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- an Innovation System Approach to an Emerging Area

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by funding *needs-driven research*
and developing *effective innovation systems*.

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Nanotechnology in Sweden

- an Innovation System Approach to an Emerging Area

Eugenia Perez & Patrik Sandgren

Foreword

There are major expectations that nanoscience and nanotechnology will create new applications and innovations and thereby major growth. Some 30 countries have initiated national strategies and initiatives for nanotechnological development. From an international perspective, Swedish nanotechnology is regarded as occupying a strong position in terms of knowledge and nanotechnology has been highlighted as a potential growth area for Swedish industry. Despite this, Sweden lacks a strategy for nanotechnological development. Designing a successful strategy requires an understanding of Swedish circumstances in an international context.

VINNOVA's task includes identifying needs and developing effective innovation systems. There is currently no overall description of the innovation system in Sweden related to nanotechnology. The purpose of this study is to contribute to such a description and thus increase VINNOVA's and Sweden's awareness of nanotechnology from an innovation system perspective.

This report was authored by Eugenia Perez and Patrik Sandgren at VINNOVA's Strategy Development Division, in cooperation with The Royal Swedish Academy of Engineering Sciences, IVA. The authors would like to thank all the interviewees and others who contributed to the creation of the report, and IVA for providing supporting material and insightful contributions.

VINNOVA in March 2008

Göran Marklund
Head of Strategy Development Division

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Abstract

By 2015, it is anticipated that the market for nanotechnology will reach USD 1,000 billion. In order to foster the opportunities which nanotechnology is expected to provide, some 30 countries have designed strategies and created policy initiatives for nanotechnological development. Swedish nanotechnology occupies a strong position internationally in terms of the knowledge base within certain niches and nanotechnology has been highlighted as a potential growth area for Swedish industry. Despite this, there is weak knowledge about nanotechnology and its applications in Sweden. The purpose of this study is to contribute to a description of the Swedish nanotechnology innovation system, firstly by clearly revealing the actors, the framework and the networks that constitutes and affects the system, secondly by providing a picture of the Swedish potential for creating nanotechnology innovations.

The innovation system is currently at an early stage, centred on research and the creation of knowledge. There is great uncertainty regarding regulations and markets and there are generally no standards, specialised workforce or strong industrial organisations in Sweden.

Nanotechnological activity is currently run by companies, universities and institutes. Networks are being formed and frameworks developed. In this sense, there is a nanotechnology innovation system in Sweden. A total of 85 companies with varying degrees of connection to nanotechnology have been identified. Of these, 34 are “pure” nanotechnology companies with operations built around nanotechnology, whilst 51 use nanotechnology in the development of some of their products. The turnover of the “pure” nanotechnology companies in 2005 was SEK 1.5 billion and they employed 680 people. However, in an international comparison, Sweden has relatively few nanotechnology companies. Fifteen Swedish universities and nine institutes with nano-relevant research have been identified. A small number of venture capital companies and research financiers are interested in nanotechnology.

Pronounced market potential and international initiatives are pushing ahead the construction of the nanotechnology innovation system in Sweden. At the same time, there is uncertainty regarding applications and their specific market potentials. Sweden has a strong scientific knowledge base which is highly attractive to foreign contributors and there are good collaborations with international actors. At the same time, there are relatively few inter-academic collaborations or ones between academia and industry. The result

is that the technical knowledge base and interdisciplinary diffusion of knowledge has potential for development.

Regarding commercialisation, there is a relatively high level of experimentation with nanotechnology applications. However, commercialisation is hampered by weak links between academia and industry plus low levels of knowledge as to production and marketing. It has also been difficult for the pure nanotechnology companies to identify applications. Furthermore, uncertainty regarding the technology and its toxicology and regulations is weakening the legitimacy of nanotechnology in existing industry.

There is currently adequate general human capital and infrastructural research resources, but a lack of human capital with sufficient interdisciplinary expertise. The nanotechnology investments in Sweden have been scattered and the financing structure of research in Sweden is making things difficult for those conducting research. Nanotechnology is attracting ever larger private and public investments in many parts of the world, but not in Sweden. Swedish venture capital interest in nanotechnology is lukewarm.

The generic nature of nanotechnology makes it difficult to discuss the technology more generally in terms of research, industry and markets. This may very likely be one of the explanations for the lack of focus in Swedish nanotechnological research investment. For, despite no integrated nanotechnology investment having been made, nanotechnology is dispersed amongst various research fields. Sweden has a good potential for taking a leading position within nanotechnological fields, but in order to meet the international competition, it has to assemble them.

There is a growing industry within nanotechnology in Sweden, but there is clear potential for improvement. The participation of established industry in the development of nanotechnological innovations is critical, since they possess production, market and commercial knowledge.

1 Introduction

During the past few decades, there has been increasing discussion of nanotechnology. Nanotechnology is expected to create over two million employment oportunities around the world and by 2015 the market for nanotechnology is anticipated to reach USD 1,000 billion[1]. Visionaries are talking of the Third Industrial Revolution.

There are major expectations of nanotechnology, but far from everyone is convinced these will be met. Still, it can be stated that this is a field with many possibilities. Whilst many classify nanotechnology as a hype, it has given rise to previously unattainable applications in such things as cosmetics, paints and drugs; products which are already all around us[2].

Swedish nanotechnology is regarded as occupying a strong position internationally in terms of knowledge, and nanotechnology has been highlighted as a potential growth area for Swedish industry. However, the current knowledge about the nanotechnological field in Sweden is weak from an innovation system perspective.

1.1 About the study

In order to safeguard the opportunities which nanotechnology is expected to provide, almost 30 countries have commenced some form of national initiative for investment in nanotechnology. A strategy has also been laid out within the field at EU level[3]. Despite this, Sweden has no overall take on nanotechnology. Nanotechnology in Sweden is currently a fragmented field of disparate activities and investments. There is no overview.

In the light of this, the Royal Swedish Academy of Engineering Sciences, The Royal Swedish Academy of Engineering Sciences, IVA, commenced a project in 2005 to develop a national strategy for nanotechnology in Sweden. Designing a successful strategy requires an understanding of Swedish circumstances in an international context. There is currently no cohesive description of the innovation system in Sweden which can relate to nanotechnology. The purpose of this study is to contribute such a description by:

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[1] Roco (2004).
[2] Allianz and OECD (2005).
[3] Ahlgren and Jonsson (2005).

- Providing overall clarification of the actors, plus the institutioins[4] and networks involved in, and influencing, the Swedish innovation system regarding nanotechnology.
- Providing a picture of Swedish potentials for creating nanotechnology innovations, on the basis of a number of aspects relevant to the innovation system.

The study is general for the nanotechnology field but with a greater emphasis on the field of materials and electronics; fields in which nanotechnology has long been used. The biotechnology side is particularly breifly surveyed. The aim has been to give an initial insight into the wide field refered to as nanotechnology. The definition of nanotechnology has been kept broad, meaning that the conclusions must be regarded as wide-ranging and tentative.

The major part of the material in the study comes from reports, articles and webpages but also from a number of interviews with participants and seminars relating to nanotechnology.

Chapter 1.2 below attempts to give a general picture of nanotechnology and the disciplines, technical fields and markets linked to it. Chapter 1.3 below briefly introduces the innovation system approach and what is meant by the nanotechnology innovation system in Sweden. Chapter 2 centres on issues raised under the first point on the aims of the study, namely the description of the actors, frameworks and networks involved in and influencing the Swedish innovation system within nanotechnology. Chapter 3 gives an assessment of Swedish potentials for creating nanotechnological innovations by analysing a number of aspects of the innovation system. There is also a discussion on the output of the innovation system, in other words, how good the system is at producing innovations. Chapter 4 summarises the obstacles to the creation of innovations identified in the analysis in Chapter 3 and presents five proposed measures which may increase the creation of innovations.

1.2 About nanotechnology

In 1959, the American physicist Richard Feynman heralded the future possibilities of nanotechnology in a speech which came to be regarded as the first step in the development of the concept of nanotechnology. Despite not actually using the term *nanotechnology*, he spoke of designing structures atom by atom.

[4] i.e. laws, regulations and norms that affects the innovation system

The “nano” in nanotechnology indicates a unit of measurement spanning the interval (0.1-100) $*10^{-9}$m. However, the measurement is not really the key issue. The important thing is rather that when components are made sufficiently small, new properties appear. This presents opportunities such as:

- Miniaturisation to molecular and atomic level. This increases speed and reduces the size of products.
- Interdisciplinary synergy effects when different disciplines are brought together in a converging context, such as when biology meets electronics on a molecular and atomic level.
- New materials which arise when building one atomic layer at a time, with the opportunity to change such things as the chemical composition of crystals.
- New properties other than those in the traditional bulk materials when the structure or particles reach a certain size. Examples of this may be changes in light absorption, conductivity, magnetism, hardness etc.

Researchers also proceed from the basis of material comparisons and structures in nature when seeking new properties to imitate by means of nanotechnology. This field is called biomimetics. An example is the so-called lotus effect used in self-cleaning surfaces. Materials have been developed which imitate the water-repellant wax material and structure of the lotus flower.

Often-used terms are *nanoscience* and *nanotechnology*. Nanoscience is the study of new phenomena and properties arising particularly at atomic and molecular level. Nanotechnology is the application of nanoscience to create new properties through the manipulation of molecules and small structures. Accordingly, nanotechnology often includes the manipulation aspect. Thus, the mere capability to study nanostructures and their properties is not really nanotechnology. However, nanoscience is very often (though not always) the basis of the technology. It is therefore also important to clarify nanoscience when discussing nanotechnology from a systems approach.

Nanotechnology is often referenced as a horizontal, key, generic, or enabling technology. Nanotechnology is strongly interdisciplinary in nature and covers a broad spectrum of sciences and technologies within physics, biology and chemistry.

Use of the term “nanotechnology” varies. Some place it on equal footing with atomcraft, the manipulation of atoms, and during the 1990s that term was more common than nanotechnology. Others start from the size level which nanotechnology aims for and include a broad spectrum of fields when speaking of nanotechnology[5]. There are also those who claim that, with the exception of isolated cases of atomic manipulation, nanotechnology deals with normal, conventional materials science or ordinary chemical engineering[6]. The following definition of nanotechnology is used in this study:

> *Nanotechnology comprises the understanding and controlled manipulation of structures and applications at molecular and atomic level.*

The number of dimensions of nanometre size being worked with may vary from one to three, with one dimension corresponding to one layer or one film and three dimension corresponding to a free particle or a surface with three-dimensional structure. Opinions differ as to whether or not nanometre-thick surfaces and films should be included in the nanotechnology field. Some consider that nanotechnology only becomes interesting when working in two dimensions at nanometre level[7]. However, this study includes surfaces and films in nanotechnology since new properties which have been established as central to nanotechnology do also occur at one dimension.

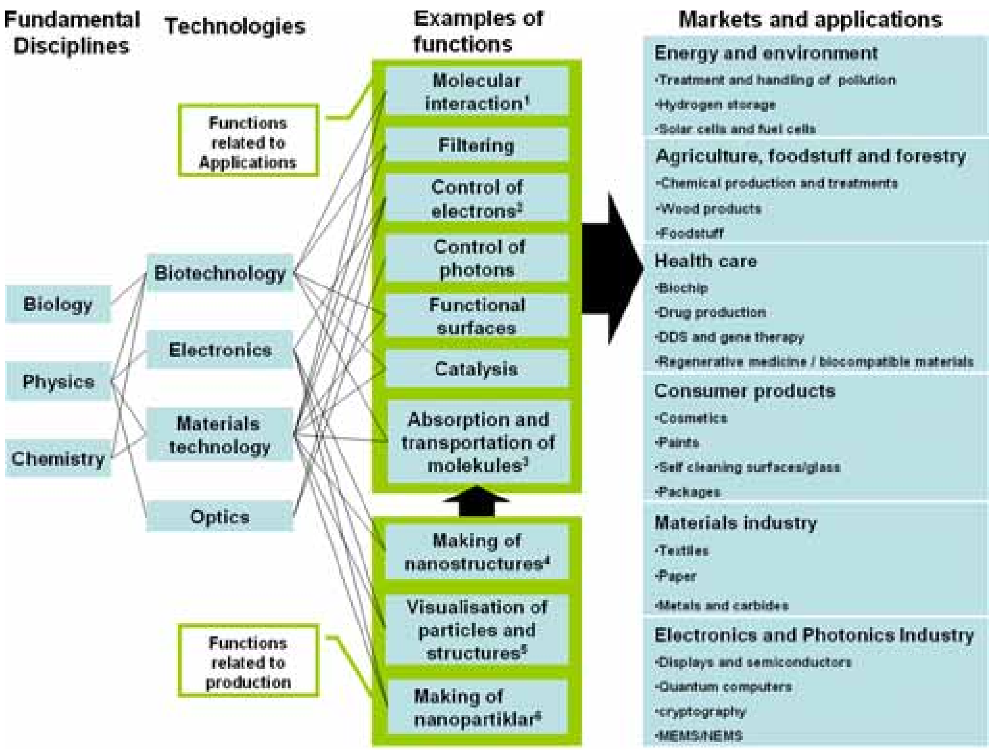
There are two ways to work at nano-level: bottom-up and top-down. Bottom-up relates to the creation of nanometre-sized structures by building one molecule or one atom at a time. Epitaxy is an example of this, whereby nanometre-thick surfaces can be created through the ordered growth of crystalline film. Top-down involves starting with a larger element and, using controlled processes, attempting to create nanometre-sized structures in a larger material. This has been the general approach to nanotechnology in fields such as electronics and materials engineering. This can be achieved through such things as lithography.

