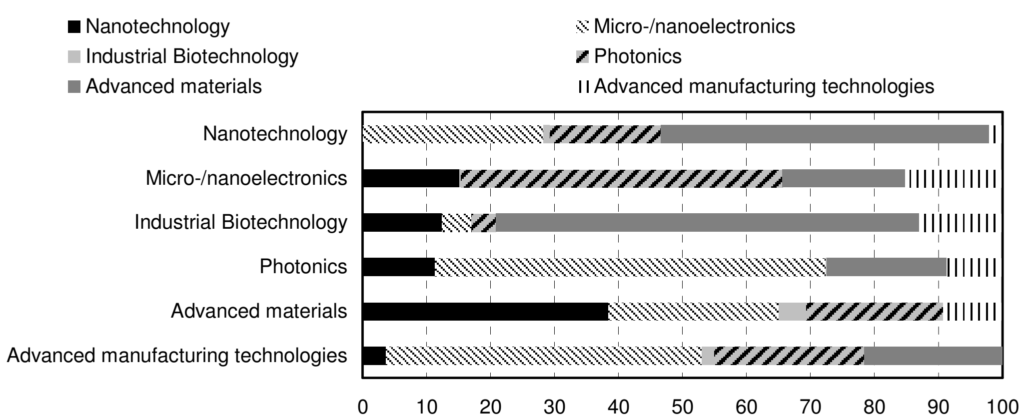
**Figure 9-5: Share of patents by KET that have been assigned to other KETs (EPO/PCT patents 1981-2007; percent)**




*Source: EPO: Patstat. ZEW calculations.*

The high degree of overlap in nanotechnology is due to three subfields within nanotechnology. Nanomaterials are also part of advanced materials. Many nanoelectronics patents are linked to microelectronics, and most nanooptics patents are also classified as photonics patents (Figure 9-6). Microelectronics and photonics show a considerable overlap with each other. The rather low degree of overlap in advanced materials relates to nanotechnology, microelectronics and photonics. Of the few advanced manufacturing technologies patents with co-assignement to other KETs, microelectronics, photonics and advanced materials are the three most important KETs. The very few industrial biotechnology patents with a link to other KETs primarily relate to advanced materials.

**Figure 9-6: Links to other KETs of overlapping patents by KET (EPO/PCT patents 1981-2007; percent)**

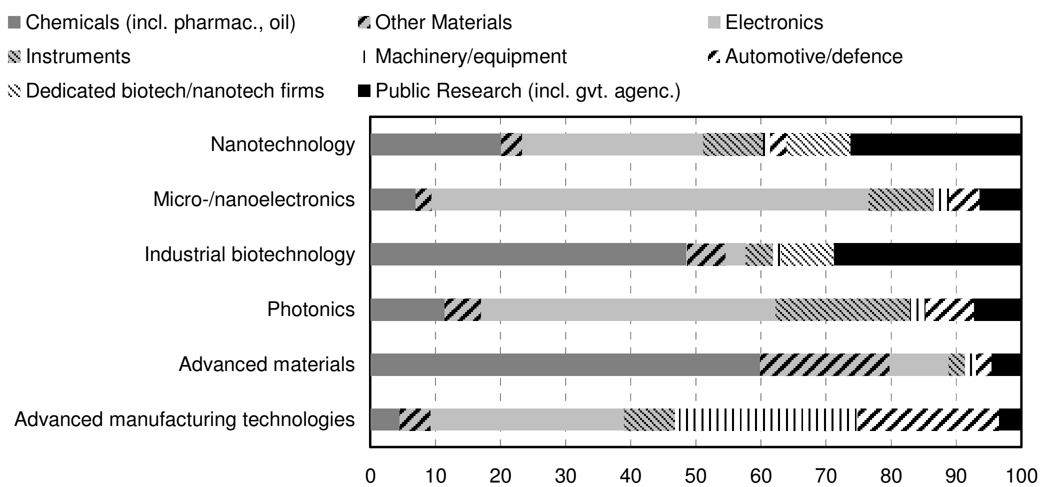



*Source: EPO: Patstat. ZEW calculations.*

*Sector links*

The six KETs show quite different links to economic sectors. Based on an analysis of the sector affiliation of the most important patent applicants (covering between 60 and 100 percent of all patents, depending on the KET), we find a focus of advanced materials and industrial biotechnology on the chemical industry (including pharmaceuticals and processing of petroleum). Microelectronics and photonics are rather closely linked to the electronics industry as well as to the manufacturer of instruments. Most patents in advanced manufacturing technologies are produced by companies from the electronics, mechanical engineering and automotive/defence industries. Nanotechnology patents primarily come from the electronics and chemical industry industries, though public research and dedicated nanotechnology and biotechnology companies are also very important sources for technological advance in this KET. Together they account for more than 35 percent of all patents. This also holds true for industrial biotechnology. In the other four KETs, public research and dedicated technology companies are of minor importance as producer of patents.

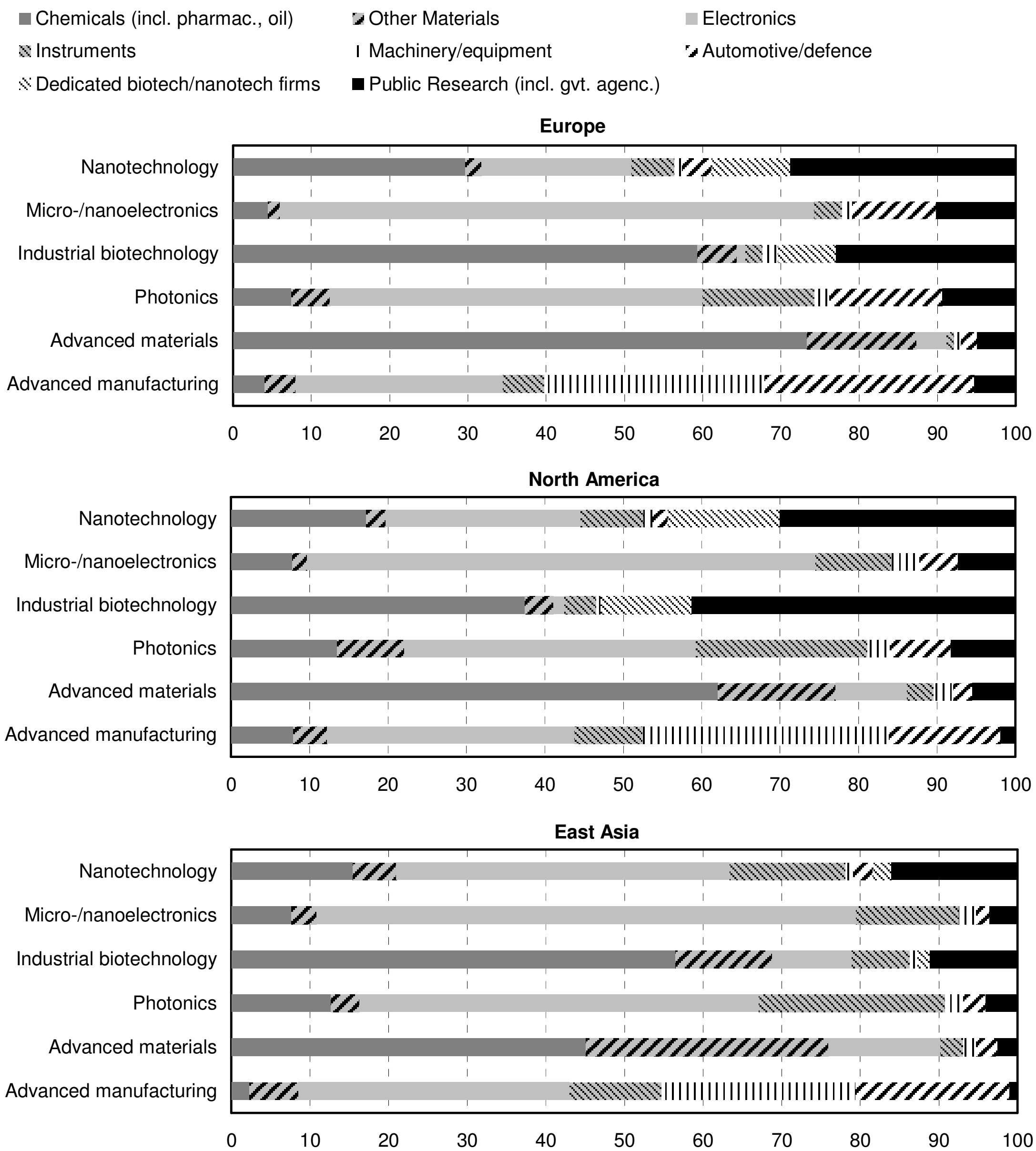
**Figure 9-7: Sector affiliation of patent applicants by KET (EPO/PCT patents 1981-2007; percent)**




*Source: EPO: Patstat. ZEW calculations.*

There are some singificant differences in the sector composition of the actors that produce new technologies in each KET among the three main regions (Europe, North America, East Asia). Europe and North America show higher shares for public research, and North America reports the highest shares for dedicated technology companies in nanotechnology and industrial biotechnology. Europe reports very high shares for the chemical industry in nanotechnology, industrial biotechnology and advanced materials, but below-average shares in microelectronics and photonics. The electronics industry is of higher importance in East Asia in all six KETs, reflecting the specialisation of this region on manufacture of electronic products. In Europe, the automotive industry (including to a small extent also manufacture of aircraft and defence technologies) is of greater significance as patent producer compared to the other two regions. The manufacturers of instruments are more important in North America and East Asia than in Europe for most KETs.

**Figure 9-8: Composition of overlapping patents by KETs (EPO/PCT patents, 1981-2007 applications; percent)**




*Source: EPO: Patstat. ZEW calculations.*

*Summary overview*

Table 9-1 makes an attempt to summarise main results of the quantitative analysis conducted in this study. Over the past 15 years, nanotechnology is the KET with highest growth in patent output, followed by microelectronics and photonics. Industrial biotechnology and advance materials show rather slow increases in the generating of new technological knowledge. The strong growth in nanotechnology patenting helped Europe to maintain its market share in global patent output. In microelectronics Europe was even able to gain in market shares, though startging from a very low level. Europe's position is strongest in advanced manufacturign technologies with a market share of almost 50 percent which coulde be sustained over the past 15 years. Europe is also leading in patent output in industrial biotechnology though loosing significantly in global shares. When looking at subfields within KETs, it turns out there is at least one subfield in each KET where Europe performs particularly well, but there are also several subfields with weak performance. As a consequence, attention to KETs should be aware of the wide variety of individual technologies within each area and that competitiveness differs by subfields.