1.2.1 Attempting to find the way from knowledge to application

Given the generic nature of nanotechnology, attempting to deduce the connection between scientific basic disciplines and nanotechnology applications is not all that simple. However, this is important in order to understand the development of knowledge around nanotechnology from a systems point of view. Figure 1 is an attempt to do precisely this and provide a simplified picture of the field.

[5] Karhi (2006).
[6] Karhi (2006).
[7] Karhi (2006).

Figure 1. Technological analysis of nanotechnology.



1. Including nanomagnetism.
2. Including spintronics and quantum dots, but also using carbon nanotubes.
3. For example in fullerene structures such as carbon nanotubes.
4. Using such things as lithography (atomic force microscopy (AFM) and scanning tunnelling microscopy (STM)), epitaxy and self-organisation.
5. Using such things as atomic force microscopy (AFM) and scanning tunnelling microscopy (STM).
6. Using such things as lithography and self-organisation.

Three basic disciplines, biology, physics and chemistry, lay the basis for nanotechnology. It is largely within basic research that the field has developed, chiefly in physics. Work has long been under way at nanometre level in chemistry and physics, so nanotechnology is really nothing new. Through the developments of recent years in biotechnology, biology has made strides into the nanotechnology field, one example of this being genetic engineering. The discipline has also acted as a source of inspiration in the construction of nanostructures through biomimetics.

Furthermore, the basic disciplines are branching out into new types of technologies. Materials engineering and electronics have been the two driving technologies where it concerns the advancement of nanotechnology. Within electronics, demands for increased performance through smaller components have paved the way to the nano level. The driver in materials engineering has been the search for new properties in materials. In recent times, performance demands on new materials have also come from biotechnology through the development of such things as regenerative medicine. The capacity of nanostructures to manipulate light in new ways has meant that nanotechnology is also linked to optics.

As stated, nanotechnology enables a common interface in which such areas as biotechnology, electronics and materials engineering can meet and create new functions and applications. It is often in these functions where the true news value of nanotechnology appears. Figure 1 contains two types of functions; one related to production functions necessary to create nanoscale components and the other to functions made possible by nanotechnology and which are linked to applications. The link between these functions and possible products are endless, since nanotechnology is anticipated to open up innumerable new applications within a large number of different markets. Thus, to create a clear picture, the link between each function and application or market has been replaced by an arrow.

There are products which have been on the market for decades, such as sun protection factor and anti-scratch sunglasses[8]. The electronics market will probably be reached by an increasing number of nanotechnology products within the near future, such as displays and TV sets. Even now, the computer industry is working at nanometre level and further into the future, we find improved wireless technology and huge processor power. Within the materials industry today, there are new textiles with wind and waterproofing properties. Further on in time, new materials may lead to lighter vehicle designs; on land as well as in air and space. It is also thought that the medical applications will generate a major market and there are great hopes for nanotechnology. Today, there is DDS, drug delivery based on early-stage nanotechnology and so-called lab-on-a-chip diagnostic instruments. In the future, prostheses are expected in biocompatible materials and materials for regenerative medicine. Within the energy and environment field, it is widely expected that the catalysis and filtration properties of nanostructures will be exploitable for purposes such as filtering the salt out of water. It is also hoped to be able to create lighter materials for increased energy efficiency, plus brand new forms of energy such as artificial photosynthesis.

There are also a number of transverse markets relevant to the nanotechnology innovation system; the security and automotive industries for example. A number of transverse applications can also be mentioned, such as instruments for production and measurement of nanotechnology

[8] The applications and markets have been identified from a large volume of material, but above all from Allianz and OECD (2005)

structures and sensors for various functions. This is linked to the production-related functions in Figure 1.

1.2.2 Subdivisions of nanotechnology

In this study, nanotechnology is subdivided into Biotechnology, Electronics, Instruments and Equipment, and Materials and Surface Engineering. The generic nature and diversity of nanotechnology in terms of technologies, applications and markets, plus its role as an interdisciplinary interface technology, makes it difficult to generate clear sub-categories and subdivide participants and their activity. Below are the criteria used in classifying the industrial actors.

Biotechnology: The technical exploitation of organic molecules and biological systems such as cells and cell constituents on nanometre level in order to produce or modify products.

Electronics: Monitoring the movement of electrons on nanometre level in order to produce electronic components within such things as radio, computer technology and communications.

Instruments and Equipment: Manufacture of precision tools or apparatus for measurement and analysis on nanometre level, such as sensors, spectroscopes and other measurement instruments, plus production of equipment to produce structures on nanometre level.

Materials and Surface Engineering: The technical exploitation and development of inorganic materials so as to achieve desired properties in materials and on surfaces, based on nanometre-level processing.

The basis for the above subdivision has been IVA's[9] division which has been consistent with other identified subdivisions of the field.

The subdivision of nanotechnology is not entirely without problems since the various fields merge into each other as well as making various intersections with the nanotechnology field. This has been a limitation to the study in terms of classification of the industrial actors. In particular, the Instruments and Equipment field has had strong links to Materials Engineering, Electronics and/or Biotechnology since it starts with applications instead of technology like the others. The choice to nonetheless single out this field has been made so as to capture the important group of companies who, aided by nanotechnology, are creating capabilities to measure and produce on nanometre level.

[9] IVA's project "Strategy for a Swedish nanosystem", IVA 2006.

1.3 About the innovation system

The following report takes an innovation system approach. This means that a number of actors, networks and frameworks are examined from a systems perspective[10] in which the task of the system is to generate nanotechnology innovations. The following definition of the innovation system is used in this analysis:

> *Actors who develop, produce or use nanotechnology, public and private organisations plus institutions and frameworks supporting their action.*

The system in this report is defined on the basis of two aspects: a technology and a geographical area, in this case a country. In the case of nanotechnology, things are a little unusual as it is not really a true technology or product group. Nor is there a defined group of scientific disciplines behind the development. Strictly speaking, the innovation system described in this report is built up around the concept or phenomenon of nanotechnology which gives rise to a number of technologies and products. Concerning the geographical demarcation, this may be discussed but given that the report is written in the light of the production of a national strategy, the demarcation is considered appropriate.

General characteristics of both the Swedish innovation system and nanotechnology globally will shape what will be regarded in this study as a Swedish innovation system in nanotechnology. This will take place with a sectorial emphasis on nanotechnology. However, given the breadth of the field, it is not really possible to talk of such a unified sectorial system for nanotechnology in general. This receives more detailed discussion in Chapter 4.2. Nevertheless, the purpose of this study is to provide an overall picture of the structure and mechanisms which generate nanotechnological innovations and for that, the innovation system approach is considered a suitable analytical tool.

[10] These elements are interconnected to form a whole in which the various parts influence and are affected by each other.

2 Nanotechnology in Sweden

Despite Sweden having no formal national nanotechnology initiative, a number of activities have been completed and it is now possible to find several participants who relate their activity to nanotechnology. In this sense, there is a nanotechnology innovation system in Sweden. The purpose of this chapter is to give overall clarification of the Swedish participants in the nanotechnology innovation system in Sweden, as well as the frameworks and networks influencing the field.

2.1 Development of the innovation system

Different innovation systems are at different stages, depending on the conditions which existed for systems to grow. Despite certain types of nanotechnology products, such as sun creams and paints, having been out on the market for a good while in Sweden, the Swedish innovation system within nanotechnology has had around 15 years to develop and today, shows clear signs of still being at an early stage. Participants are seeking their places in the value chain, networks are being formed and frameworks are being developed in order to support the development of the technology. As early as 1987 the nanotechnology field was touched upon in the Micronic programme, which was financed by STU and which aroused the interest of industrial actors. However, the mainstay of the Swedish nanotechnology innovation system is often given as the material consortia created in the 1990s, where able researchers were assembled from various disciplines surrounding strategic research questions[11].

Today, the system is still characterised by a focus on research and the accumulation of knowledge, high levels of uncertainty regarding regulations and markets, difficulties identifying the field and highly dynamic actors. There are no standards, specialised workforce or trade organisations. At this stage, it is important to have the opportunity to change market rules, standards or other policy frameworks. Furthermore, it is important to attract new participants to the system and for there to be test-markets where applications can be developed. It is also important to generate confidence and support for the technology through political activity[12]. Another important aspect is to generate guidelines and guide the participants so that they start to go in the same direction [13]. These aspects are more important

[11] Fogelberg (2002).
[12] Carlsson and Jacobsson (2004).
[13] Hekkert et al (2004).

than others if the system is to continue developing and for system growth to gather momentum.

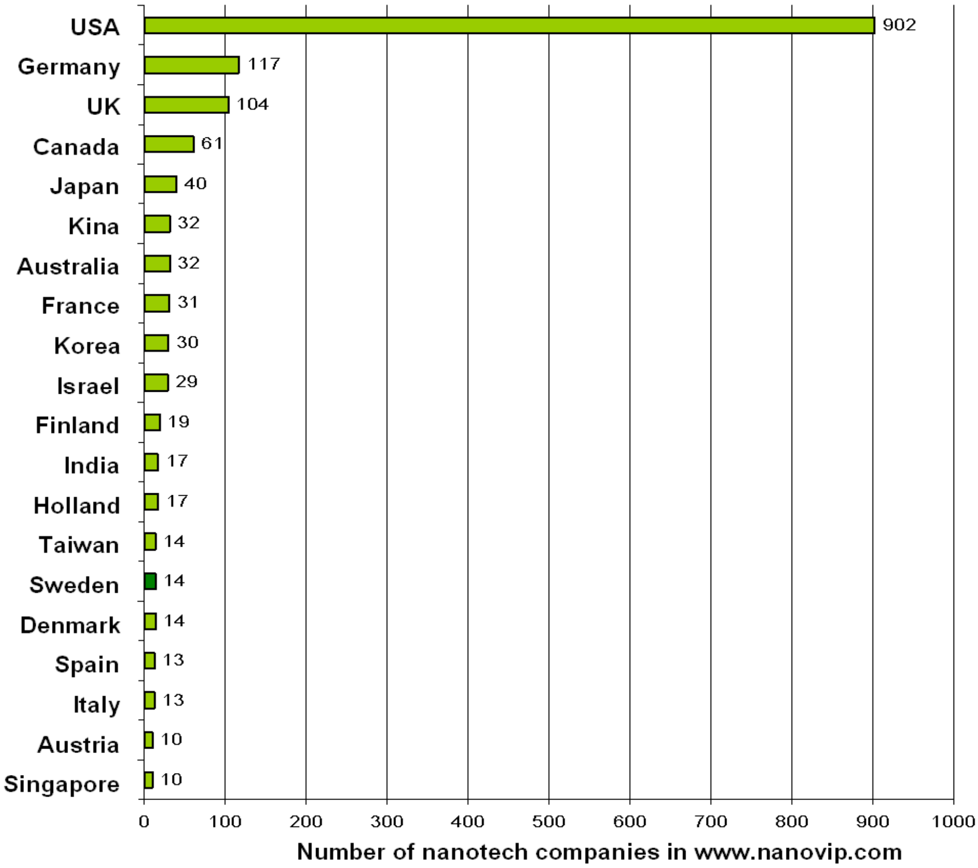
2.2 Participants

There is currently nanotechnological activity with a number of participants in industry, at the universities and in institutes. A number of financiers are also interested in the field from a research and innovation perspective, as well as political actors.

2.2.1 Industry

In an international comparison, Sweden has relatively few nanotechnology companies. In a database of nanotechnology companies compiled by Nanovip.com[14], Sweden is only 15th in the world with 14 nanotechnology companies (Figure 2).[15]

Figure 2. Number of nanotechnology companies in various countries (2006-07).



[14] However, this database is the only one in existence and which allows a comparison between countries. Cientifica has made previous survey studies in which Sweden performed similarly, for example in Allianz and OECD (2005).
[15] Nanovip.com (2006). This is the first network for nanotechnology companies.

Nevertheless, this is a weak indicator which becomes apparent when a comparison is made with the number of Swedish companies identified in this study. In Sweden, a full 85 companies have been identified with varying degrees of connection to nanotechnology. Of these, 34 are “pure” nanotechnology companies with operations built around nanotechnology. The other 51 uses nanotechnology to a greater or lesser extent to facilitate existing activity. These 85 companies are divided into the fields of Biotechnology, Electronics, Instruments and Equipment plus Materials and Surface Engineering. Their regional distribution is shown in Figure 3.

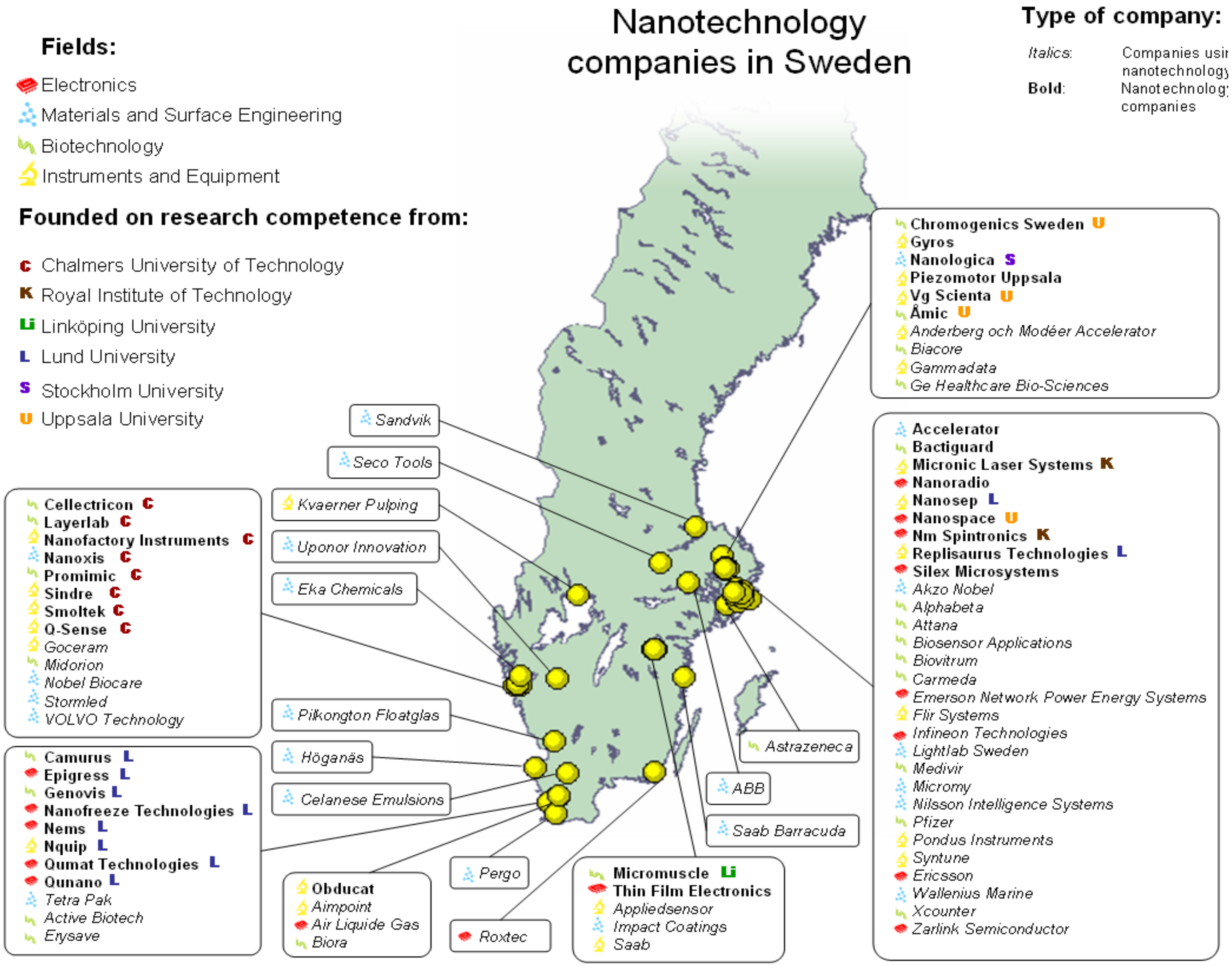


Figure 3. Companies connected with nanotechnology, distributed across Sweden. Data from UC (2006).

The Swedish nanotechnology companies are concentrated on Stockholm/Uppsala, Göteborg and Malmö/Lund, which is expected since the majority of companies have links to the universities nearby. These have been an important source of the origins of "pure" nano-companies [16]. Over three quarters (26/34) of the "pure" nano-companies are built wholly or partly on a product concept from academia. Of these, 10 were from Lund University (LU) and eight from Chalmers University of Technology (CTH).

During the years 1991-2004, 34 of the 85 companies had 133 patents approved.[17] A so-called cluster analysis of patenting organisations in Sweden has been made in order to show the structure of Swedish nano-patenting. In regard to patent classes, the link is shown between different companies' nanotechnology activity.[18]

Figure 4. Cluster analysis of patenting organisations in Sweden, from Meyer (2005b).

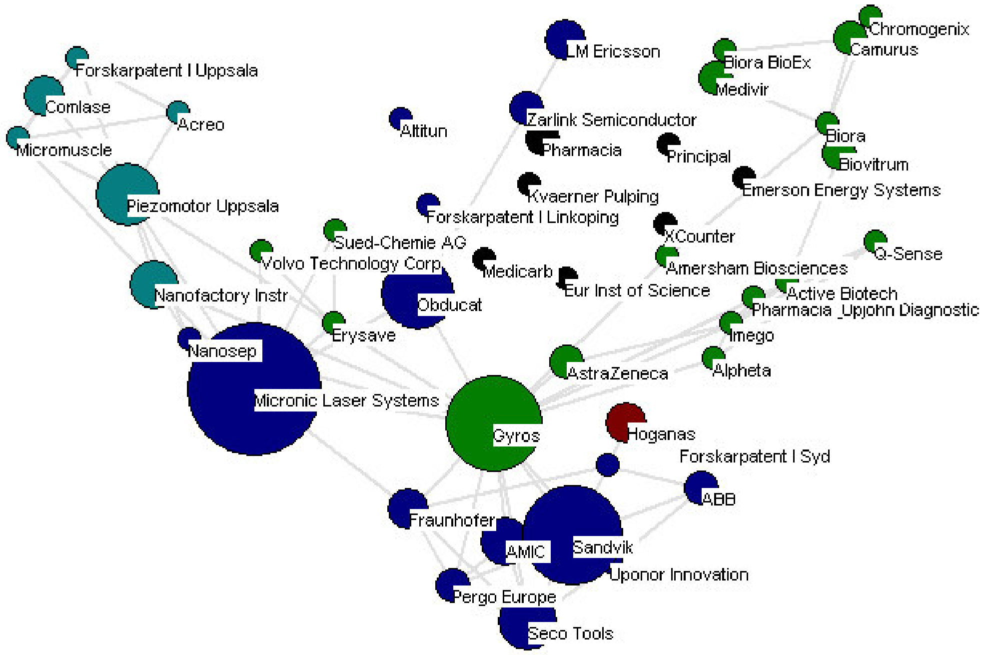


Figure 4 shows how Micronic Laser Systems, Sandvik and Gyros dominate. Micronic forms a cluster with Sandvik for patents within materials and instruments. Through Gyros, there is then an open link to the cluster relating to biotechnology, where companies such as AstraZeneca and Camarus are

[16] The origins have not been traced in the same way for other nanotechnology companies. For this reason, these companies' origins are not shown in Figure 3 either.
[17] Within USPTO, Meyer (2005b).
[18] The proximity of companies equates to the similarity of patent classes, by patents held. A link represents accord in a patent class at four-character level under the International Patent Classification (IPC). The size of the circles represents the number of patents held. The organisations are not merely companies but also ss and holding companies which hold patents. However, only six patents under this category are involved.

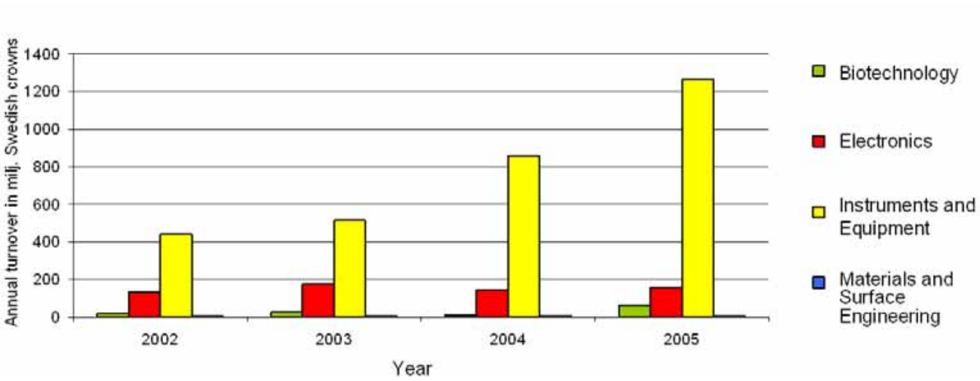
found. On the left, industrial research institute Acreo links to several companies in instruments, which link to other companies through Micronic Laser Systems.

Pure nanotechnology companies

In 2005[19], the 34 “pure” nanotechnology companies turned over SEK 1.5 billion and employed 680 people, but only 15% managed to show a profit in 2005[20]. Around 65% (22) of the nanotechnology companies were established after January 2000. The corresponding figure for the other companies is 21%. Accordingly, many of the pure nanotechnology companies are only a few years old and still in their start-up phase[21]. For this reason, many of them lack clients and their capital comes from various forms of financial start-up support, such as Industrifonden and Innovationsbron. Some of them have gone on to obtain some venture capital and reference clients. However, there are those who have progressed a great deal further such as Micronic Laser Systems, founded back in 1989.

Looking at the development of recent years for pure nano-companies, it is the Instruments and Equipment field which has grown the most in absolute terms. This applies to both turnover (Figure 5) and employees. However, Biotechnology is the field which has grown the most, relative to its size. The turnover amongst biotechnology companies almost quadrupled between 2002 and 2005 and the number of employees has more than doubled.[22]

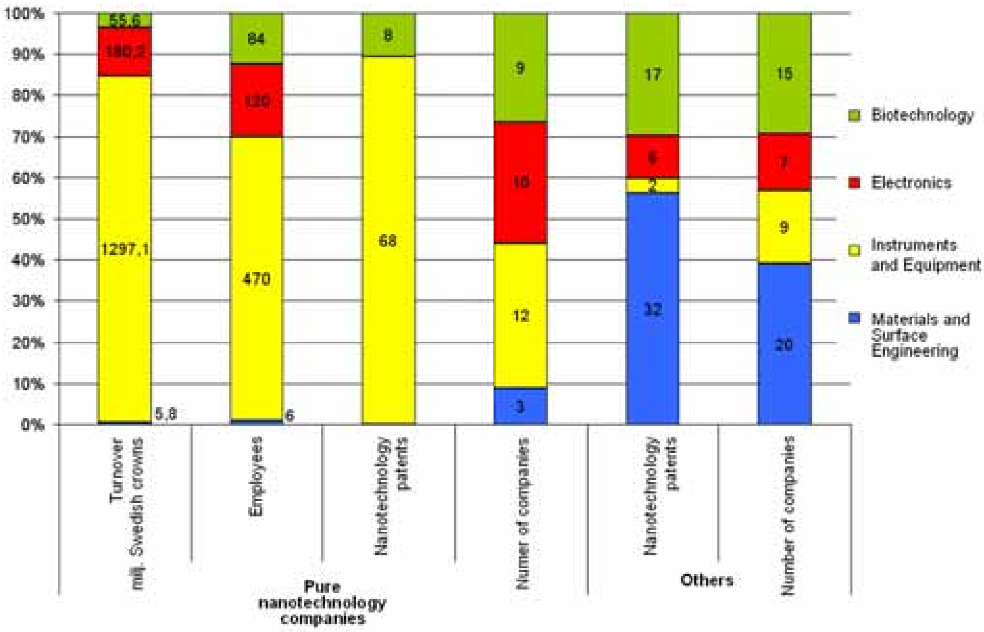
Figure 5. Development of turnover (MSEK) in pure nano-companies distributed by fields of application.



[19] In a few cases, the data relates to 2004, depending on companies’ last reported financial year.
[20] The corresponding figure for other companies with nanotechnology activity was 50%.
[21] As the product has not been commercially tested.
[22] The development is partly attributable to the young age of companies, plus business cycle fluctuations.

In total, the pure nanotechnology companies held 76 of the 133 nanotechnology patents identified for the industry between 1991 and 2004[23]. Figure 6 shows the distribution across the fields for nanotechnology companies and other companies by number of companies, patenting activity, turnover and number of employees.

Figure 6. Distribution across the fields for the pure nanotechnology companies and others, financial data from UC (2006), patents from Meyer (2005).