**Table 9-1: Summary overview on technological competitiveness of Europe in KETs**

| | Nano-technology | Micro-/ nano-electronics | Industrial Biotech-nology | Photonics | Advanced Materials | Advanced Manu-facturing Techno-logies |
|---|---|---|---|---|---|---|
| **Patent Output in Europe** | | | | | | |
| No. of EPO/PCT patents in 2005 (European applicants) | ~500 | ~1,900 | ~600 | ~1,900 | ~3,000 | ~4,600 |
| Compound annual growth rate 1991-2005 (percent) | 12.8 | 10.4 | 3.9 | 7.5 | 4.3 | 6.5 |
| Share in global no. of EPO/PCT patents (percent) | 27 | 22 | 36 | 29 | 31 | 48 |
| Change in global market share 1991-2005 (percentage points) | -1 | +4 | -11 | -7 | -4 | -2 |
| World region with highest market share in 2005 | North America | East Asia | Europe | East Asia | East Asia | Europe |
| Subfields with particularly high market share of Europe | nanobio-technology | devices | fermen-tation, enzymes | solar | macro-sca-led mate-rials, ener-gy-effi-cient ma-terials | robots, measuring, control-ling, regu-lating, tools |
| Subfields with significant improvement of Europe's market share | nano-electronics | measure-ment, X-ray | - | - | - | robots, CIM |
| **Patent producers (Europe)** | | | | | | |
| Share of start-ups/dedicated technology firms in total no. of patents (percent) | 10 | <1 | 7 | <5 | <1 | <1 |
| Share of public research in total no. of patents (percent) | 29 | 10 | 23 | 9 | 5 | 5 |
| Share of 15 largest applicants in total no. of patents (percent) | 21 | 50 | 26 | 40 | 35 | 21 |
| **Sector links (Europe)** | | | | | | |
| Sector with highest share in total no. of patents | chemicals | electronics | chemicals | electronics | chemicals | machinery |
| Sector with strongest increase in its share in total no. of patents between 1990s and 2000s | public research | semicon-ductors | public research | lighting | plastics | vehicles |
| **Market potential (global)** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Current market size (billion US-$, ca. 2008) | 12 - 150 | 200 - 300 | 80 - 100 | ~230 | ~100 | ~150 |
| Expected market volume in 2015 (billion US-$) | 30 - 3,100 | 300 - 350 | 125 - 150 | 450 - 500 | ~150 | ~200 |
| Expected compound annual growth rate (percent) | 16 - 46 | 5 - 13 | 6 - 9 | ~8 | ~6 | ~5 |
| **Success factors and barriers (global)** | | | | | | |
| Key barrier for rapid and broad commercialisation | lack of venture capital; health, environ-ment and safety concerns | achieving substantial decrease in unit costs | environ-ment and ethic concerns, price-cost advantages over traditional chemicals | mastering complex technology | long product cycles | adoption barriers at the side of potential users |
| Role of public funding for R&D | very high | low | medium | high | low | low |
| Role of public policy for stimulating demand | low | no | high | low | no | low |
| Significance of health, environment, safety concerns | high | low | medium | low | low | low |

*Source: ZEW compilation.*

Patenting in KETs is driven by different groups of actors. Public research is a main source for new technological knowledge in Europe in nanotechnology and industrial biotechnology and is also significant in microelectronics and photonics. Dedicated start-ups show a higher share in nanotechnology and industrial biotechnology but are quite rare in photonics and almost negligible in microelectronics, advanced materials and advanced manufacturing technologies. In these three KETs, a few large enterprises dominate patenting. KETs are very much related to the chemical and electronics industry.

Current market size of KETs ranges from about $100 billion for advanced materials and industrial biotechnology to about 250 billion for microelectronics. For nanotechnology, estimates of current market size vary a lot, ranging from $12 to $150 billion. This range indicates the difficulties in determining the borderlines of this emerging industry. Though one cannot simply add market size of individual KETs to get a total volume of demand for KETs as several KETs overlap to some extent, it is still fair to estimate the global market volume of the six KETs to be about $700-800 billion at present. This is certainly a considerable size when compared to the market volume of established industries such as the electronics, automotive, chemicals, pharmaceuticals or machinery industry. Each of these industries generates global sales between $1,500 and 2,500 billion each year. More importantly, demand for KETs is expected to increase at rates above the average expansion rate of world markets for most KETs. Expected annual growth rates are particularly high for nanotechnology (ranging from 16 percent compound annual growth to an extreme of 46 percent), high for microelectronics, photonics and industrial biotechnology (about 8 to 10 percent per year) and rather moderate for advanced materials and advanced manufacturing technologies (5 to 6 percent, which is about the expected medium-term growth of global demand for goods and services). The differences in expected future growth of KET demand reflect differences in the underlying factors that drive market potentials of KETs.

Future technological and commercial success of KETs depends on a large variety of factors which are difficult to weight or prioritise. Based on literature, one can nevertheless identify some factors for each KET which seem to be particularly important for future prospects. In nanotechnology, funding (particularly availabiltiy of venture capital) is an important driver, as well as health, environment and safety concerns. In microelectronics, being a more mature industry, main challenges refer to combining higher performance of ne microelectronic technologies with a substantial decrease in unit costs. Industrial biotechnology is confronted with environmental and ethic concerns about likely impacts of new biological chemicals on the one hand and a lack of price-cost advantages over traditional chemicals which decelerates diffusion of innovations.

Photonics is a field of technology that is particularly subject to complex technologies, and intergrating various technologies into complex products is a therefore a main challenge which demands high investment in R&D and cooperation of actors with different industrial and disciplinary background. Advanced materials is a rather traditional KET driven by large companies with longstanding R&D and market experience. A main barrier for the rapid diffusion of advanced materials is long product cycles and often high investment needed to adopt new materials. In advanced manufacturing technologies, the situation is quite similar, though barriers to adoption are different. As many users of more advanced process technology are small manufacturing firms, specific barriers to technology adoption by SMEs (lack of external capital, lack of specific skills, uncertainty of price-cost advantages over the life cycle of new technologies) matter.

Governments' role in advancing KETs differs with respect to the role of public funding for conducting R&D, the role of public policy for stimulating demand (e.g. through public procurement, taxes or regulation), and the role of environment, health and safety issues. Governments tend to be important players in nanotechnology and industrial biotechnology since public funding and regulation are important for commercialising new research results. In photonics, public policy is first of all important for funding R&D. In the other three KETs, governments tend to be less directly involved in advancing technology. Their role tends to be more focused on providing a favourable environment for industry, including to maintain a strong industrial base as a key starting point for developing and commercialising new technologies.

## 9.2 Conclusions from Cluster Analyses

Whereas the patent analysis has given the insights into the general development within the KETs worldwide, and enabled to give general policy recommendations, our cluster benchmark has given us some more specific insight about how KETs develop and flourish in certain regions. We find it essential to note that whereas key enabling technologies are absolutely global in their applications and hence their markets (most clusters export around 75 percent of their products), their origins are often strongly embedded in local clusters. The size and concentration of the clusters may vary, but with the name of a flourishing technology (like biotech) almost always comes the name of an area (biotech Cambridge). In our analysis we describe how and why the regional aspect of technology development in important and which policy recommendation can be derived from that.

*Clusters: knowledge base and path dependency*

First of all, technologies do not just appear. They develop out of existing knowledge and (re)combination of existing, or existing and new knowledge. Knowledge and capabilities are not static facts though that can be bought off the shelf. Innovation and technology development is not the result of a simple transfer of tangible information: it is the creative process of invention and creation between *people* who carry with them specialist knowledge and know how. It is therefore that new KETs and the KET clusters grow on the foundations of already existing knowledge 'hot spots', clusters or industries.

Characteristic of all clusters is that they grow either around a very strong knowledge infrastructure (thick network of world-class universities and research labs for instance) or on the foundations of well established and successful industries. In all the clusters we studied we saw this as a major prerequisite for cluster development. In some cases the clusters were more originated by science and universities, e.g. the Cambridge biotechnology cluster and the Grenoble microelectronics and nanotechnology cluster, and others were more strongly stimulated by the presence of dominant firms and strong industries, e.g. Ontario micro-and nanotech and Berlin-Brandenburg photonics. Overall though, we see in all clusters an important role for both knowledge base and industrial base as foundations for world class knowledge (science) and application (industry).

The policy implications of this observation are that whereas technologies can be stimulated in general, and clusters can be too, clusters cannot be made or planned. Successful cluster development will always have to have a basis in science and industry. Hence, successful policies should focus on looking for emerging clusters of technology development, and strengthening these emerging clusters. Once a start has been made, which will often be a more or less spontaneous and unpredictable process, momentum can be gained by tailoring policy measures to stimulate the technology (through general policy measures), the region (for instance with regional development funds) and the entrepreneurial climate (for instance by providing tax breaks, incentives for locating in the area) and of course the cluster by (co)financing a cluster platform. By combining general technology policy measures, with more tailored regional and cluster measures, an interesting self perpetuating cycle of activities can evolve which will strengthen the developing cluster. Path dependency – the process by which actions and sediments of those actions in the past, form a basis for even more and better actions and results in the future, will be the natural accompaniment of these policy actions.

*Cluster development: time scale and realistic expectations*

Another cluster fact is that mature and successful clusters are old. From research we have learned that technology developments generally take up to 30 years to get from invention to broad scale implementation. Clusters are no different. The clusters that we examined were often between 20 to 100 years old. If they appeared to be young, because their cluster status had recently been formalised in supportive policies, or because their cluster platform had recently been established, they always went back on old foundation on closer examination. This can be no surprise: if technologies take long to develop, companies and their complementary cluster partners will also grow and evolve along with the speed and success of the (application of the) technology.