As is apparent, the ***Instruments and Equipment*** field dominates amongst the pure nanotechnology companies. Micronic Laser Systems, a producer of instruments for the manufacture and measurement of photomasks[24], stands out most prominently with 280 employees. This is the only company with over 50 employees amongst the nanotechnology companies. They hold 30 patents of the companies' total of 133. Larger companies in this context are also Gyros, which manufactures microlaboratories, Obducat, which produces nanolithographic solutions, Piezomotor, a manufacturer of micromotors, and Q-Sense, which makes measurement instruments for research; these are included in the Instruments and Equipment field.

Within ***Electronics***, the largest actors are Nanoradio, a manufacturer of WLAN[25], Silex Microsystems which produces MEMS[26], and Thin Film

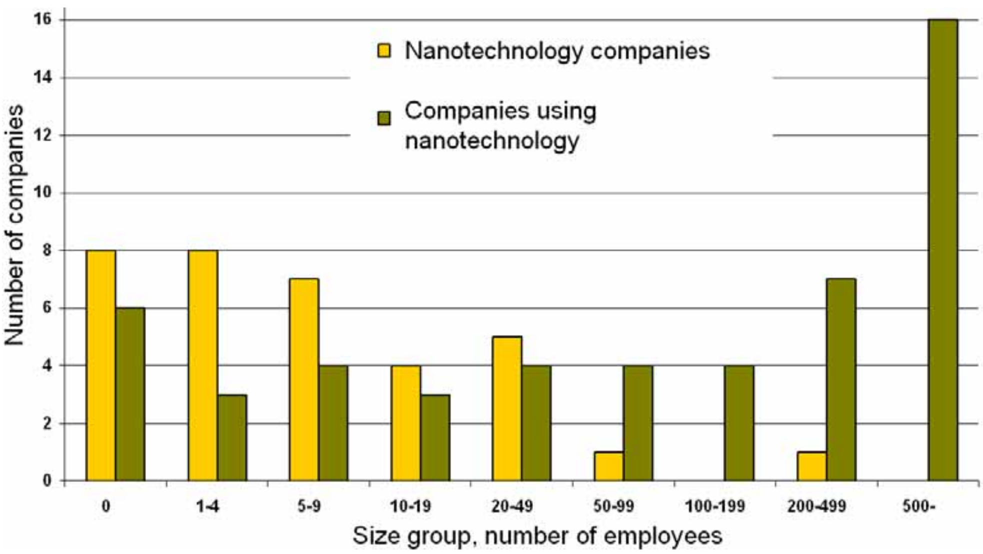
[23] Meyer (2005b).
[24] A photographic glass plate with the wiring pattern for an integrated circuit, National Encyclopaedia (2006).
[25] Wireless Local Area Network, a local network for wireless transfer of signals between computers and components.
[26] Micro Electrical Mechanical systems, micro-appliances with both mechanical and electrical functions.

Electronics, an R&D company which licenses solutions for data processing systems. However, they are relatively small and there are as yet no nanotechnology patents within the field. Within the ***Biotechnology*** field, there are eight nanotechnology-related patents chiefly held by Åmic (4) and Camurus (2). Åmic operates within diagnostics and Camarus develops DDS, drug delivery systems. Including Cellectricon, which has produced a test system in which living cells are connected by microchip, these companies have the largest number of employees within the Biotechnology field. Within the ***Materials and Surface Engineering*** field, there are only three nanotechnology companies: Nanologica, Accelerator and Nanoxis. It is worth mentioning that many of the other companies were originally formed on materials engineering expertise but that they now belong to some of the other fields. Those companies currently within Materials and Surface Engineering are also very young and closely tied to research.

Other companies with activities in nanotechnology

The other type of company with nanotechnology-related activity is large established companies with the resources to enter the field in order to improve an existing operation. Figure 7 shows the major differences in size between the types of company.

Figure 7. Distribution of companies across size groupings, data from UC (2006) relates to 2005.



In comparison with the pure nanotechnology companies, the patenting activity of other companies within nanotechnology is relatively modest. The ***Materials*** field dominates both in regard to the number of companies and patents (Figure 6), through such companies as Sandvik (17) and Seco Tools (6). Tetra Pak, ABB, Saab and Volvo are other large companies belonging to the materials field. Amongst other companies, the ***Instruments and Equipment*** and ***Electronics*** are smallest in regard to the number of companies and patents. These fields were large amongst nanotechnology companies.

2.2.2 The universities and institutes

During the past five years, “nanotechnology” has spread as a buzz-word in the research world[27]. Increasing numbers of people are linking their activity to the terms “nanoscience” and “nanotechnology”. According to Forskning.se[28] there are fully 500 active researchers within the field in Sweden. Lund University (LU), Chalmers University of Technology (CTH) and the Royal Institute of Technology (KTH) have all highlighted nanotechnology as a strategic research field. A large number of research groups (over 50 in total) are linked to the concept of nanotechnology in an overall “nano-profile” for each university. KTH estimates a full 15% of university research to be within nanotechnology, which is also expected to increase.[29]

A summary of research groups

Fifteen Swedish universities and nine institutes with nano-relevant research have been identified. Figure 8 shows the geographical distribution of these with some examples of departments and research groupings for each university[30]. Appendix A attempts a description of the direction of the institutes and universities.

CTH (with Göteborg University, GU) has gathered most of the nano-related research surrounding the nanotechnology laboratory MC2 (Department of Microtechnology and Nanoscience) and around the Nanometer Structure Consortium at Lund University. These two bodies, plus KTH and Linköping University (LiU) are the most active within the nanotechnology field. IVF, Acreo, Imego, SP, KIMAB, Stfi-Packforsk, Trätek, YKI and Sicomp are the institutes active within nanotechnology. But the activity of institutes within the field is not as extensive as in universities, partly because nanotechnology is at an early stage, with much of the research in the field still linked to basic research and thus tied to the universities. The application and production-related development of nanotechnology has not yet got as

[27] The research world is finding that nanotechnology is still helping to attract funding and is thus labelling its research accordingly. At the same time, there is a certain fear that this usage will be classed as pure marketing and others are therefore opting to use the term more cautiously.

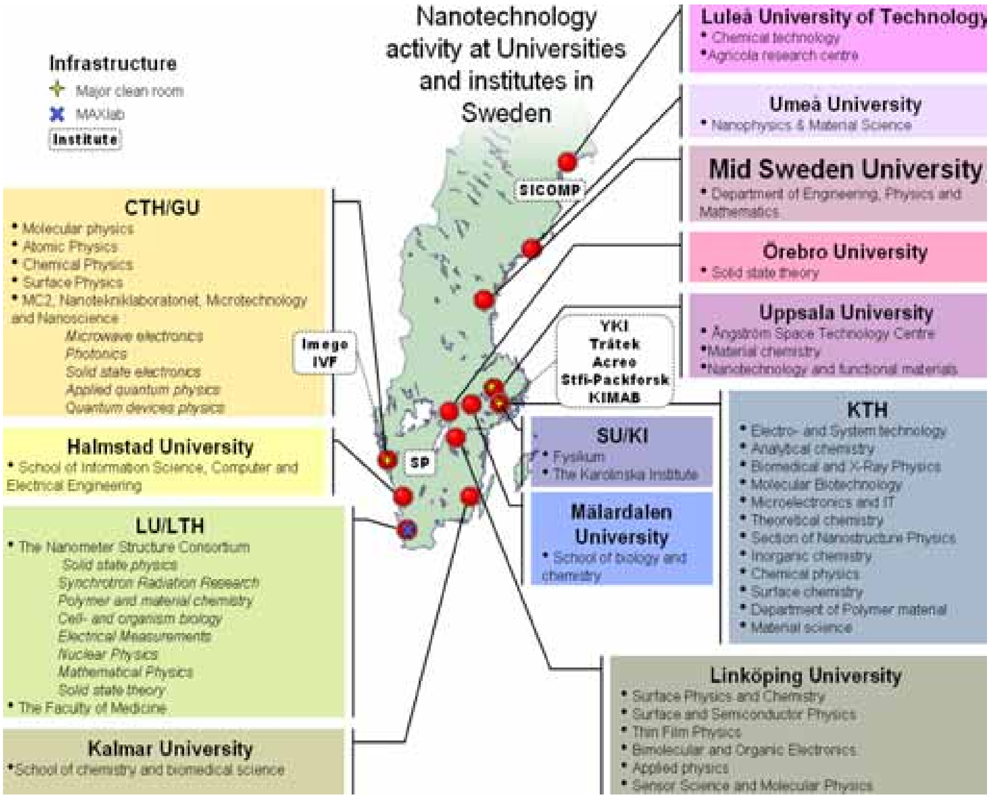
[28] A publicly financed website covering research.

[29] KTH (2006).

[30] The complete structure of research groups around nanotechnology has not been analysed. Figure 8 only gives a summary of varied levels of activity.

far. However YKI has distinguished itself in bibliometric context [31]. Imego and Acreo also have one nanotechnology patent each.

Figure 8. Universities and institutes in Sweden with nanotechnology activity 2006.



The Nanometer Structure Consortium LU, a continued existence from the days of the materials consortia[32], is often stated as the internationally best-known Swedish university in this context. Research groups at CTH/GU are considered to be eminent mainly within scanning tunnelling microscopy and quantum computers and KTH has solid expertise in semiconductor technology. LiU has a generally strong profile in nanotechnology in relation to its size. Many prominent researchers work there, particularly within the functional materials field. Uppsala University (UU) is solidly interdisciplinary in character, chiefly through strong biotechnology and life science connections[33].

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[31] See Appendix B.

[32] The materials consortia were interdisciplinary collaborations between research groups at various universities. The consortia were started up in 1993 by NUTEK by the Swedish Natural Science Research Council and were then taken over by the Foundation for Strategic Research (SSF).

[33] The Royal Swedish Academy of Sciences (2005).

Many of these participants are taking part in a nanotechnology-related project under the EU's Sixth Framework Programme for research and development (FP6)[34]. Those from LU clearly dominate the Swedish participation in nanotechnology-related projects being pursued by CTH, KTH and LiU. GU and Stockholm University (SU) follow, with UU appearing in 7th place, as shown in Figure 9.

Figure 9. Distribution of funding and participation in nano-related projects in FP6.

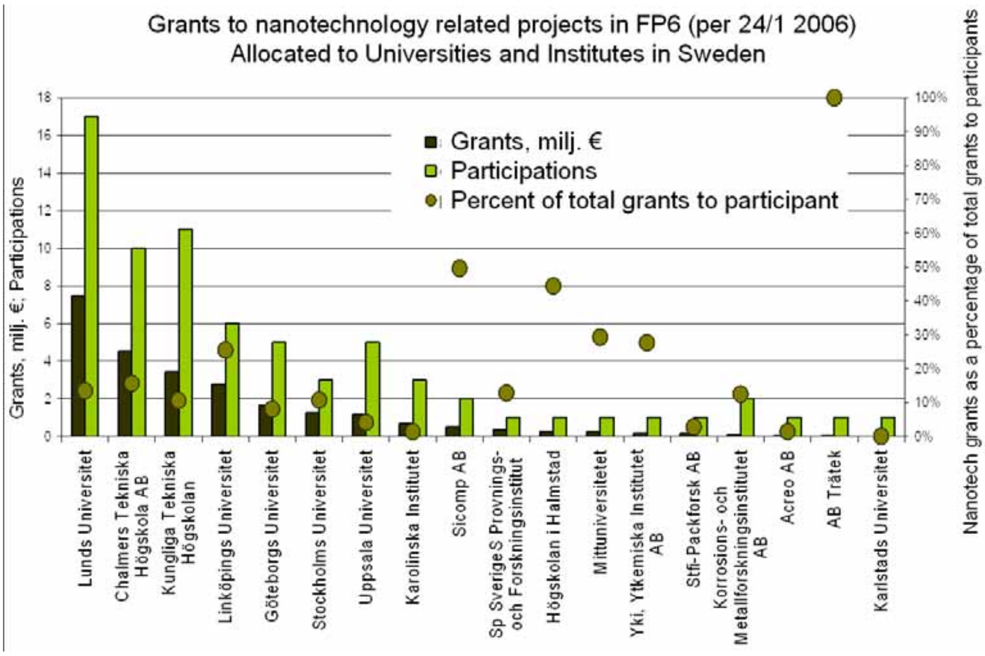

Figure 9 shows the percentage share of the participants' total funding under FP6. This provides an indicator of their focus on nanotechnology.[35] However, amongst the eight participants most involved in framework programme research, LiU's relative specialisation towards nanotechnology stands out, with a full 26% of the funding they receive from FP6 being nanotechnology related. The corresponding figure for CTH is 16%, for LU 13% and for KTH 11%. Figure 9 may also be considered an indicator of how good connections are with the European research field.

The number of publications and scientific articles is a well-tried indicator for measuring the level of scientific activity in research. When ranking the

[34] This distribution of funding may be regarded as an indicator of how strong these actors are within their field, if it is assumed that a actor with prominent research is the one that receives funding. However, this is only one of the factors which counts when assessing applications. Nevertheless, strong participation in FP6 can be considered a sign of actors' strength.

[35] For actors who receive less funding, each entry gives a relatively large yield. Trätek for example, which only participates once in the framework programme, and with a nanotechnology project.

world's most published organisations within nanotechnology from 1996-2001, CTH comes in 24th place (7th in Europe), LU in 32nd place (8th in Europe), UU in 55th place and GU in 72nd place[36]. A total of six Swedish actors are found amongst the 100 most-published in nanotechnology in Europe.

The quality of research is often measured by the number of times an article is cited[37]. The Karolinska Institute (KI) is amongst the 10 most cited organisations in Europe on nanotechnology. Appendix B presents the activity level and quality of publication activities within nanotechnology for Swedish actors[38]. There, CTH and LU stand out amongst the universities as active whilst KI has by far the most citations per publication. Umeå and Luleå have a small number of articles with many citations. Amongst the other participants, the Institute for Surface Chemistry, YKI, has published the most and also performs well in relation to the universities. Other types of actors with a high publication frequency are the Swedish Defence Research Agency, FoI, and Imego. Amongst the companies, the major pharmaceutical actors publish the most, but ABB has also published scientific articles. When companies and institutes have published, it has often been a case of co-publication with the universities.

The Swedish universities are mentioned amongst researchers in Europe in terms of nanotechnological research[39]. CTH and LU distinguish themselves the most, but KTH and UU are also named as prominent. In one study[40], LU was classed as the fourth most eminent European actor within nanotechnology for interaction, detection and microsystems. Within nanobiotechnology, LU and CTH shared 16th place and within nanotechnology for information management, they shared 20th place amongst the European actors. For Materials and Surface Engineering, CHT takes 12th place, LU has 19th place and LiU 31st place.

In Sweden today, there are also a number of so-called strategic research centres, or *Centres of Excellence*, related to nanotechnology[41]. An average count for 2005 gives SEK 14 million invested in nanotechnology through

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36 Noyons et al (2003), from the database: http://studies.cwts.nl/projects/ec-coe/cgi-bin/izite.pl?show=home

37 The so-called *impact factor*, the number of citations per published article.

38 Noyons et al (2003). No bibliometric data after 2001 on publication by Swedish actors has been found. It is necessary to obtain this in order to give an up-to-date picture of the actors' activity.

39 Meyer et al (2001). The researchers are divided into four research focuses. The assessments were made by researchers within the same fields. Only researchers from a country other than that of the commentator are mentioned.

40 Meyer et al (2001).

41 These partially overlap one another as to time and field.

the formation of centres (see Appendix C). During 2007, LU will have four centres financed by different research funding organisations. CTH has received support from two financiers within the quantum field. KTH and UU have formed one centre each, financed by VINNOVA and the Swedish Research Council and VINNOVA respectively. It is interesting that LiU, with its relatively small size, has received support from three different areas in the formation of two centres.

Infrastructure

At MC2, (CTH) and Elektrum in Kista (KTH) and at the Ångström Laboratory (Uppsala University, UU) there are quite large cleanroom facilities (Figure 8)[42]. MAX-lab, an electron accelerator laboratory is in Lund. The emphasis of the "national" facilities reflects the research at the universities linked to the laboratories. The following is a brief description:

- MC2: Profiled towards the production of nanostructures, such as nanolithography. The laboratory is run as an independent entity but is strongly linked to the university and well-connected with industry.
- The Elektrum Laboratory: Profiled towards semiconductor technology and photonics with a relatively broad research spectrum. The laboratory provides services for academia and established industry as well as supporting start-ups.
- The Ångström Laboratory: profiled towards materials, energy engineering, biotechnology and physics. This laboratory is connected with industry to a lesser extent and is somewhat closer to academia. The laboratory is characteristically interdisciplinary in its research.
- MAX-lab: a National laboratory for accelerator physics, synchrotron radiation and nuclear physics.

Around the start of the year, discussions were underway as to whether the European Spallation Source, ESS, should be located in Sweden. ESS will be a pan-European, multidisciplinary research installation with the world's most powerful neutron source for research into such things as nanotechnology. ESS is expected to be a self-sufficient laboratory, independent of existing facilities. Discussions have centred on a location in the Öresund region. Many people in Sweden supported the proposal and a national initiative has been commenced. However there has been criticism regarding the costs which ESS would entail for Sweden, despite EU support.

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[42] There are fewer cleanrooms in other universities and institutes.

2.2.3 Financiers

There are a number of different public and private financiers in the Swedish system. The research foundations have shown great interest in the field of nanotechnology. The Foundation for Strategic Research invested some SEK 70 million in the field during 2005. The Knut and Alice Wallenberg Foundation also invested an estimated SEK 78.8 million in 2005, chiefly in equipment. VINNOVA is the most important Swedish state agency for commercially-related nanotechnological R&D funding, within a number of quite varied measures and programmes. In 2005, the agency invested over SEK 50 million in the field. For the Swedish Research Council, which is the state research financier in basic research, the corresponding figure is approx. SEK 40 million. The EU is also a major financier in this context and in 2005 contracts were signed under the framework programme for research and development FP6, giving Swedish actors around SEK 14 million. The EU is also financing nanotechnological activity in Sweden through the structural funds, for example the Nano Øresund project[43]. The national actors and EU investments in FP6 are listed in Appendix D.

There are also a number of general participants which financially support the development of innovations, but which do not have any nanotechnology-specific programmes. These include the universities' incubators, Innovationsbron, Industrifonden, ALMI Innovation and private venture capital companies.

In addition to Swedish companies, foreign companies including foreign venture capital companies have financed research and development in Sweden. There are also foreign state financiers, such as the US Office of Naval Research, which finances nanotechnological research at LU.

2.2.4 Policy

A number of actors influence the innovation system by giving directives, creating laws and appraisals and otherwise influencing the system's framework and structure. The above financiers are also politically active.

Some 30 countries have commenced some form of national initiative for investment in nanotechnology and a strategy has also been drawn up at EU level. The US' *Nanotechnology Initiative*, which commenced in 2000, has been the starting shot for many policy actors all over the world to generate national strategies coordinating research, development and commercialisation of nanotechnology. In the research bill, *Research for a better life*[44], the Swedish government indicated nanotechnology as a field

[43] See also Chapter 2.3.2.
[44] The Swedish government (2005).

with industrial potential where Sweden was at the forefront. The government also confirmed the field to be of strategic importance in the longer term. At the same time, it was emphasised that the picture of involvement by research and industry within the field is fragmented. Despite this, Sweden does not have a politically approved, nationally coordinated strategy; in fact, proposals that were laid out were rejected in parliament[45].

On 12th May 2004, the European Commission presented the Communication, *Towards a European Strategy for Nanotechnology* [46] the purpose of which is to strengthen the European position within nanotechnological research and innovation. In the final communiqué of 7th June 2005, an action plan was presented for nanotechnology in Europe up to 2009[47]. This action plan emphasises the need for interdisciplinary procedures, intensification and coordination of research on the national and European levels, construction of a world-class R&D infrastructure, the need for education and further training of human capital and enabling of commercialisation through suitable standards and intellectual property rights structures. Particular emphasis was given to the importance of meeting society's expectations and concerns and carrying out risk assessments. The Commission intends to initiate sections of the action plan itself. However, a number of exhortations to member states to act nationally have also been presented.

In the light of this and on account of Sweden's lack of a national initiative within nanotechnology, The Royal Swedish Academy of Engineering Sciences, IVA, commenced a project[48] to generate a long-term strategy. In 2006, they presented a plan for the Swedish innovation system within nanotechnology.

A Nordic attempt to coordinate and muster efforts relating to the field of nanotechnology was made by the Nordic Innovation Centre (NICe) during 2003-2004. The objective was to coordinate and increase research in the Nordic countries, and the result was *The Nordic MINT (Micro- and Nanotechnology) Initiative*[49]. The emphasis of the initiative is on commercialising existing research.

OECD has also acted within the nanotechnology field. The organisation has seen the need to reduce and avoid uncertainty regarding regulations chiefly within patenting and standardisation. At the time of writing, the OECD

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[45] Ahlgren and Jonsson (2005).
[46] European Commission (2004).
[47] European Commission (2005a).
[48] IVA (2006b).
[49] Nordic Innovation Centre (2006).

committee on research and technological policy is considering how to advance the work with policy issues relating to nanotechnology in which the US has been the instigating actor. An initial meeting has taken place, but so far no decision has been taken on a definite action plan[50].

The work surrounding nanotechnology as a field, which has attracted much attention, has also been ongoing within the UN since 1997 through the activity of UNIDO, the United Nations Industrial Development Organisation. They are currently working on such areas as standards and trade issues, as well as technological development in developing countries and environmental aspects of nanotechnology. UNESCO, the United Nations Educational, Scientific and Cultural Organisation, is working on ethical issues and research questions surrounding nanotechnology.

2.3 Frameworks and networks

An innovation system is influenced by frameworks[51] and networks within and beyond its boundaries. Some are general to the national innovation system and others are unique to nanotechnology. In this chapter, the emphasis is upon frameworks and networks which specifically influence nanotechnology, plus some general ones which influence the nanotechnology innovation system to a particularly large extent[52].

2.3.1 Frameworks

Discussions regarding nanotechnology and frameworks today often centre on laws and regulations which limit the use of nanotechnology, but which in the long-term benefit the growth of the field through reduced uncertainty.

There are currently no specific national laws and regulations affecting the nanotechnology innovation system in Sweden. This also applies to the rest of the world, with the exception of the US' *21st Century Nanotechnology Research and Development Act*[53] which contains directives regarding activities under NNI, the National Nanotechnology Initiative. Many actors in the US believe the priorities set out in the Act regarding research are not wholly favourable to the development of nanotechnology. In addition, the Act contains regulations regarding social aspects of nanotechnology which may affect activities within the field. In the US, the National Institute of

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[50] OECD (2006).
[51] In this case, laws, regulations and standards and otherwise cultures and attitudes too.
[52] General questions such as research ethics and the general Swedish corporate climate are thus not touched upon in detail, but this does not exclude their importance to the system's ability to generate innovations.
[53] OLPA (2006).

Occupational Safety and Health[54] has also presented a number of recommendations for the management of nanomaterial for research and production. The US Food and Drug Administration is also looking at the need for regulations relating to nanotechnology within its field[55], despite there being no formal regulations based on nanotechnology. Just at the moment, nanomaterial is regarded as a variant of the material in bulk form. Despite these initiatives from American actors not directly affecting the Swedish actors in the short term, they do affect development and progress of Swedish nanotechnological innovations, given the potential in the American market and the US' role as a pioneering country regarding nanotechnology issues.

Despite there being no special laws and regulations nationally or within the EU, there is some activity in the field particularly relating to environmental and health aspects. Today, there are material regulations at EU level which are administered in Sweden by the Swedish Chemicals Agency. Current toxicological regulations are based on the properties of the bulk material and it can therefore be difficult to predict the effect on the surroundings of the material at nanoscale, given the new properties which may arise. Furthermore, the EU regulations relate only to the use of substances emitted as more than one tonne; in nanoparticles, this may be regarded as a very large quantity. The question is then whether toxicological aspects of nanotechnology should be regulated separately and whether it is possible to do this within the framework of current toxicological regulations. One of the European Commission's appointed working parties has drawn the conclusion that the current structure of toxicological regulations is sufficient to also cover nanotechnology, and that structure and particles developed from existing substances should be classed as a special use of these. New materials created with nanotechnology should be classed as new materials. Therefore, special legislation for nanotechnology is not deemed necessary and the conclusion of the working group was that nanoparticles and structures should be dealt with under the existing chemical legislation[56].

Standards are an important element in innovation systems since they often contribute to growth by disseminating technical knowledge in the system, facilitating coordination of development and aiding entry into new markets. However, it is difficult to speak generally of nanotechnology in a standardisation context. Today there are large number of standardisation organisations, such as ISO, DIN, EIC, CEN, ANSI and IEEE, all of which work with standardisation in nanotechnology. A few disparate standards

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[54] NIOSH (2006).
[55] US Food and Drug Administration (2006).
[56] IVA (2006).

exist within various subfields of nanotechnology and standardisation is generally regarded as inadequate. There is no uniform nomenclature for the field and organisations have seldom got further than confirming the lack of and need for standards. However, in 2004[57], certain European actors considered there was no need for standardisation since the technology was at too early a stage and patenting activities, which often form the basis for standardisation, were still overshadowed by publication. However, standardisation activities are on the increase and in November 2005, the International Standards Organisation, ISO[58] held an introductory meeting on the standardisation of nanotechnology. The aim was to seek standards relating to terminology, nomenclature, measurement methods, modelling and simulation, plus health and environmental aspects.