For policy this means that realistic expectations should be set at the start. Neither KETs nor clusters will be successful within the usual policy cycles of a limited number of years (for example 4 years). Policy measures can accommodate this fact by adjusting its policies to the phase of development technologies and clusters are in. For instance, emerging technologies and clusters will much more depend on funding of basic research and knowledge exchange, whereas mature clusters tend to depend on the successful organisation of critical and creative mass in the cluster and internationalisation. Once a cluster is past its heydays, regeneration of the cluster should be put on the agenda. This process is illustrated in Table 9-2 below.

**Table 9-2: Policy recommendations for different phases in the life cycle of a cluster**

| Emergence | Development | (Fast) growth | Maturity | Post maturity / regeneration |
|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| What happens? | Existing basis of excellence is important (research, industry)<br>Basic research funding<br>Relationships need to be built | Knitting of PP partnership<br>Increasing number and variety of actors<br>Technologies and products become better | Cluster builds reputation<br>Starts attracting firms and excellent labor<br>Attractiveness of cluster stimulates start-ups<br>Fast growth in number of firms and their turn-over | Cluster reaches critical mass<br>Internationali-sation<br>Cluster attract firms, specialist service providers and qualified people internationally<br>Cluster has excellent reputation | Cluster declines<br>Technologies are overtaken by new developments<br>Cluster characterised by mergers and acquisitions (concentration)<br>Actors start looking for 'new wave' to ride |
| What should be done in support? | Public policy recognizing potential growth areas based on scientific or industrial excellence<br>Finding protagonists to champion cluster development<br>Support collaboration | Tax measures and public funding to create favourable business environment and attract new entrants<br>Funding of research and collaboration<br>Establishment of cluster platform<br>Public policy setting clear goals | Attracting or creating sources of private funding<br>Working on commercialisation<br>Creating international reputation<br>Tax measures and public funding to attract lead firms<br>Shift focus funding from basic to applied | Stimulate export development<br>Ample attention to start-ups and spin-offs to keep momentum<br>Keep the cluster open – track new development to prevent myopia<br>Provide or stimulate funding structure for commercialisation / internationali-sation | Stimulation of new developments / technologies that build on old capabilities and knowledge.<br>Stimulating new contacts with actors outside the cluster / technology field<br>Establish links between smaller actors of the 'new wave' with potential anchor firms |

*Source: TNO compilation*

*Funding structure for all stages of technology development*

A known problem in technology development and commercialisation is the so called 'valley of death': whereas funding for basic research is often available, seed- and venture capital often helps early start-up, and the market will pick up the technologies that have (partly) proven themselves in the market, large investments are often still needed for the phase in between the applied research and commercial application. This stage, sometimes referred to as scaling up, requires large investments in proto-typing, testing, and the scaling up of production facilities. These activities are usually not covered by policy interventions as the market is to pick up technologies at that stage. In the clusters we have studied we have also observed this problem. In the European clusters this problem is often solved when large firms are present in the cluster: they will be well informed about promising new development and have the funds, distribution channels, and international connections to get past this stage. An example of this is Cambridge biotech.

In the non-European clusters there is much more attention to the commercialisation stage, and also more elaborate funding structures are available to support firms at all stages of development and growth. For example in Canada, very favourable tax measures make for a good knowledge development and commercialisation climate. In the non-European clusters we also see that governments pay explicit attention to the commercialisation phase. They implement ideas of public procurement in their policies (like in the microelectronics Ontario cluster) or give clear indications of desired directions of applications (like in the case of the Kyoto nanotechnology cluster). We observe that those clusters are very strong in commercialisation, whereas some of the European clusters, for example the Berlin-Brandenburg photonics cluster, run the risk of staying ‘stuck’ in knowledge development and inter-firm collaboration between local smaller firms, without making ‘the jump’ to large scale application and commercialisation.

China and Japan also form a special case as the governments here very explicitly govern the markets in the sense that they actively stimulate and if necessary help create, the funding structures for these developments. They for example set up venture capital schemes or make sure private actors provide seed capital. They do not shy away from interfering into the market and thereby actually create an indirect route for making sure companies can find funding for technology development and commercialisation. However, we are not sure if such lessons could be transferred to European economies as we do not have a tradition of more central planning, and such government interference would perhaps also clash with our dominant business culture and ethic.

The policy implications of the observations on cluster and technology development, and the interconnectedness of the two, are that we are dealing with staged processes that need different forms of policy support in different stages of development. Whereas in the early stages emphasis will be on knowledge development and careful building of a strong core in the cluster, later stages will involve more knowledge exploration activities and the cluster will expand and create more external ties to be able to reach a world market. We have illustrated this process, and given policy advice, in Table 9-2 above.

Next to that, we emphasis that policy measures should not only be fit for the type of technology and cluster it should also be adopted to the culture of the respective area or country. Whereas the Asian countries seem to be successful in implementing more centrally governed strategies, the Anglo-Saxon follow more of a ‘market’ model of development in which general tax measures and stimulation of entrepreneurship play a crucial role, and Europe seems to focus more on the stimulation of basic research and R&D collaboration. These models all seem to work, but we strongly believe they also do because they are suited to the countries they are designed for. Still though, European countries do seem to be able to learn from the non-European countries in the sense that the funding of the whole trajectory of technology development and application is much better organised. Also, European countries could learn from the scale of non-European clusters and focus less on small evolving clusters, and more on potentially strong clusters that have lead actors in them, or other anchor firms, that can enable the cluster to develop into maturity.

*Regional embedding and collaboration: strong and weak ties*

Although the development and application of KETs is a global affair, the evolution of knowledge and technology is a regional – though not isolated - matter. This is so because excellent knowledge and knowhow is developed by people. Innovation no longer takes place in isolated research labs. Through the high level of specialisation necessary to belong to the top of a specific technology field, companies and research organisations alike, need to collaborate with complementary partners. Although modern day technology can enable such collaboration across large distances, the social processes and trust underlying fruitful collaborative relationships cannot be displaced by technology.

From research in this field we know that for successful collaborative innovation, both strong ties and weak ties play a role. Within the clusters strong ties can develop with other actors that are close by: with this we mean both geographically proximity and not too big cognitive distance (complementary knowledge and skills, but also often similar or compatible culture, norms and values). In almost all the clusters that we studied we found that close interaction between the clusters actors, and a general cluster culture supportive of such collaborations, was considered crucial for cluster growth. The dense clusters provide rich labor markets, where people can find and change jobs, but also start for themselves. Such dynamism also promotes spillovers and positive externalities, and gives the cluster an identity people and companies want to be related to as it improves their legitimacy and credibility. Next to this we see the close and repetitive collaborations between cluster actors. Through longer term collaboration, trust can grow, and the relationships will be increasingly open and creative, increasing the innovative potential of the actors. The Cambridge and Grenoble cluster form good examples of this type of regional cluster 'buzz'.

Whereas this relates to the close relationships within the cluster, weak ties within and outside the cluster are also of crucial importance. Through these weak ties, new knowledge and skills can be fed into the cluster that prevent myopia and provides new knowledge and inspiration for KETs to develop. In nearly all the clusters we studied we saw how especially in the more mature stages of cluster development, weak links - often through universities and large actors - form an essential link to 'the outside world'. Functions that these links fulfill go both ways: new ideas and knowledge will feed into the cluster, but these links will also provide a bridge to foreign markets – to sell products and promote the cluster building its international reputation.

The policy implications of this are that next to technology stimulations, measures should be in place that encourage – or at least don not hinder – collaboration. Cluster platforms form an excellent instrument for this, and we have seen very successful examples of these platforms in this study. The cluster platforms should focus on both establishing of weak and strong ties. Within the cluster they should stimulate collaboration by organizing network events, using firm databases to increase transparency of the actors present in the cluster, provide intermediary services etc. Next to that, the external links should be encouraged to prevent becoming an ‘in-crowd’ club that misses out of important external developments. Cluster platforms can facilitate this by organizing marketing and knowledge visits to other countries or other countries, visiting trade fairs, and other actions to get into contact with new actors that can provide access to new knowledge and markets.

This is a function that is well understood in nearly all the clusters we studied. It is remarkable though that the European technology policies seem to put more emphasis on collaboration, whereas non-European policies more rely on tax-breaks and tax-incentives to attract actors and stimulate KETs. This is a more indirect route for getting the density of actors in a certain area. We see no clear difference in the effect of both policy routes: in European as well a non-European clusters collaborations plays a determining role in making the cluster successful, hence, we conclude that both direct and indirect policies are possible.

*Lead markets, public procurement and the role of anchor firms*

In the design of this study we anticipated that there could be a role for public procurement and lead markets to explain the successful development of KETs. In the study however, we found very little proof of this. We explain this by the fact that first the KETs are technologies that are still in a very early stage of development, second that the technologies are intermediary products that do not have a direct demand, and third, that KETs have so many applications (one technology or material can be used in many applications) that it is difficult to identify key application areas. We did find two clusters in which public procurement was mentioned as a means to stimulate technology development. However, we found no proof other than that there were good intentions.

In stead of an important role for lead markets, we found a key role for lead or anchor firms. In nearly all clusters lead firms played an important role to create critical mass and funding opportunities, international connections and distribution channels. Next to that, some clusters have strongly developed thanks to the spin-offs of large companies that were present at an early stage of the cluster’s development, the so called anchor firms. Examples of this we saw with CEA in the Grenoble, and Nortel in the Ontario microelectronics cluster. In these cases, the anchor firms played an essential role in ‘kick-starting’ the cluster. From the large organisations there have been many spin-off that have greatly increased the level of dynamics and viability of the cluster by having a good mix of young entrepreneurial firms, but also the large ones.

The policy implications of these observations are that policy makers should not only look at technology and cluster development, but also at the composition of the cluster. The right mix is mostly a mix of large, medium-sized and small players. To attract large firms into the area, tax measures can play an important role as it can reduce the operations costs of the firms. Another strong factor attracting large players is a well developed labor market which can be stimulated with good knowledge institutes and good labor laws.