Nanotechnology is characterised by being deeply rooted in academia. The field is still regarded as being closely connected to academic research and it is very often within universities and not companies that the basic ideas of nanotechnological innovation are born. This means that regulations such as the so-called “professor’s privilege”[59] affect the growth of the innovation system. In general, employers have the rights to patentable inventions of their employees. However, “teachers at universities, colleges or other institutions coming under academic entitlement” are exempt from the law. This means that teachers, researchers and doctoral students own the rights to their patentable inventions, which also provides the opportunity to commercialise the idea. There is a general notion that researchers within nanotechnology, given the in-depth research which the field requires, often lack experience of entrepreneurial activity for which reason commercialisation of an idea can seem beyond the researcher. In Sweden, a lively debate is currently underway on the pros and cons of the professor’s privilege; its deeper implications for nanotechnology remain to be explained.

Another general national regulation is the so-called “third task”.[60] According to the Higher Education Act, a university should “collaborate with the surrounding society and inform of its activity”. This can be viewed as academia having to take the initiative to collaborate and that interaction, particularly with industry, should be actively sought by the universities. Combined with the professor’s privilege, this has in some cases been viewed as pressure on academia to adopt the role of networker, despite not always seeing itself as suitable or having been allocated resources to do this.

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57 Nanoforum (2004b).
58 ISO (2006).
59 LAU 1949:345, Government legal information portal (2006).
60 Higher Education Ordinance 1977:263, Government legal information portal (2006).

2.3.2 Networks

The nanotechnology field today is crisscrossed by large numbers of networks. Those networks considered most relevant to the nanotechnology innovation system in Sweden are presented here.

National networks

There is currently no national umbrella industrial organisation for the nanotechnology industry. However, the need for this is unclear, but it is probable that certain synergy effects might be gained by bringing together the small and relatively similar industrial actors.

The national network which largely covers the nanotechnology field is the Swedish Nano Network (Svenska Nanonätverket), formed in 2000. Approx. 500 researchers from different disciplines are involved, as well as industrial representatives and other participants interested in nanotechnology. This political network aims to promote nanoscience and highlight the potential of the field to policy actors. Amongst other things, the network works to keep Swedish research at the forefront and increase research collaborations and interactions between academia and industry. In terms of activity, the network’s status is currently pending.

µ-Fab, *The Swedish Micro and Nano Fabrication Network*[61], is a national network linking together the three cleanrooms at CTH, KTH and UU. Its purpose is to coordinate the infrastructure offered by these three facilities in terms of research, development and verification[62]. The network was founded in 2003 on a proposal from an evaluation of the three cleanrooms[63]. The activity level of the network is deemed relatively low.

Networks relating to research groups

The research groups within the field of nanotechnology form nodes in distinctive formal and informal networks with national actors. The Centres of Excellence[64] link individuals at different departments within and between universities and in some cases attract institutes, industrial actors and other organisations. Even though the specific Centres of Excellence do not always formally construct networks outside universities through their projects, participating research groups interact with those around them through other networks. There are often well-developed international collaborations. The Centres of Excellence at LU are assembled around the Structure

[61] Myfab (2006).
[62] In which an idea is supported, checked and protected by means of such things as novelty search, prototype production and patent application.
[63] The Royal Swedish Academy of Sciences (2002).
[64] See Appendix C.

Consortium, which has a number of established national partners. Even when the Nanometer Structure Consortium was being formed, there were companies such as Epigress, Ericsson and Tetrapak linked to LU. A number of companies have been founded on research expertise from the centre and remain today as partners. Qumat Technologies, QuNano and Nems are amongst them. There are other collaborations, for example with Aimpoint, Obducat and the Swedish Defence Research Agency, FOI.

At KTH, two departments and the industrial research institute KIMAB have been gathered under the title of Hierarchic Engineering of Industrial Materials. This centre is not strictly nanotechnological but contains many elements of nanotechnology. Höganäs, Sandvik Tooling and Seco Tools are linked to the centre, as is the spin-off company NM Spintronics.

The Ångström Laboratory at UU is Sweden's largest cleanroom. The Laboratory brings together participants, creating an informal network of research groups within and beyond the university, plus participants from industry like Piezomotor, Åmic, Chromogenics and Silex Microsystems.

At CTH, the activity within nanotechnology centres on MC2 and the collaboration with GU is well-developed. There is also a connection to KTH through the NANODEV centre and the collaboration with other national and international universities is strong, particularly through participation in EU projects[65]. For 10 years, the CHACH[66] Centre of Excellence has linked together two departments at CTH with companies like Zarlink, Ericsson and Saab. There has also been collaboration with Acreo and Imego. Through the MC2 cleanroom, there are strong connections to smaller nanotechnology companies, often their own spin-offs such as Nanofactory Instruments and Cellectricon.

In Linköping, there are Centres of Excellence relating to Materials and Surface Engineering. FunMat, partnered with UU and Luleå University of Technology, also unites large companies such as ABB, Volvo Technology, Sandvik Tools and Seco Tools, and smaller companies such as AppliedSensor and the portfolio company Accelerator.

There are geographical groupings around the metropolitan regions and the larger universities. Often spin-offs remain near their parent university and it is often regional actors who are linked to cleanrooms, with the exception of individual participants needing specific instruments. A certain competition between the regions has also been observed, partly due to the financing structure of the Swedish research system. Since groups are forced to

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[65] See Appendix E.
[66] Financed by VINNOVA/NUTEK 1995-2005

compete for funding, not only between universities but in some cases against institutes, it can lead to the formation of tensions in the system and groupings, often geographical ones, arise. Naturally, this creates obstacles to the national network.

Networks linked to the EU

The European Commission's work with nanotechnology has created many networks, the most important of which is Nanoforum[67], which aims to link together all activity within nanotechnology in the EU and disseminate information within all fields of nanotechnology to researchers, companies and the general public. A Nanoforum report from 2005[68], identified 64 international networks within nanotechnology; principally instructive networks centring on research, but also within innovation and patenting plus purely political networks. Many of these networks are structures built up around projects within the EU's framework programme. Swedish actors are participating in a total of 58 projects within the context of the Sixth Framework Programme, FP6, and through these are involved in some of the existing networks. Thirteen projects with several international participants are also being coordinated by Swedish actors (Appendix E).

NODE is the largest project coordinated by a Swedish actor and in addition to LU, Qumat Technologies is involved as a Swedish participant. Another major project in which LU participates but does not coordinate is Nano2life[69], a so-called Network of Excellence, which integrates expertise within nanobiotechnology in terms of both research, development and innovation. SINANO[70] is another project which has no fewer than five Swedish actors but all from universities. CTH, GU, KTH, LiU and UU participate in this Network of Excellence with 42 other participants. The network aims to assemble the European expertise within silicon-based nanocomponents for electronics.

One example of a coordinating network within the framework of FP6, a so-called ERA-Net, is MNT-ERA-Net. This network for micro and nanotechnology coordinates national investment in the field and is comprised of national financiers. The network was started in 2004 and is anticipated to run for four years. Today, 17 countries are involved in the network with VINNOVA as Swedish representative[71].

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[67] Nanoforum.org (2006).
[68] Nanoforum (2005). Unfortunately, a quick inspection of the material shows insufficient basic data.
[69] Nano2life (2006).
[70] SINANO (2006).
[71] MNT ERA-Net (2006).

EUREKA is another of the EU's instruments regarding market orientated, industrial research and development. There is a total of 11 nano-related projects with Swedish participants. One of these is NANOCRETE, relating to the development of cement with new photocatalytic properties. This project forms a network involving seven Swedish and three Finnish actors, including Skanska, Cementa and YKI.

Some 30 so-called European technology platforms currently exist which are generating formal networks of industrial actors. These aim to define research needs and priorities within a technology or sector and often consist of larger companies. There are currently two platforms within nanotechnology: ENIAC - *European Nanoelectronics Initiative Advisory Council* and NanoMedicine - *Nanotechnologies for Medical Applications*. ENIAC gathers some 45 active European nanoelectronics companies. From Sweden are Air Liquide, Ericsson and Infineon. NanoMedicine is a newly started platform from autumn 2005 and also has around 45 member companies but only one, Gambro, is Swedish[72].

Multinational political networks

Many political networks related to nanotechnology are working to benefit and promote nanotechnology from various angles. Nano Øresund is an example of a political and instructive network linking together Swedish and Danish research, training, infrastructure and innovation resources in the Öresund region. The aim is to coordinate the region's resources and market the region internationally[73].

Another example is the European Nanobusiness Association. This is the European trade organisation for nanotechnology[74]. The organisation is relatively recently established and its activity and membership figures are unknown.

Many of the other international networks also have political functions.

Other international networks

There are a large number of international networks in nanotechnology. GNN, the Global Nanotechnology Network is one which collaborates primarily within workshops relating to nanotechnology[75]. All types of participants from industry, academia and state organisations are represented. KTH and LU are amongst those who have contributed to workshops arranged by GNN. The network was founded in 2001 with the aim of

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72 European Commission (2005c).
73 Nano Øresund (2006).
74 European Nanobusiness Association (2006).
75 Global Nanotechnology Network (2006).

facilitating the exchange of knowledge and access to critical resources for the development of nanotechnology.

Nanovip[76] is another network for companies involved with nanotechnology. Its main purpose is to gather all activity relating to nanotechnology on one website. Their corporate database is the first to concentrate solely on nanotechnology.

There are often networks around standardisation issues which may be characterised as both political and instructive. These are presented in Chapter 2.3.1. One example of this is the network being constructed around IEEE, the Institute for Electric and Electronic Engineers. Amongst other things, they are working with nanotechnology standards within electronics. The IEEE Nanotechnology Council is forming a virtual network for participants within the field.

[76] Nanovip.com (2006).

3 The Swedish potential for generating nanotechnology innovations

The previous chapter presented the structure relating to nanotechnology in Sweden. The following chapter deals with the capacity of the structure to generate innovations in regard to aspects of importance to the performance of the innovation system[77]. A picture is thus provided of the Swedish potential for creating nanotechnology innovations and growth.

3.1 Driving forces

Driving forces generate guide lines and attract participants to nanotechnological activity. When a new field such as nanotechnology develops, participants need guidance. At the same time, more participants are needed in the innovation system in order to generate a critical mass so that growth of the system will gather momentum.

Activity within nanotechnology has exploded in recent years, partly due to participants increasing their activity within nanotechnology and partly because increasing numbers of participants are relating their existing activity to nanotechnology. Initial hype about nanotechnology drove this forward. Now, the hype is said to be cooling but no reduction in patenting has been demonstrable. However, a downturn in access to venture capital in nano-related projects has been identified.[78]

Apart from the market potential, two general driving forces for growth of the nanotechnology innovation system can currently be identified; one political and one relating to engineering. These two forces are influencing the attraction of participants to the field of nanotechnology.

The political driving force within the nanotechnology innovation system is largely visionary. Political visionaries often formulate pictures of the future in which nanotechnology is expected to have enormous economic, environmental and health effects. This urges policy actors on to joint initiatives in the field. Through such things as the National Nanotechnology Initiative in the US and the EU's initiative, the policy actors have taken a prominent role as driving forces in the system.

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[77] Bergek et al (2005).
[78] See also Chapter 3.6.2.

Despite the pressure on academia to commercialise and industry to collaborate, there is no real pulling motivation in the system since a compelling client or market demand has yet been discovered or identified. The result is a kind of pushing motivation; a coercion to generate innovations in the system placed upon academia, which is not always at ease in that role. This is generally the case for the Swedish innovation system.

Researchers occasionally find it difficult to relate to the grandiose visions built up around nanotechnology. Some believe nanotechnology to be nothing new, but rather a new label on research which has long been happening. Sometimes, the notion of nanotechnology is perceived as more political than scientific[79]. The hallmark hype of nanotechnology and links to grandiose visions of saving the world have led participants to dismiss the field and choose not to associate their own operations with it for fear of being associated with fancifulness and insecurity[80].

Despite there being obvious market potential, no critical mass of participants in Sweden has sought out the Swedish innovation system. This can be related to the visionary elements of the market estimates which often exist on a very general level, plus a lack of concrete demand from the market. It is unlikely that anyone will demand nanotechnology for its own sake. Demand is generated by the arrival of concrete applications indicating new properties, and not for nanotechnology but for the applications themselves. This means the market will only be observed as a definite driving force for growth from innovations when more nanotechnology products come out on the market and the opportunities are made real. In the US, NNI and related ventures have been successful in attracting participants to the system. Thanks to the initiative, nanotechnology actors in the US have been transformed from a band of optimists into a critical mass[81], as witness the number of companies in the American system.

An increasing number of Swedish actors are now also rallying around the concept of nanotechnology. It is no longer important to ponder whether the concept of nanotechnology is actually hype as many resolutely claimed a number of years ago, or whether it is a genuinely new world in which multidisciplinary scientists will generate revolutionary solutions to major problems, because the Swedish innovation system surrounding it is already beginning to take shape. Now, a number of participants are already sharing visions, collaborating and holding discussions on goals for the field, even

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[79] Fogelberg (2002).
[80] Karhi (2006).
[81] Karhi (2006).

though this has not been coordinated at national level. They are forming the structure of what may be regarded as an innovation system[82].