The occurrence of spin-offs/outs, start-ups, and entrepreneurship in general can be stimulated with incubator firms, business angels, seed- and venture capital. Some clusters also provide business parks and incubator centres to support these activities. An entrepreneurial spirit in the area is also important but will be difficult to encourage with government policy (e.g. Anglo-Saxon countries will naturally harbor more entrepreneurs than more centrally planned countries like China).

*Overall conclusion: the role of policy and funding in the KET clusters*

After this elaborate discussion on key factors for KETs and cluster development, and the implications of this for government policy, we shortly summarise the main findings from the European and non-European clusters and the lessons we derive from it:

All KET clusters receive considerable funding and support for technology development and for business and cluster development. This support is very important and has in the cases studied proven very effective.

In all KET clusters we find the presence of cluster platforms. These platforms are active in bringing parties together, promoting the cluster, spreading information, promoting funding for companies, marketing, internationalisation etc. The platforms are very useful and successful and a relatively cheap and legitimate way to provide business support as it doesn't favor one firm over another.

We observed that technology and cluster development go hand in hand and take a long time. Twenty to thirty years should be considered a normal time range for technologies to catch on and clusters to reach maturity. This implies that there is also a need for long term consistent policies that take into account the staged phases of development.

In all clusters the regional component plays an important role. Local firms collaborate, good relationships exist with the knowledge infrastructures, and a dense labor market provides the people that can make it happen. At the same though, the weaker links with actors more distant from the cluster are essential for keeping up to date with new developments and preventing the cluster from becoming to close (turning from a hot spot to a blind spot).

From the EU/non EU comparison we learned that non-European countries make more use of tax incentives and – breaks which are very successful at attracting new entrants and large (international) firms to the cluster. This is a lesson that European countries could take on board to extent their policies with.

From this comparison we also saw that non-European countries also manage, in various ways, to close the gap between basis research and application funding (the valley of death) better than the European countries do. They do so by not only making the technology or cluster attractive to technology driven firms, they also encourage funding actors (like venture capitalists) to come and invest in the area, sometimes by tax measures, sometimes by strong governance (China).

Characteristic of the European approach seems to be the strong emphasis on collaboration. Whereas this shouldn't be a goal in itself, especially the Asian countries could learn from that. The more hierarchical structures that characterise their economies can form an obstacle for innovation as these lack the trust and openness for open knowledge exchange and creative innovation.

## 9.3 Failures and Success Factors

***Market failures hindering KET development***

Market failures relate to failures in *market structure or demand* in providing the right conditions for new technologies and businesses to evolve. Market structure relates, for instance, to high entry barriers or lack of innovation incentives due to dominant incumbent firms (Klein Woolthuis, 2010). Markets can also fail to invest sufficiently into the generation and application of new technology, in which case government intervention in the way of co-funding R&D may be required. Market demand can be distorted due to insufficient transparency or inefficient pricing mechanism due, for instance, to the inability to include negative externalities in prices.

*Funding*

A known problem in technology development and commercialisation is the so called 'valley of death' (see USBA, 1994). Whereas funding for basic research is often available, (private) funding for later stages is often lacking. Mainly the "scaling up" phase, which requires large investments in proto-typing, testing, and the scaling up of production facilities is often difficult to fund. Such expenditures are usually not eligible in most policy programmes, while uncertainty is still too high for commercial firms to pick-up the technology.

In the European clusters analysed in this study, the problem is in some cases solved by large firms in the cluster that become lead users or anchor firms. They typically have the funds, distribution channels and international connections necessary to get across 'the valley of death' (Nordicity Group, 1996). An example of this is the Cambridge biotechnology cluster. Among the non-European clusters investigated there is much more attention for funding in all stages of technological development, including the commercialisation stage. Tax measures

(Canada), government strategy and interventions (Changsha advanced materials cluster, Kyoto nanotechnology cluster) and public procurement (Ontario microelectronics cluster) form policies to address this market failure. All in all, the lack of funding for later stages of technology development in the investigated clusters is rather poorly developed in Europe when compared to the non-EU clusters.

*Market structure*

For the development of healthy KETs, there is a need for large as well as small entrepreneurial companies. Large companies can serve as lead or anchor firms, i.e. they can provide the guidance, capabilities and capacity to develop technology from incubation to maturity (Wolfe, 2008; Nordicity Group, 1996). Small companies can play an equally important role in keeping the market flexible and innovative. Start-ups, university spin-offs and company spin-offs are important to advance KETs since they are more capable than large firms to adopt entirely new technologies and develop markets with a low sales volume at the start and uncertain prospects. Such markets are often unattractive to large companies since they do not allow for leveraging scale economies.

Small firms need open markets to develop. Dominant firms that are blocking the market for new entrants or innovations should be forced into competition. Barriers to entry can be lowered by providing joint facilities, lowering the costs of start-ups and stimulating entrepreneurship (Den Hertog et.al., 2001). In the European clusters investigated, the market structures often lacked large players that could have the power to develop a KET into maturity, and take into their wake a larger group of firms. Many of the European clusters that have been analysed consist of a many SMEs with similar capabilities (e.g. Berlin-Brandenburg photonics). Such firm structure can be regarded as a weakness for Europe. Also, Europe seems relatively weak in promoting entrepreneurship compared to for instance the USA and Canada where culture, market openness and supportive infrastructure are better developed (Pierson and Castles, 2006).

*Demand*

Whereas successful KET clusters are often characterised by a strong market focus, less successful ones tend to have a primary orientation on research. For successful KET development, there is a need for both. (David, 1997). The European clusters under study often show a strong focus on basic research and scientific and technological excellence but they seemed less focussing on (niche) markets. In Chinese and Japanese clusters studied, the government tends to play a strong role in co-determining the focus of KETs by defining key technology fields and choosing strategic markets. For instance, the Japanese government has chosen nanotechnology as a top national priority and China focuses on batteries for the export market. In this way, governments help to put forward a strong vision and concentrate funds to a limited number of activities. In Europe these processes tend to grow more organically and decentralised, which implies that developments can take longer to mature. In the USA, there seems to be a stronger focus on linking technologies and market. As funding more often comes from private sources, the potential for commercialisation plays a key role during the whole process of KET development.

*Labour markets*

An essential success factor for KETs is a highly skilled labour force and a thick labour market (Wolfe, 2008). In all clusters that have been analysed, the quality of the labour force was emphasised as being crucial to success, with the best clusters attracting talented people from all over the world (e.g. Grenoble, Silicon Valley). Whereas the importance of skills is widely acknowledged, e.g. for cluster dynamism and hence success and longevity (Malmberg and Power, 2006), it is observed that investments in higher education in Europe have deteriorated over the last decades, leading to a lower number of graduates and researchers in some fields of natural sciences. A main challenge is to train students in cross-disciplinary fields which are particularly important for research in KETs. A lack of skilled people is a severe problem as it may jeopardise current and future KET developments. The problem becomes more acute when compared to the efforts of emerging economies (such as China, India and may south-east Asian countries) to catch up with Western economies in education levels.

***System failures that hinder KET development***

System failures relate to those factors in the system that hinder innovation (Klein Woolthuis, 2010). Examples for such failures are a lack of interaction between actors which hinders knowledge exchange an innovation (*interaction*), or ill functioning rules and regulations (*formal institutions*) that discourage innovation (e.g. lack of IP protection), or a culture that discourages openness, creativity, innovation and risk taking (*soft institutions*). Capabilities in the fields of technology, organisation and marketing are also necessary for innovation to be successful (*capabilities*).

*Entrepreneurial culture*

Many studies have shown that the USA, the UK and Canada are more oriented toward entrepreneurial cultures whereas continental Europe is so to a lesser extent (Pierson and Castles, 2006). Although there are incentive schemes in place in all clusters investigated, entrepreneurship clearly seems to thrive more in those countries where these policy measures are paired with an entrepreneurial culture. In many European countries there is, however, less acceptance of risk and failure, and cultural attitudes tend to be more egalitarian. In Anglo-Saxon cultures, one is challenged to stand out, and risk and failure are considered part of that

(Thomas and Mueller, 2000). The presence of funding for entrepreneurial ventures forms the material appreciation of this.

*Marketing capabilities*

A focus on entrepreneurship is often linked to a focus on commercialising innovations. An invention is not an innovation unless adopted and diffused. In the non-European clusters analysed, the attention for, and capabilities in the fields of marketing tend to be more developed. Marketing capabilities, entrepreneurial culture and funding are forming a crucial triangle for KET success in clusters in the Anglo-Saxon countries examined in this study. These capabilities seem weaker developed in continental Europe, where basic research and industry-science collaboration dominate KET development (which are also the elements for which funding is most readily available). A more balanced approach which takes into account both R&D and commercialisation would be beneficial for KET development in Europe.

***Public procurement, lead markets and public funding***

*Public procurement*

In theory, public procurement can play an important role in stimulating KET development (Klein Woolthuis 2010). In practice, public procurement does not play an important role in the clusters that have been studied, for the same reasons that market potentials were difficult to estimate (see chapter 6). KETs are no final products and generally in a very early phase of their development.

However, public procurement can still play an important role in stimulating KETs by specifying specific goals for public purchases, e.g. sustainability (Edler and Georghiou, 2007). KETs can play an important role in meeting sustainability goals and will benefit from market developments of products that embed these technologies (e.g. solar, LED lights, bioplastics).

*Lead markets or lead / anchor firms*

A lead market is commonly defined as a regional market that adopts early a specific technological solution to a certain problem that will later be adopted by users in other regions as well (see Beise, 2001). Lead markets tend to develop through an interaction of various supportive demand-side factors, including anticipatory demand, international orientation of users, intense competition, and a price advantage over alternative technological solutions. Lead markets are often different from those regions where a certain new technology first has been developed. Deliberately creating lead markets by policy intervention is difficult. Policy can play an important role in creating lead markets for specific KETs in case regulation is critical for the application and diffusion of technologies. In this case, anticipatory regulation that refrains from a too strong predefinition of technological solutions but rather emphasises progress in technological features that are critical for users can help to establish markets which early adopt KETs. This early success of KET applications can stimulate other countries to adopt similar regulation, and by diffusion of regulations, the early adopting market can become a lead market. Examples for such type of regulation-driven lead markets can be found in environmental technologies (see Beise and Rennings, 2005).

In contrast to lead markets, lead or anchor firms do play an important role for a KET's development as mainly large players have the capacity (funds, capabilities, absorptive capacity) to develop KETs (Wolfe, 2008; Nordicity Group, 1996). In nearly all clusters lead firms played an important role to create critical mass and funding opportunities, international connections and distribution channels. Next to that, KETs have strongly developed thanks to the spin-offs of large companies (ex researchers starting a patent based business, ex employees starting new (supplier) firms. Examples of this were observed with CEA in the Grenoble, and Nortel in the Ontario microelectronics cluster.

*Public funding*

KETs, both in Europe and in non-European countries, receive considerable public funding and government support for technology development. This underscores the importance given to technology development as a basis for economic growth. European countries tend to emphasise the funding of (basic) research and industry-science collaboration, though they also provide supportive infrastructures such as incubators and joint research facilities. Almost all EU countries have at least one cluster programme in place (Furre, 2008). Europe tends to be relatively weak though in funding the later stages of technology development as good developed private funding structures are underdeveloped (e.g. venture capital, business angels).

Asian countries combine research and development funding with clear policy guidance in choosing technologies and (niche) markets. Funding is focused on these key areas and funding covers all stages of KET development (also scaling up and commercialisation). The clusters studied in the Anglo-Saxon countries (USA, UK, Canada) have relatively much availability of generic policy measures to stimulate KET development. Measures include tax breaks and incentives, creating an attractive climate for investments in high growth areas (clusters), R&D subsidies and stimuli for scaling up and commercialisation. Less use is made of measures stimulating collaboration although such measures (such as cluster development) slowly gain popularity (Sölvell, 2008). Next to technology stimulation, government funding was observed to be used to stimulate entrepreneurship through good funding infrastructures and availability of incubators and business parks.

## 9.4 Generic Policy Conclusions

***Europe's Competitiveness in KETs***

Europe is an important source for technological advance in all KETs considered in this report. Europe is clearly world market leader in advanced manufacturing technologies and also holds a top position in industrial biotechnology. It has a strong position in advanced materials which could be maintained over the past 15 years despite a rapid increase in technology output in East Asia. Europe's position is less well in photonics, nanotechnology and microelectronics where Europe contributes less to the global production of new technology than North America and East Asia. In microelectronics, Europe could significantly increase its global share over the past 15 years, though starting from a very low level.

All in all, Europe is neither loosing ground nor moving ahead in KETs. In all KETs, Europe is confronted with an increasing competition from East Asia which caught up significantly in the past decade whereas North America tends to show decreasing shares in global technology output.

Europe's position in KETs tends to be better in fields related to chemical technologies compared to technologies linked to electronics. Another peculiarity of Europe is the significant role of automotives as source of technological advance in some KETs (microelectronics, photonics, advanced manufacturing technologies) which points to the high degree of technological competence of this particular industry in Europe. Public research plays a more prominent role in Europe, though in some KETs (industrial biotechnology, nanotechnology) North America reports an even greater share of public research in total patent output in KETs. Dedicated technology start-ups are less significant in Europe compared to North America, but more relevant compared to East Asia.

***Market and System Failures***

Analysis of successful KET clusters has shown that success factors and barriers tend to be similar across KETs, though each KET is showing some peculiarities. For each KET, basic research and linkages between public research and industrial firms are key issues, as is the role of regulation, funding of innovation through venture capital, and the urgent need of high qualified personnel.

Advance in KETs is affected by a number of generic technology market failures, which are typically addressed by a well-developed set of research and innovation policy instruments. High knowledge spillovers and a substantial degree of technological uncertainty which could prevent private R&D investment are tackled by public R&D funding schemes as well as cluster and network initiatives. The need for large fixed investment in specific R&D

laboratories constitute high entry costs, particularly for smaller firms while the need for cooperation with partners from different institutional and disciplinary backgrounds results in high coordination costs and require effective mechanisms to protect the intellectual property of each party involved. Policy responds to these market failures by offering networking and cooperation programmes and by providing joint R&D facilities.

In addition, KETs are subject to financial market failures arising from high technological uncertainty, long time horizons between R&D investment and potential economic returns, and high information asymmetries over the prospects and risks of KET-related R&D activities. As a consequence, traditional ways of external funding are restricted while public funding and venture capital are important sources to complement (limited) internal funds of actors engaged in KET-related R&D. Particularly small firms and start-ups are dependent upon these financial sources. Furthermore, networking and cluster activities can reduce information asymmetries and help to link financial market actors and technology organisations.

Each KET is also subject to technology-specific barriers that may hamper technological advance. Most prominently, R&D on KETs is often research at the technological frontier which has to master complex technologies and solve upcoming technological challenges that have been unknown yet. Most often, technological advance requires joint efforts from different scientific disciplines and fields of technology. This is particularly true for nanotechnology and photonics, but is also increasingly important in advanced materials and microelectronics. Bringing together these different competencies can be complicated by different disciplinary routines and approaches and involves substantial coordination costs.

Some KETs need to pay particular attention to health, environment and safety issues. Nanotechnology, industrial biotechnology and advanced materials are to be named here. Developing procedures and regulations to deal with these issues which at the same time provide incentives for further technological advance and innovative dynamics is a main challenge in this area.

The development of KETs heavily depends upon knowledge and creativity. Access to highly qualified people is thus a key success factor. Many KETs require very specific skills, particularly cross-disciplinary knowledge from disciplines such as chemistry, physics, biology, computer sciences, mechanical engineering and material sciences. Acquiring such knowledge is particularly time-consuming, and many higher education institutions are not prepared to offer curricula that meet the specific demands of KETs. What is more, career opportunities of cross-disciplinary studies are unclear to many students (e.g. because commercial applications and thus job opportunities in KETs have yet to evolve), resulting in low perceived attractiveness of such studies and a low number of students.

Linked to the cross-disciplinary nature of KETs, technological advance often depends on the co-occurrence of technical progress in different scientific disciplines and fields of technologies, i.e. joint innovative activities by many actors at the same time. Different actors from both public research and industry need to be co-ordinated, which rarely takes place sufficiently by market mechanisms. Policy activities such as providing incentives for networking and clustering among various actors can help to overcome this specific failure.

Another obstacle for KETs are barriers to adopting new technology at the side of users. Information asymmetries over the expected returns compared to established technologies can result in low adoption rates. High investment costs for applying KETs may exceed the available internal funds of users, particularly for SMEs, while external financing can be difficult if the technology is completely new and no experience over the likely returns are available to financing institutions. In-house capabilities for dealing with new technologies -skills of workers, coordination among departments, integration of suppliers and customers- may be missing and cannot be built up in short term. Finally, applying KETs may need adjustments to the product produced which may result in complex changes in a firm’s internal and external organisation (involving marketing and users).

***Public Policy in Favour of KETs***

The critical role of KETs for manufacturing calls for policy attention, regardless of the current technological competitiveness. A mix of generic measures and KET specific interventions is most promising to accelerate the development, diffusion and use of KETs and their impacts on the wider economy:

- KETs are strongly research driven. Maintaining a strong research base is thus essential. Funding basic research with a long-term view is a key policy task. Basic research funding in KETs need to be balance between setting thematic priorities (in order to obtaining a critical mass of knowledge and to promoting cooperation among researchers working on similar subjects) and providing free space for explorative research into entirely new areas.
- Since KETs are technologies that originate at the border between scientific research and industrial applications, the exchange between both groups of knowledge producers is essential, too. In particular, incentives need to be in place at public research for actively engaging in technology transfer. This includes a proper IP management, promotion of spin-offs, acknowledging the importance of technology transfer in evaluations and funding and offering linkage programmes such as researcher mobility programmes.
- Industrial R&D on KETs is characterised by high knowledge spillovers and high technological uncertainty. Public co-funding of business enterprises’ R&D efforts is therefore clearly justified. R&D programmes should follow a long-term perspective, align

technology priorities with thematic priorities of basic research programmes and include incentives for co-operative R&D.

- Although KETs are characterised by particularly high investment in R&D and high technological and market risks, a generally favourable framework for innovation and commercialisation of new technology can be helpful as well. Policy measures that stimulate start-ups, including a culture of entrepreneurship and risk taking, can be important activities, as well as a favourable financial environment, including tax incentives for R&D and investment in new technologies.
- Linked to R&D project funding, policy should encourage actors in KETs to build up networks for joint technology development, particularly in those areas of KETs that require a high degree of cross-disciplinary and cross-technology fertilisation. Networking could take place at different geographical levels. While for some areas, global networks of the leading organisations from research and industry are best suited, regional networks (clusters) can spur technology development in case close and frequent co-operation among actors is needed. Clusters can be particularly helpful for linking R&D and commercial applications.
- Maintaining a competitive manufacturing base within each KET is critical if one wants to fully utilise productivity and innovation impacts of KETs. While pure technology development could be spatially separated from production, direct interaction between R&D, manufacture and application in user industries is needed for creating new fields of application and developing efficient production facilities for new technologies.
- Promoting higher education and training in the fields of KETs is essential in order to serve KETs with the skilled personnel they need. Strengthening cross-disciplinary education is a main challenge here. A likely shortage of skilled labour should be tackled through both education and immigration policies.
- A vital venture capital market is important for commercialising research results in KETs through university spin-offs and other types of start-ups. Above all, venture capital needs a supportive regulatory environment. When private venture capital markets in Europe are not fully capable of providing sufficient funds for start-up and early stage financing, public programmes may have to fill these gaps.
- Addressing barriers in adopting new technologies is another important policy task. Innovation policy has also gained extensive experience in promoting the rapid and broad diffusion of certain KETs such as advanced manufacturing technologies. These findings stress the role of consulting, skills and training, access to external funding as well as co-operation and mutual learning among SMEs.
- Policy should also acknowledge the role of lead firms and lead markets in commercialisation KETs. An early incorporation of large, globally active companies can

help to match research with global market prospects early and thus link technological advance to market needs. Venture capitalists can also play a role in this process.