The European initiative has contributed to the growth of the Swedish innovation system, since there is a political will to gather around the concept at EU level. Within the Sixth Framework Programme, a shift of emphasis from research to innovation has been noted concerning nanotechnological research; this is indicative of the EU's will to generate driving forces for innovation[83].

The other driving force in attracting participants to the system relates to engineering opportunities and solutions to problems presented by nanotechnology. For example, miniaturisation, which is regarded as unavoidable when seeking to increase performance in such things as electronics. Applications within microelectronics have often been highlighted as the most important driving force in the development of nanotechnology. Examples which can be mentioned include transistors, lasers and detectors for fibre-optic communication. As structures become smaller and smaller, the transition to nanotechnology becomes necessary. Participants then enter the system in the hunt for better performance. This is often the way in which industrial actors are drawn into the system. By controlling and building on the basis of the smallest components, new and improved functions can be created.

Political and engineering driving forces exist in parallel and for all intents and purposes complement each other. Both contribute to attracting new participants to the system, but they do not always converge. They attract different types of participants to the system, with different purposes in their activities. To benefit the system's future growth, it is important to be aware of both these driving forces and how they function.

Given the innovation system's limitations, there is a geographical driving force propelling participants in nanotechnology to Sweden. It is easy to attract young, ambitious foreigners to Sweden since Swedish academic activity within nanoscience is perceived as strong. However, it is harder to keep these young participants and attract more senior researchers. This is often linked to deficiencies in the academic financing system where it must be demonstrated that a strong research group has been built up before resources are given. This is a Catch-22 situation for migrant researchers, since it takes time to build this up.

[82] Fogelberg (2002).
[83] Fogelberg (2002).

The strong knowledge base within academia also attracts international industrial actors since the Swedish actors possess special expertise in certain fields. The newly established knowledge intensive companies also emphasise the importance of Swedish academia, particularly where it concerns the supply of human capital. However, many companies within nanotechnology lack Swedish clients and regard themselves as relatively unconnected to Sweden. At the same time, it has been maintained that Swedish reference clients are important in order to enter the market since, despite not being financially strong, these are often seen as competent in the international arena. Additionally, a lack of capital is perceived in the Swedish market which prevents participants from entering. The stronger and more mature the industrial actors, the weaker the national motivation linked to geographical proximity and supply of knowledge-capital from Swedish academia. These stronger actors have the resources to look around in the international arena and the motivation to seek out the national system is more a matter of the participant's special expertise within a specific field.

It can be confirmed that there are currently no strong leaders in the national system such as motivating clients and other participants which can generate guidelines. The lack of the Swedish strategy or initiative and motivating Swedish actors makes development of common guidelines for the system more difficult.

3.2 The nanotechnological knowledge base

Developing nanotechnology innovations presupposes scientific or technological knowledge, and for that knowledge to lead to innovations requires its diffusion between participants.

3.2.1 Scientific knowledge level

The level of scientific knowledge within nanotechnology in Sweden is generally perceived as high by national actors as well as internationally[84]. Swedish researchers are perceived as eminent and Sweden has good potential for further development in nanotechnological research.

The number of scientific publications which a country produces is an important measure of scientific production. Sweden is one of the 20 countries which, between the years 1994-2004, published the most nano-related publications (Appendix F)[85]. Between 1992-2001 Sweden produced over 1,800 publications, 1.8% of the total production[86]. Sweden has had a

[84] Meyer et al (2001).
[85] EPSRC (2005) data from ISI Thomson, commissioned and published by EPSRC.
[86] Meyer (2005a).

rate of increase in nanotechnology publications similar to that of the Netherlands, Italy, Austria, Spain and Israel[87]. However, countries like China, India and Korea have increased at an appreciably faster rate. If the number of publications is related to inhabitants or GDP[88], Sweden is amongst the foremost, but related to national investment in research[89], comes in 17th place and in relation to the number of researchers, 9th place[90].

The Swedish nano-related publications are maintaining a qualitative level which matches the quantity of publications. Measured by citation rate[91] Sweden comes in 13th place [92]. Other competing countries such as Switzerland, Israel and the Netherlands are showing a higher scientific quality in the results being published (Appendix F). Sweden has had a relatively stable development in terms of scientific quality of publications. The number of citations referring to Swedish publications has increased similar to countries like Israel and Russia, but countries like the US, Great Britain and Japan have lost out even as China and Korea doubled and almost trebled their share of citations during the Nineties[93]. A number of Swedish universities have distinguished themselves quantitatively, a fewer qualitatively[94].

Sweden is showing a modest degree of emphasis on nanotechnology. Of the total Swedish publications between 1993 and 2003, 4.6% are nano-related, a touch higher than the world average. However, Sweden is a long way from the emphasis which China and Korea are showing. In principle, all countries in the world are showing an increased emphasis on nanotechnology. In particular, the US has increased its proportion considerably[95]. Within FP6, there is also a certain Swedish focus on nanotechnology (Appendix G), but in relation to countries like Germany, France and Belgium there is a modest degree of focus. Sweden comes in 8th place in regard to the proportion of funds received, a normal position for Sweden in a framework programme context. So far, Sweden has (as at 24/1/06) received EUR 27 million relating to nanotechnology through FP6, equivalent to 4.8% of nano-related funding.

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87 Meyer (2005a).
88 Noyons et al (2003).
89 GERD, Gross Domestic Expenditure on Research and Development.
90 Meyer (2005a).
91 Number of citations per article.
92 Meyer (2005a).
93 Meyer (2005a).
94 See Appendix B.
95 Warris (2004).

There is currently a palpable fear that Swedish research expertise is falling behind somewhat and this is faintly discernible in the bibliometric data[96]. Occasional knowledge gaps have also been pointed out within specific fields such as high-speed photonics and in the interface with biotechnology. A deeper analysis of the knowledge base and the innovation system's need for knowledge is required in order to point out detailed weaknesses. However, there are opinions that Swedish research is sprawling somewhat and that this is leading to a falling behind in the depth of certain fields[97]. At the same time, there is awareness in the system of the difficulty in maintaining both breadth and depth and a wish to find a Swedish niche where Swedish resources can be concentrated. Identifying a niche and gathering around it requires Swedish actors to collaborate and dare to prioritize to a greater extent than currently. Doing this requires participants to rearrange their research priorities and a suitably strong incentive should be created to facilitate this.

3.2.2 Technical knowledge level

Patenting activity can provide an understanding of the level of a country's technical knowledge[98]. The number of Swedish nanotechnology patents has increased from just under 30 in the first half of the Nineties to over 140 during the period 2000-2004; a growth which is anticipated to continue positively[99]. Sweden is one of the few countries that have succeeded in increasing the number of nano-related patents. Swedish patenting activity is somewhat above the international average, both in absolute terms and in relation to the size of the country. Under the European Patenting Office, EPO, 41 Swedish nanotechnological patents were approved between 1992-2001, 12th place in comparison with other countries. In the American system, USPTO, the corresponding figure was 18 patents, equivalent to 15th place.

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[96] Sweden fell one place in the world ranking of the number of quotations, from 16th to 17th place between 2000-2004.

[97] This in turn lead to difficulties for the emerging knowledge-intensive companies which in some cases expressed difficulties in obtaining personnel with sufficient depth in a desired field.

[98] Due to the generic nature of nanotechnology, it is currently associated with certain problems when using the standardised patent classes to identify nanopatents. These are found in the majority of traditional patent classes. There is also a whole raft of general problems relating to the use of patents as indicators associated with such things as a company's need to use secrecy instead of patenting, since a patent reveals the idea to competitors. Different companies have different patenting strategies and different sectors have different patenting cultures. Painting activity differs between different patenting organisations.

[99] Meyer (2005b).

On average, Swedish actors are generating approx. 0.5 USPTO patents per 1,000 research-years. This is clearly lower than corresponding levels for countries like the US, the Netherlands, Switzerland and Canada. If the Swedish USPTO patents are compared with the number of inhabitants, Sweden comes in 11th place (Appendix H). This is a weak result compared with publishing activity. Sweden appears to be stronger in nanoscience than in nanotechnology.

There are many reasons for Sweden's relatively low level of patenting activity. One reason may be that Swedish companies are not orientated towards the nano-related research to the same extent as companies in our competitor countries. Previously, it was shown that Sweden is modestly directed towards nanotechnology in FP6. The industry's proportion of funding under FP6 is 9.4% for nanotechnology and 14.3% in total. The lower level of Swedish patenting activity may also be linked to a different patenting strategy amongst Swedish nanotechnology companies. In Swedish industry within nanotechnology, there are many small participants with relatively few resources. Holding and defending a patent demands resources which makes things difficult for small participants. Another explanation for the weakness of patenting activity in relation to the scientific quality may be that the link between research and patenting is weak within the nano field. Yet another reason may be that Swedish companies have not yet profiled their patents as "nanotechnology", making them difficult to identify.

The technical knowledge in the system is perceived as deficient by the majority of participants in the Swedish system. This image is further augmented by the relatively weak role of institutes as research implementers. Despite universities having an increasingly strong focus on the nanotechnology field, industry and institutes are still very much working with microtechnology[100]. Given the system's relatively early stage this may be taken as rather common.

Much of the research being conducted in the Swedish universities is theoretically orientated and this is also the case for the majority of European countries[101], with the exception of a number of German universities which have a stronger technical leaning. Sweden's institute sector is relatively small which increases the importance of technical research and development in universities and industry. Swedish nanotechnology actors in universities have pointed out that it should be possible for the Swedish institutes to be a participant in developing the technical knowledge, but that they need strong expertise and that this requires resources or reordering of priorities. The

[100] Söderkvist and Vogel (2004).
[101] Heinze (2004).

industrial sector is a relatively strong research participant in the Swedish innovation system. However, in the case of nanotechnology, the emphasis is still on academia. In order to be able to strengthen a technical knowledge base, it is important to increase the activity of industry within nanotechnology.

3.2.3 Diffusion of knowledge in the system

It is not only important for there to be sufficient knowledge; that knowledge must also be spread between different participants in the system. Within nanotechnology, the dissemination of knowledge has proved to be particularly critical in view of both the strong interdisciplinary nature of nanotechnology and also the early stage of the innovation system where knowledge needs to diffuse and mature. The field has developed from various quarters and where disciplines meet there are obstacles to the dissemination of knowledge. Researchers from differing disciplines generally have varying degrees of difficulty in understanding one another. It has been perceived as easier to create understanding between researchers in the interface between physics and electronics, whilst the interface with biology has been perceived as more difficult. Given the belief that much future nanotechnology will inhabit the interface with biology, it is important to pay attention to this obstacle.

As a researcher, it is easy to be too focused on one’s own field and difficult to find incentives to embark on new ones. Amongst other things, this is linked to the financing structure of research. The large proportion of competitive funding is leading to researchers specialising and subsequently not venturing from their specific niche, for fear of not getting renewed funding. Cultural aspects and pride of pre-eminence within a field occasionally come into play, making a person unwilling to get into something new. Being interdisciplinary requires dynamism. The lack of incentive for more dynamism in the form of collaboration, both in existing groupings and in the formation of new ones is creating obstacles to the diffusion of knowledge. This is not unique to the nanotechnology field, but is of particular importance given the interdisciplinary nature of the field.

It is important for knowledge to spread between Swedish and international participants. Swedish actors are participating in a number of networks and the partnership with international actors, particularly those at the larger universities, is regarded as strong. Many universities have strongly established contacts with foreign research groups in Europe, the US and Asia and a number of contract researchers for foreign companies within nanotechnology. For institutes, there is potential for improvement in terms of expanding their international collaboration within nanotechnology.

A patent involves publishing research results and can be viewed as one way to spread knowledge. Patenting activity in Sweden has been established as relatively weak, which in the long term may inhibit the development of knowledge. The same reasoning can be applied concerning standards. Standardisation work requires a certain openness regarding knowledge in order to succeed, which can entail problems with intellectual property issues.

Another aspect linked to the spreading of knowledge is its diffusion between academia and industry. This aspect is discussed in the next chapter.

3.3 Commercialisation

Nanotechnological knowledge is not enough to generate an innovation which provides growth. The knowledge must lead to new ideas with the potential to become innovations. The ability to produce competitively and understand the market must be present, in conjunction with commercial knowledge. Creating innovations which generate growth is not a one-way process in which nanotechnological knowledge leads to ideas for which a market can then be found. In some cases the starting point is the market and a knowledge of its needs and the nanotechnological knowledge is there to meet the need.

3.3.1 New ideas into innovations

Industrial actors need to create diversity and experiment with ideas so that a foundation is generated as a basis for innovations. This is important for a system in its early stages such as nanotechnology, since there is much uncertainty in the system. In order to cover this uncertainty, there needs to be diversity in industry's experimentation with ideas. A stable increase in the number of nanotechnology-related patents in Sweden has been observed[102] and in principle all patents belong to industrial actors. However, it has been difficult to assess the diversity and newness of these. Nevertheless, it can be confirmed that there is activity.