- Balancing health, environment, safety issues on the one hand and innovation incentives on the other are a main challenge for regulation in the area of KETs. Involving all main stakeholders and focusing on legislation that is flexible enough to adjust to technological progress within each KET is a promising approach.
- In order to fully leverage the potential of KETs to increase productivity and wealth, an integrated, co-ordinated policy approach is required that links policy actors from regional, national and international levels as well as from different policy domains, including research, innovation, education, competition, industry, taxation, health and environment.

# 10 REFERENCES

AFSSET (2008), *Les nanomatériaux: sécurité au travail*, Paris.

Altenburg, T., H. Schmitz, A. Stamm (2008), Breakthrough China's and India's Transition from Production to Innovation, *World Development* 36, 325–344.

Arthur, W.B. (1989), Competing Technologies, Increasing Returns, and Lock-in by Historical Events, *The Economic Journal* 99, 116–131.

Arvanitis, S., H. Hollenstein (1997), Evaluating the Promotion of Advanced Manufacturing Technologies (AMT) by the Swiss Government Using Micro-Level Survey Data: some Methodological Considerations, in: OECD (ed.), *Policy Evaluation in Innovation and Technology. Towards Best Practices*, Paris, 325–334.

Arvanitis, S., H. Hollenstein (1999), *The Determinants of the Adoption of Advanced Manufacturing Technology. An Empirical Analysis Based on Firm-level Data for Swiss Manufacturing*, Zurich (mimeo).

Arvanitis, S., H. Hollenstein, S. Lenz (1998), Are Swiss Government Programmes of Promotion of Advanced Manufacturing Technologies (AMT) Effective? An Economic Analysis Based on Micro-level Survey Data, Paper Presented at the International Conference on The Economic Evaluation of Technological Change, Georgetown University Conference Center, Washington, D.C., June 15–16.

Audretsch, D.B. (2003), Standing on the Shoulders of Midgets: The U.S. Small Business Innovation Research Program (SBIR), *Small Business Economics* 20, 129-135.

Baptista, R. (1999), The diffusion of process innovations: a selective survey, *International Journal of the Economics of Business* 6, 107-129.

Barrel, A. (2004), Innovation Champions Network – The Cambridge Cluster Description.

BCC (2005-2009), BCC Research, http://www.bccresearch.com, accessed on 14/04/2010.

Beise, M. (2001), *Lead Markets. Country Specific Success Factors of the Global Diffusion of Innovations*, ZEW Economic Studies 14, Heidelberg: Physica.

Beise, M., K. Rennings (2005), Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations, *Ecological Economics* 52, 5–17.

Biatour, B., C. Chatelain, C. Kegels. (2010), Le systeme d'innovation en Wallonie, Bureau Fédéral du Plan Working Paper Bureau Fédéral du Plan.

BMBF (2002a), *Förderkonzept Nanoelektronik*, Federal Ministry of Education and Research, Bonn: Federal Ministry of Education and Research.

BMBF (2002b), *Förderprogramm Optische Technologien, Optische Technologien – Made in Germany*, Bonn: Federal Ministry of Education and Research.

BMBF (2003), *Framework Programme. Materials Innovations for Industry and Society –WING*, Bonn: Federal Ministry of Education and Research.

BMBF (2005), *From the Transistor to Dresden Advanced Mask Technology Center – Nanoelectronics for Mankind*, Federal Ministry of Education and Research, Bonn: Federal Ministry of Education and Research.

BMBF (2006), *The High Tech Strategy for Germany*, Berlin: Federal Ministry of Education and Research.

BMBF (2007), *Optische Technologien – Wirtschaftliche Bedeutung in Deutschland*, Bonn/Berlin: BMBF.

BMBF (2008), *Weiße Biotechnologie – Chancen für neue Produkte und umweltschonende Prozesse*, Bonn/Berlin: BMBF.

BMWi (2007), *Optische Technologien: Wirtschaftliche Bedeutung in Deutschland*, Berlin: Bundesministerium für Wirtschaft und Technologie.

Brand, L., H. Eickenbusch, N. Elsner, O. Krauß, D. Pohle, S. Rijkers-Defrasne, A. Zweck (2009), *Monitoringbericht 2008. Innovations- und Marktpotenzial neuer Werkstoffe*, Düsseldorf: VDI Technologiezentrum (= Zukünftige Technologien Nr. 81).

Changsha Commerce Bureau (2010a), Invest in Changsa. About us, Changsha Commerce Bureau, Changsha Government. 2010, available from: http://www.csinvest.gov.cn/gywm_swjjj.asp

Changsha Commerce Bureau (2010b), Invest in Changsa. Advanced Materials Cluster, Changsha Commerce Bureau, Changsha Government. 2010, available from: http://www.csinvest.gov.cn/jjcs_cssyscy_6.asp

Chen, K., M. Kenney (2007), Universities/Research Institutes and Regional Innovation Systems: The Cases of Beijing and Shenzhen, *World Development* 35, 1056–1074.

Chiesa, V., D. Chiaroni (2005), *Industrial Clusters in Biotechnology - Driving Forces, Development Processes and Management Practices*, London: Imperial College Press.

Chiesa, V., D. Chiaroni (2006), Forms of creation of industrial cluster in biotechnology, *Technovation* 26, 1064–1076.

CIPI (2010), Photonics in Canada – National Innovation Strategy, Presentation by President and CEO of CIPI, available from: http://www.photonics21.org/download/Annual_Meeting/Presentations_General_assembly/5.Robert Corriveau_PhotonicsinCanada_NationalInnovationStrategy.pdf

Collet, C. (2007), Synthetic presentation of the major clusters in nanoelectronics, Nanotrendchart, Presentation available from: http://www.nanotrendchart.com/pdf/clusters-nanoelec.pdf

Conseil Economique et Social (2008), *Les nanotechnologies*, Paris.

Council of the European Union (2007), Brussels European Council 8/9 March 2007 – Presidency Conclusions, 7224/1/07 REV 1, Brussels.

CPC (2009), Illuminating a world of opportunity, available from: http://www.cipi.ulaval.ca/fileadmin/template/main/publications/surveys_and_other_reports/Photoni cs_report_16_ENG_Final.pdf.

Crépon, B., E. Duguet, J. Mairesse (1998), Research, Innovation and Productivity: An Econometric Analysis at the Firm Level, *Economics of Innovation and New Technology* 7, 115–158.

David, P. (1997), *Path dependence and the quest for historical economics: One more chorus of the balad of QWERTY*, Discussion Papers in Economic and Social History 20, Oxford: University of Oxford.

Den Hertog, P., E.M. Bergman, D. Charles (2001), Creating and sustaining innovative clusters, Towards a synthesis, in: OECD (ed.), *Innovative clusters: Drivers of National Innovation Systems*, Paris: OECD.

Diaz Lopez, F. (2010), *Eco-innovation in the Chemical Industry*. Leiden, Ann Arbor, Maralte. 290

Ding, K. (2007), *Domestic Market-based Industrial Cluster Development in Modern China*, IDE Discussion Paper 88, Chiba: Institute of Developing Economies, Japan External Trade Organization.

Dobson, W., A.E. Safarian (2008), The transition from imitation to innovation: An enquiry into China's evolving institutions and firm capabilities, *Journal of Asian Economics* 19, 301–311.

DoC (2007), *Opportunities in Canada's IT corridor – Industry Sector Analysis*, Washington: US Department of Commerce.

Eaton, J., S. Kortum, J. Lerner (2004), International Patenting and the European Patent Office: A Quantitative Assessment, in: OECD (ed.), *Patents, Innovation and Economic Performance*. OECD Conference Proceedings, Paris: OECD, 27-52.

EC (2007), *Contributions of modern biotechnology to European policy objectives*, Analysis report, DG JRC/IPTS, Brussels: European Commission.

EC (2008a), *Photonics Components and Subsystems – in the 6th Framework Programme 2003–2006*, Luxembourg: European Commission.

EC (2008b), *The Bio4EU Analysis report*, Brussels: European Commission.

EC (2008c), *Regulatory Aspects of Nanomaterials. Summary of legislation in relation to health, safety and environment aspects of nanomaterials, regulatory research needs and related measures*, Commission Staff Working Document, accompanying document to the Communication from the Commission to the Council, the European Parliament and the European Economic and Social Committee, COM(2008)366*,* Brussels: European Commission.

EC (2009a), *Preparing for our future: Developing a common strategy for key enabling technologies in the EU,* Communication from the Commission, COM(2009)512, Brussels: European Commission.

EC (2009b), *Current situation of key enabling technologies in Europe,* Commission Staff Working Document accompanying the Communication from the Commission, COM(2009)1257, Brussels: European Commission.

EC (2009c), *European Innovation Progress Report 2008*, Brussels: European Commission.

EC (2009d), *Nanosciences and Nanotechnologies: An action plan for Europe 2005-2009. Second Implementation Report 2007-2009*, Commission Staff Working Document, accompanying document to the Communication from the Commission to the Council, the European Parliament and the European Economic and Social Committee, COM(2009)607*,* Brussels: European Commission.

ECRN (2009a), PLASTIWIN: Ever heard about the plastics and rubber Walloon value chain?, ECRN - News 10.

ECRN (2009b), *"Who is Who" of Chemical Regions in Europe*, Brussels, European Chemical Regions Network Secretariat: 86.

ECRN. (2010), Wallonia, European Chemical Regions Network. 2010, available from: http://www.ecrn.net/abouttheecrn/wallonia.php

Edler, J., Georghiou, L. (2007), Public procurement and innovation - Resurrecting the demand side, *Research Policy* 36, 949–963.

ERA (2003), *Building the European Research Area in micro- and nano-electronics*. Brussels.

ETEPS AISBL (2007), *Consequences, Opportunities and Challenges of Modern Biotechnology for Europe*, Task 2 Main Report. Brussels.

EuropaBio (2009), *Time for Action. The Financial Crisis and Biotech SMEs*, September 2009 – Rev 06, Brussels.

Fagerberg, J. (1995), User-producer interaction, learning and comparative advantage, *Cambridge Journal of Economics* 19, 243–256.

Fagerberg, J. (2000), Technological progress, structural change and productivity growth: a comparative study, *Structural Change and Economic Dynamics* 11, 393–411.

FAITC (2009), *Benefits of conducting your microelectronics research and development in Canada*, CMC Microsystems.

Färe, R., S. Grosskopf, M. Norris, Z. Zhang (1994), Productivity Growth, Technical Progress, and Efficiency Change in Industrialized Countries, *The American Economic Review* 84, 66–83.

Festel Capital (2009), Market evaluation of FESTEL CAPITAL, in: OECD (eds.), Discussion Paper - Session II "Industry Structure and Business Models for Industrial Biotechnology", OECD Workshop on Outlook on Industrial Biotechnology, DSTI/STP/BIO(2009)22.

Festel, G. (2006), Economic potentials and market strategies in the field of industrial (white) biotechnology, Workshop "White Biotechnology", University Potsdam, July 6, 2006.

Foresight Panel UK, Materials (2000), *Shaping our society*, London.

Fraunhofer CNT (2008), *Annual Report 2007*, Dresden: Fraunhofer CNT.

Frost & Sullivan (2003), *Advances in Biotechnology for Chemical Manufacture*. London.

Furre, H. (2008), *Cluster policy in Europe – A brief summary of cluster policies in 31 European countries*, Frederiksberg: Oxford Research A/S.

GC (2010) Canadian Photonics Sector, Website of the Canadian government, available from: http://investincanada.gc.ca/eng/publications/photonics.aspx

Gibney, J., A. Murie (ed.) (2008*), Toward a new strategic leadership of place for the knowledge based economy*, Birmingham: School of Public Policy University of Birmingham.

Gouvernement Région wallonne (2005a), *Contrat d'avenir pour les Wallonnes et les Wallons*, Namur: Gouvernement conjoint Communauté française - Région wallonne.

Gouvernement Région wallonne (2005b), *Plan stratégique transversal - Création d'activités et d'emplois*, Namur: Gouvernement conjoint Communauté française - Région wallonne.

Gouvernement Région wallonne (2008), *Biotech in Wallonia*, Namur: Ministry of Wallonia Region, Directorate General of Technology, Research and Energy.

Griffith, R., E. Huergo, J. Mairesse, B. Peters (2006), Innovation and Productivity Across Four European Countries, *Oxford Review of Economic Policy* 22, 483–498.

Griliches, Z. (1990), Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature* 28, 1661-1707.

Hall, B.H., J. Mairesse (1995), Exploring the relationship between R&D and productivity in French manufacturing firms, *Journal of Econometrics* 65, 263–293.

Harhoff, D., F. Narin, F.M. Scherer, K. Vopel (1999), Citation Frequency and the Value of Patented Inventions, *The Review of Economics and Statistics* 81, 511–515.

Harhoff, D., F.M. Scherer, K. Vopel (2003), Citations, Family Size, Opposition and the Value of Patent Rights, *Research Policy* 32, 1343–1363.

Harrison, R., J. Jaumandreu, J. Mairesse, B. Peters (2008), *Does Innovation Stimulate Employment? A Firm-Level Analysis Using Comparable Micro-Data from Four European Countries*, NBER Working Paper No. 14216.

Hausberg, B., S. Stahl-Rolf, J. Steffens (2008), *Entwicklung von Kompetenzclustern und -netzen zu internationalen Kompetenzknoten*, Duesseldorf: VDI Technologiezentrum.

Heinze, T. (2004), Nanoscience and nanotechnology in Europe: Analysis of Publications and patent Applications including Comparisons with the United States, *Nanotechnology, Law & Business* 1.4.

Helpman, E. (1998), *General Purpose Technology and Economic Growth*, Boston: MIT.

House of Commons (2003), *UK Biotechnology Industry*, London: Trade and Industry Committee.

Huang, Z., H. Chan, Z.-K. Chen, M. Roco (2004), International nanotechnology development in 2003. Country, institution, and technology field analysis based on USPTO patent database, *Journal of Nanoparticle Research* 6.

Hullmann, A. (2006), *The economic development of nanotechnology - An indicators based analysis*, Brussels: European Commission.

Igami, M., T. Okazaki (2007), Capturing Nanotechnology's Current State of Development via Analysis of Patents, STI Working Paper 2007/4, Paris: OECD.

Initiative Photonik 2020 (2009), *Licht ist Zukunft – Memorandum zur Zukunft der Optischen Technologien in Deutschland*. Berlin.

Innova (2008), *Microelectronics clustering efforts in Grenoble*, Europe Innova Cluster Mapping, Case Microelectronics Grenoble.

IQ (no date), Quebec – a dynamic and profitable business environment, Investissement Quebec, http://www.photoniquequebec.ca/documents/Investissement_Quebec_OpticsPhotonics.pdf

ITRI (2010), Industrial Technology Research Institute, Taiwan, http://www.itri.org.tw/eng/

IWEPS (2009), *Evaluation du Plan d'actions prioritaires pour l'Avenir wallon. Rapport de synthèse Période 2006-2008,* Namur, Institut Wallon de l'evaluation de la Prospective et de la Statistique, 151.

Jahns, J. (2001), *Photonik – Grundlagen, Komponenten und Systeme*, München, Wien.

Janz, N., H. Lööf, B. Peters (2004), Firm-Level Innovation and Productivity – Is there a Common Story across Countries? *Problems and Perspectives in Management* 2, 184–204.

Ketels, C. (2007), *The role of clusters in the Chemical Industry*. Brussels, The European Petrochemical Association.

Klein Woolthuis, R.J.A. (2010), Sustainable Entrepreneurship in the Dutch Construction Industry, *Sustainability* 2, 505–523.

Klein Woolthuis, R.J.A., M. Lankhuizen, V. Gilsing ( 2005), A system failure framework for innovation policy design, *Technovation* 25, 609–619.

Koplow, D. (2007), *Biofuels – At What Cost? Government support for ethanol and biodiesel in the United States: 2007 update*, prepared for The Global Subsidies Initiative (GSI).

KPMG (2009), *Changsha Investment Environment Study 2009*, Guangzhou, KPMG Huazhen: 24.

KPMG (2009), *The Road to Recovery in the Global Semiconductor Industry – A Survey of Industry Executives – Fourth Quarter 2009*.

Kutas, G., C. Lindberg, R. Steenblik (2007), *Biofuels – at What Cost? Government support for ethanol and biodiesel in the European Union*, prepared for The Global Subsidies Initiative (GSI).

Lerch (2008), Bewertung und Begleitung der Netzwerkentwicklung von OpTecBB - Abschlussbericht, Freie Universität Berlin, available from: http://www.wiwiss.fu-berlin.de/institute/management/sydow/media/pdf/07_OpTecBB_Bericht_Sydow_Windeler_Lerch_Endversion.pdf

Lerch, F., J. Sydow, K.G. Provan, K.G. (2006), *Cliques within Clusters – Multi-dimensional Network Integration and Innovation Activities*, paper presented at the 22nd EGOS Colloquium, Bergen.

Leti (2010), Leti History, available from: http://www-leti.cea.fr/en/Discover-Leti/About-us/History

Li, D.-Y., Z. Ya-Qing (2006), Cluster Competitiveness and Strategy Based on Modified GEM Model - An Analysis on Changsha Engineering Machinery Cluster in Center China ICMSE '06. 2006 International Conference on Management Science and Engineering ICMSE.

Li, X. (2009), China's regional innovation capacity in transition: An empirical approach, *Research Policy* 38, 338–357.

Li, X., T. Lin, H. Chen, M. Roco (2007), Worldwide nanotechnology development: a comparative study of USPTO, EPO and JPO patents (1976–2004), *Journal of Nanoparticle Research* 9.

Link, A., P. Kapur (1994), A Note on the Diffusion of Flexible Manufacturing Systems Technology, *Economic Letters* 46, 357–362.

Lipsey, R., K. Carlaw, C. Bekar (2005), *Economic Transformations – General Purpose Technologies and Long-Term Economic Growth*, Oxford: Oxford University Press.

Liu, S.-J. (2007), Changsha government arranged the marriage of production industries trees produce scientific and technological innovation, Shangsha City Fancy Ebroidery Co., Ltd. 2010, available from: http://www.fancy-china.com/en/article.php?id=55

Liu, X., S. White (2001), Comparing innovation systems: a framework and application to China's transitional context, *Research Policy* 30, 1091–1114.

Lu, Y., (ed.) (2010), *Science & Technology in China: A Roadmap to 2050. Strategic General Report of the Chinese Academy of Sciences*. Beijing, Dordrecht, New York, Chinese Academy of Sciences. Science Press Beijing, Springer.

Lucas, R.E. (1988), On the Mechanics of Economic Development, *Journal of Monetary Economics* 22, 3–42.

Luther, W., G. Bachmann (2009), *nano.DE-Report 2009. Status Quo of Nanotechnology in Germany*. Berlin: Federal Ministry of Education and Research.

LuxResearch (2006), *The Nanotech Report,* New York: Lux Research Inc.

LuxResearch (2009), *Nanomaterials of the Market Q1 2009: Cleantech's Dollar Investments, Penny Returns*, New York: Lux Research Inc.

Maine, E. and E. Garnsey (2006), Commercializing generic technology: The case of advanced materials ventures, *Research Policy* 35, 375-393.

Malmberg, A., D. Power (2006), True clusters: A severe case of conceptual headache, in: B. Asheim, P. Cooke, R. Martin (eds.), *Clusters and Regional Development*, London: Routledge.

Marshall, L.S. (2010), *Northern Lights: The photonics Industry in Canada*.

McCormack (2010), U.S. Becomes a Bit Player in Global Semiconductor Industry: only One New Fab Under Construction in 2009, *Manufacturing & Technology News* 17, no. 3.

McKinsey (2003), *Industrial Biotechnology*. New York.

McKinsey (2009), *White Biotechnology*, Press briefing, February, 2009.

Minalogic (2010), Grenoble – A high-tech hub, Minalogic Website, available from: http://www.minalogic.com/en/environnement-grenoble.htm

Miyazaki, K., N. Islam (2007), Nanotechnology systems of innovation – An analysis of industry and academia research activities, *Technovation* 27, 661–675.

Moed, H., W. Glänzel, U. Schmoch (eds.) (2004), *Handbook of quantitative science and technology research: the use of publication and patent statistics in studies of S&T systems*, Dordrecht: Kluwer.

Moskowitz, S. (2009), *The Advanced Materials Revolution. Technology and Economic Growth in the Age of Globalization,* Hoboken: John Wiley & Sons, 255ff.

Mowery, D.C., J.T. Macher, A. Di Minin (2007), The "Non-Globalization" of Innovation in the Semiconductor Industry, *California Management Review* 50, 223ff.

MTC and NSTI (2004). Nanotechnology in Massachusetts, http://www.nsti.org/outreach/NIM/NIM.pdf, Massachusetts Technology Collaborative and the Nano Science and Technology Institute.

Nanomicro (2010), Nanoscience & Nanotechnology, http://www.nanomicro.recherche.gouv.fr/us/pole-compet.html

NNI (2007), *The National Nanotechnology Initiative. Strategic Plan,* Washington: Subcommittee on Nanoscale Science, Engineering, and Technology, Committeee on Technology, Nantional Science and Technology Council.

NNI (2010), *The National Nanotechnology Initiative. Research and Development Leading to a Revolution in Technology and Industry. Supplement to the President's 2011 Budget*, Washington: Subcommittee on Nanoscale Science, Engineering, and Technology, Committeee on Technology, Nantional Science and Technology Council.

Nordicity Group (2006), *Regional/local industrial clustering: Lessons from abroad*, Ottawa: National Research Council Canada.

Noyons, E.C.M., R.K. Buter, A.F.J. van Raan, U. Schmoch, T. Heinze, S. Hinze, R. Rangnow (2003), *Mapping Excellence in Science and technology across Europe nanoscienec and nanotechnology*. Final Report to the European Commission, Leiden, Karlsruhe: CSTS and Fraunhofer-ISI.

OCRI (2006), Industry Overview – Semiconductors, available from: http://www.ottawaregion.com/Business_in_Ottawa/Industry_Overview/semiconductor.php

OECD (2008), *Information Technology Outlook*, Paris: OECD.

OECD (2009a), *The Bioeconomy to 2030: Designing a Policy Agenda*, Paris: OECD.

OECD (2009b), Industry Structure and Business Models for Industrial Biotechnology, OECD workshop on "Outlook on Industrial Biotechnology", DSTI/STP/BIO(2009)22, Paris: OECD.

OECD (2009c), *Inventory of National Science, Technology and Innovation Policies for Nanotechnology 2008*, Paris: OECD.

OECD (2009d), Financing and Investment Models in Industrial Biotechnology – Research methodology and first results, OECD workshop on "Outlook on Industrial Biotechnology", DSTI/STP/BIO(2009)23, Paris: OECD.

OECD (2010), Trends in Technology and Applications, OECD workshop on "Outlook on Industrial Biotechnology", DSTI/STP/BIO(2009)25, Paris: OECD.

OECD, FAO (2008), *Agricultural Outlook 2008-2017*, Paris: OECD.

Ontario (2007) Ontario Business Report, *Ministry of Economic Development and Trade (Canada).*

Ontario (2009) "Ontario's IT Industry" Invest in Ontario, available from: http://www.investinontario.com/resources/infotech.asp

Optech (2007) *Photonics in Europe, Economic Impact*, Photonics21 and Optech Consulting.

Ottawa (2003), Ottawa 20/20 - Economic Strategy, available from: http://www.ottawa.ca/city_services/planningzoning/2020/es/pdf/es_en.pdf

Ouimet, M., R. Landry, N. Amara (2004), *Network Positions and Radical Innovation: A Social Network Analysis of the Quebec Optics and Photonics Cluster*, Paper presented at the DRUID Summer Conference 2004. Denmark, June 14–16.

Owen-Smith, J., W.W. Powell (2006), Accounting for emergence and novelty in Boston and Bay Area Biotechnology, in: P. Braunerhjelm, M. Feldman (eds.), *Cluster Genesis. Technology-based Industrial Development*, Oxford: Oxford University Press, 61–85.

Page, K. (2003). *The Cambridge Biotechnology Cluster*.

Palmberg, C., H. Dernis, C. Miguet (2009), *Nanotechnology: an Overview Based on Indicators and Statistics*, STI Working Paper 2009/7, Paris: OECD.

PCAST (2008), *The National Nanotechnology Initiative: Second Assessment and Recommendations of the National Nanotechnology Advisory Panel*, Washington: The President's Council of Advisors on Science and Technology.

Peters, B. (2008), *Innovation and Firm Performance: An Empirical Investigation for German Firms*, ZEW Economic Studies 38, Heidelberg: Physica.

Photonics21 (2007a), *Towards a Bright Future for Europe - Strategic Research Agenda in Photonics*, Duisburg-Neumühl.

Photonics21 (2007b), *Photonics in Europe – Economic Impact*, Lindlar.

Pierson C., F.G. Castles (2006), *The Welfare State Reader*, Cambridge: Polity press.

Polt, W., W. Pointner (eds.) (2005), *Diffussionsorientierte Technologiepolitik. Eine vergleichende Wirkungsanalyse für Österreich, die Schweiz, Deutschland und die USA*. Graz: Leykam.

Porter, M.E. (1990), *The Competitive Advantage of Nations*, London: Macmillan.

QPN (2010), Quebec Photonics Network Website, available from: http://www.quebecphotonic.ca

Riese, J., R. Bachmann (2004), *Industrial Biotechnology: Turning the Potential into Profits. Chemical Market Reporter*. McKinsey & Company, 2004.

Romer, P.M. (1986), Increasing returns and long-run growth, *Journal of Political Economy* 94, 1002–1037.

Rosenberg, N. (1982), *Inside the Black Box: Technology and Economics*. Cambridge: Cambridge University Press.

Sargent, J.F. (2008), *Nanotechnology: A Policy Primer*, CRS Report for Congress, Washington: Congressual Research Services.

Scheu, M., V. Veefkind, Y. Verbandt, E. Molina Galan, R. Absalom, W. Förster (2006), Mapping nanotechnology patents: The EPO approach, *World Patent Information* 28, 204–211.

Schmoch, U., F. Laville, P. Patel, R. Frietsch (2003), *Linking Technology Areas to Industrial Sectors*, Final Report to the European Commission, DG Research, Karlsruhe, Paris, Brighton: Fraunhofer-ISI, OST, SPRU.

Schumacher, G., S. Preston, A. Smith, P. Sajgalik (2007), *Future Perspectives of European Materials Research*, Jülich: Research Centre Jülich, Matter and Materials, 35.

Scott, I. (2007) 'Revitalizing Ontario's Microelectronics Industry' *Information Technology Association of Canada.*

Shapira, P., J. Wang (2007), *R&D Policy in the United States: The Promotion of Nanotechnology R&D*, Case Study under the Project "Monitoring and analysis of policies and public financing instruments conducive to higher levels of R&D investments - The 'Policy Mix' Project, Brussels.

Shapira, P., J. Youtie (eds.) (1998), *Manufacturing Modernization: Implications of Evaluation Results for Program Improvement and Policy Development*. Proceedings of the Fourth Atlanta Workshop on the Evaluation of Industrial Modernization.

Sigurson, J. (2004), *Regional Innovation Systems in China*, EIJS Working Paper 195, Stockholm: The European Institute of Japanese Studies.

Sölvell, Ö. (2008), *Clusters: Balancing evolutionary and constructive forces*, Stockholm: Ivory Tower Publishers.

Su, Y.S., L.C. Hung (2009), Spontaneous vs. policy-driven: The origin and evolution of the biotechnology cluster, *Technological Forecasting and Social Change* 76, 608–619.

Sydow, J., C. Denner, F. Lerch, D. Kutsenko, H. Neumann,R. Mallach, G. Rössler, E. Stens (2009), *Potential to Network Innovative Clusters in the Baltic Metropoles Regions - Present State and Perspectives*, Berlin: Free University.

Sydow, J., F. Lerch, C. Huxham, P. Hibbert (2007), Developing Photonics Clusters: Commonalities, Contrasts and Contradictions, *Advanced Institute of Management Research,* available from: http://www.europe-innova.eu/c/document_library/get_file?folderId=148901&name=DLFE-6114.pdf

Timmer, M.P., B. van Ark (2005), Does information and communication technology drive EU-US productivity growth differentials? *Oxford Economic Papers* 57, 693–716.

USBA (1994), *Bridging The Valley of Death: Financing Technology for a Sustainable Future*, U.S. Small Business Administration for the U.S. Environmental Protection Agency.

USDA (2008), *US Biobased Products: Market Potential and Projections through 2025*, OCE-2008-1, Washington: United States Department of Agriculture.

van Ark, B., M. Piatkowski (2004), Productivity, innovation and ICT in Old and New Europe, *International Economics and Economic Policy* 1, 215–246.

van Beuzekom, B., A. Arundel (2009), *OECD Biotechnology Statistics 2009*, Paris. OECD.

Verhoyen, O., B. Phillipe (2009), *PLASTIWIN, une remarquable diversité*, AG de Federplast. Grand Bigard, 24.

Walker, J. (2005), Cambridge: Europe's leading location for biotechnology, *Drug Discovery Today* 10(14).

WBI (2009), *Les nouveaux clusters wallons. Wallonie//Bruxelles. Revue bimestrielle internationale*, Bruxelles: Communauté française de Belgique et la Région wallonne, 56.

Wen, J., S. Kobayashi (2002), Impacts of government high-tech policy: a case study of CAD technology in China, *Journal of Engineering and Technology Management* 19, 321–342.

Wolfe, D.A. (2005), Regional Clusters in a Global Industry: ICT Clusters in Canada, Toronto: University of Toronto, presentation available from: http://www.utoronto.ca/onris/research_review/Presentations/PresentationDOCS/Presentations05/Wolfe05_ICTClusters.ppt

Wolfe, D.A. (2008), *Cluster policies and cluster strategies: Lessons from the ISRN national study,* Centre for International Studies, Toronto: University of Toronto.

WSTS (2009), World Semiconductor Trade Statistics – Autumn Forecast Meeting 2009, http://www.wsts.org

Yeung, H.W.-C., W. Liu, P. Dicken (2006), Transnational corporations and network effects of a local manufacturing cluster in mobile telecommunications equipment in China, *World Development* 34, 520–540.