By their entry into the system, the small industrial actors are contributing to experimentation from a systems perspective, since in the case of nanotechnology they are often based on a new idea from the research world. Once established on the market, the contribution of these companies to experimentation is small as they are more product-orientated and often do not have resources to invest in anything other than their original idea. The Swedish innovation system contains general obstacles to the establishment of new companies, due to such things as a lack of venture capital and capital

[102] Meyer (2005b).

for the pre-seed stage. This reduces the entry of new innovations onto the arena and thus diminishes experimentation with new ideas.

In general, larger participants have greater resources available and greater opportunities for experimenting with new ideas. For example, Sandvik is running its own research nanotechnology project in conjunction with others including CTH. Similarly, ABB started its research programme in nanotechnology right back in 2000. Tetra Pak is experimenting with films in various materials in order to create new properties in packaging. Another example is Volvo which, in its collaboration with suppliers and universities, is examining nanometre-thin plates for catalytic converters[103].

In some cases, financiers in the system are generating conditions for experimentation. One example of this is the Swedish Defence Research Agency programme within nanotechnology. In its projects, academia is linked with industry which is experimenting with the objective of creating innovations which can be commercialised. The projects' five-year time window indicates the time it takes to develop completely commercialisable products based on nanotechnology. Examples of more major industrial actors involved in projects are companies within the Sandvik, Volvo and Saab groups. It is worth mentioning that the latter of these also has a venture capital company which enables commercialisation of ideas arising within the company, despite the developed technology not being of interest to the company in itself.

Another instrument for increasing commercial experimentation with ideas is the so-called VINN Excellence Centers[104]. Two centres related to nanotechnology will be started during 2007: *FunMat* in Linköping relating to thin film, and *Hierarchic Engineering of Industrial Materials* at KTH in Stockholm. Both are tied in with a number of larger companies such as ABB, Volvo Technology, Höganäs, Sandvik and Seco Tools. These centres have generally increased potentials for companies to experiment in new fields[105].

Achieving breadth in the experimentation involves the larger participants venturing into new fields. This is taking place to an increasing extent within nanotechnology, even as the technology is maturing and finished applications are highlighting the opportunities of nanotechnology and thus attracting industrial actors.

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[103] Wallerius (2005).
[104] See also Appendix C.
[105] VINNOVA (2005).

3.3.2 Production, commercial and market-related knowledge

Creating innovations which generate growth requires production, commercial and market-related knowledge linked to nanotechnological knowledge. Participants, particularly within academia observe that production-related knowledge is weak in Sweden. There is an understanding of nanotechnological processes, but the production is often a hurdle. Knowledge of production processes is closely linked to patenting and the weaknesses within the patenting activity indicate a weakness in production-related knowledge.

Swedish actors are generally considered capable at system construction, but less capable at producing components. This is particularly critical within nanotechnology, since the miniaturisation leads to components having to be made smaller and production process adapted. All production-related activity such as measurement, control, electricity supply etc. has to be shrunk. This is demanding, particularly for the small nanotechnology companies who often find reproducibility a problem.

Increased stress regarding getting innovations out onto the market is experienced by many participants. This stress is not specific to nanotechnology but general to high-tech companies based on research expertise and often related to the financing structure in the national innovation system where a success in the verification stage[106] and pre-seed stage[107] just before formation of a company are much-mentioned. There is often talking of slack between the financing of research and the pre-seed stage following formation of the company when venture capital is important. Company formation happens early[108] in order to take up this slack, despite the fact that production and market-related knowledge are not yet mature.

There is no nanotechnology market, but rather a number of markets with products containing nanotechnology. It is therefore difficult to get hold of suitable market knowledge when a nanotechnological research advancement can lead to products on widely differing markets. An example of this is the British company Nanomagnetics which, using its technology, went from data storage to water purification[109]. In other countries such as the US, business angels occur much more commonly than in Sweden. These actors do not merely add resources in the form of money, but often bring

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[106] In which an idea is supported, checked and protected by means of such things as novelty search, prototype production and patent application.

[107] When the inventor/entrepreneur packages his idea and carries out a market analysis and business plan.

[108] Gustafsson (2006).

[109] Cientifica (2006).

commercial and marketing knowledge plus involvement to the individual company. Despite such involvement and support being given to companies via Innovationsbron and Industrifonden it has appeared that this is not the same as the support of a smaller private participant such as a business angel.

Nanotechnology has often been described as a push technology in which connection to the market has been weak due to there having been little interaction with industry. The need for an active industry is therefore great in order to develop the market and commercial knowledge surrounding nanotechnology. In some cases, participants have joined up in order to acquire knowledge about the possibilities for nanotechnology in a market[110]. After several years of lukewarm interest, the interest of established industry has now begun to stir as it has to some extent become possible to demonstrate the opportunities of nanotechnology. A shift may now be anticipated from technology-push to market-pull, in healthcare for example[111]. However, it is critical that this interest be strengthened in order for the Swedish innovation system to generate growth.

The importance of market knowledge will increase as the system matures. This type of knowledge is particularly critical to the small nanotechnology companies and success is often associated with good market and commercial knowledge, often allied to an experienced entrepreneur[112]. Furthermore, market knowledge is particularly important to nanotechnology companies, since the real growth associated with nanotechnology is not anticipated to come from companies producing nanomaterial, but from companies using them to create new applications in large existing markets such as healthcare, energy, environment and foodstuffs[113].

Sweden has the potential to become strong within nanotechnology. But to achieve this requires production, commercial and market-related knowledge. The larger companies have resources and good prospects to develop this in combination with institutes, universities and the smaller knowledge-intensive nanotechnology companies. However, academia generally considers the large companies to be more interested for the moment in developing the technology, whilst the small ones are more product-orientated which may lead to competing interests. In the long run, it should be in the interests of larger companies for smaller companies' production opportunities to be developed, given their role as potential subcontractors.

[110] An example of this is NANOFOREST, a project in which a roadmap is being developed to identify fields within nanotechnology which may be of interest to the forestry industry. Acreo has also been at work to develop similar roadmaps for different areas.
[111] Cientifica (2006).
[112] Johannisson och Lindholm-Dahlstrand (2006).
[113] Cientifica (2006).

Institutes should also have a more prominent role, particularly in increasing the opportunities of small companies to develop production-related knowledge.

3.3.3 Collaboration for commercialisation

Given the third task described earlier, responsibility for collaboration in the Swedish innovation system is often placed upon academia. The question is whether this is optimal. Many researchers experience pressure in connection with the third task and professor’s privilege since they are responsible for research creating innovations, either through disseminating the knowledge into existing industry or by starting new companies. Combining this task with research is seen by many as difficult. One indicator is that relatively few Swedish patent inventors are linked to the universities through publications[114]. In addition, academia is finding that companies seldom communicate their problems outwardly, making it difficult to identify needs and openings for collaborations.

Institutes have generally been named as important actors in the diffusion of knowledge in the system and as a link between existing industry and academia. For natural reasons, collaboration and transfer of knowledge between universities and institutes and between institutes and companies has been perceived as simpler than direct collaboration between universities and industry. Institutes have also had a certain type of activities, above all disseminating technical and production-related knowledge in the system. However, their role has been perceived as weak within nanotechnology and it has been established that for institutes to become a strong knowledge-disseminating actor would require increased skills development and activity resources. At the same time, there is rivalry in the system since the activities of institutes and universities are sometimes placed on equal footing and both actors are obligated to compete for funding, which leads to a stifling of collaboration.

In Chapter 2.2.1, it was observed that over three quarters of pure Swedish nanotechnology companies were based on university research. For these, the link to the universities has been a natural one. However, they have been unable to show any major growth. It is hard to say whether this is due to a weakness in the production, market and commercial knowledge or the immature market and early developmental stage of the technology. However, many innovations from academia are put into companies too early, before maturity of concept and sufficient product knowledge have been attained[115]. In a number of cases, the pressure to bring out innovations

[114] Meyer (2005b).
[115] VINNOVA (2004).

mentioned earlier has led to commercial failure. Still, it has been established that there is a basis for more new companies, but that resources must then be guaranteed in order to build up sufficient knowledge prior to formation of a company. At the same time, it is stated that researchers do not always wish to accompany the entire commercialisation process and perhaps this is not ideal either. A handing over of ideas from the researchers' side places a further focus on dissemination of knowledge in the system. Researchers often want to create ideas but may not always want to put them into operation. Finding a suitable entrepreneur to take over and ensure that knowledge is transferred is time-consuming and complicated.

In some cases, the Centres of Excellence surrounding nanotechnology found in Appendix C comprise platforms for commercialisation. For example, the so-called VINN Excellence Centers are generally considered to have increased collaboration with commercial driving forces, given that universities are collaborating in many cases with industry and institutes[116]. It is difficult to say whether this is the case with the nanotechnological centres.

3.4 The market

There are different pictures of the market potential of nanotechnology. By 2010, it is anticipated the market will have passed the billion mark in dollars. Even if this does not happen, there is great market potential for nanotechnology in a large number of markets. Two factors shaping the markets and enabling the potential to be realised are the successful production of real applications for the possibilities presented by nanotechnology, and the fact that any health and environment risks associated with nanotechnology are being dealt with.

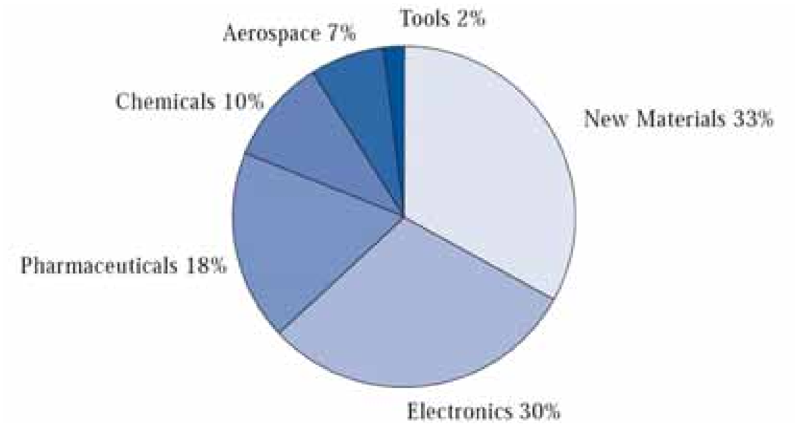
3.4.1 The markets and their development

The number of markets for nanotechnology is practically infinite. Figure 1 attempted to present a number of markets. It was established there that nanotechnology is thought to open the door to innumerable new applications within a large number of different markets. It is anticipated that the size of the nanotechnology element in these markets will comprise a significant section of the world economy. Today, 0.1% of the value of products on the world market is assumed to come from products containing nanotechnology applications. In 2014, this share is expected to be, close to 15%, approaching the size of the IT and Telecommunications market and 10 times

[116] VINNOVA (2005).

more than the biotechnology market[117]. Figure 10 shows the distribution across a number of markets in 2015[118].

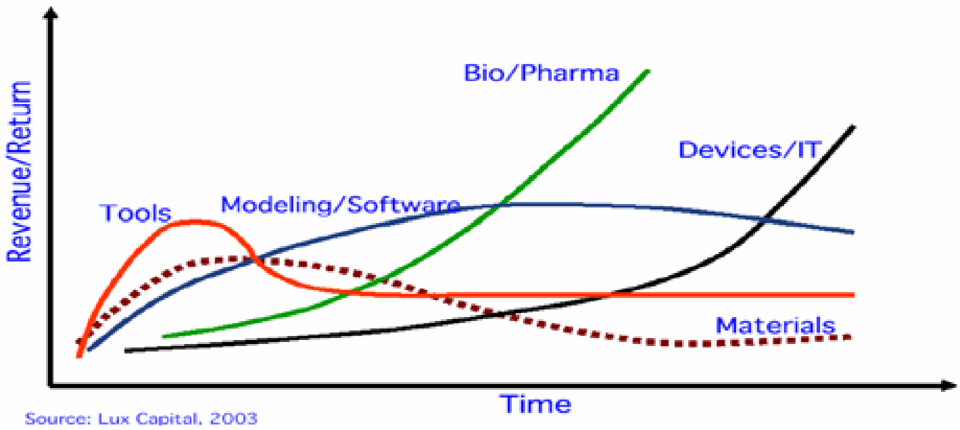
Figure 10. Anticipated distribution of sales of products containing nanotechnology in 2015, from OECD (2005).



The growth rate of the markets varies. The diagram below shows that the Instruments and Equipment (*Tools*) sector is expected to grow a lot in the beginning. This also corresponds well with the dominance of nanotechnology companies in the field, which could be seen in Chapter 2.2.1. These types of products, partly aimed at developing other fields within nanotechnology, are necessary in an introductory stage in order to be able to develop and make products suitable for an end client. Only when these are mature and other fields within nanotechnology have an infrastructure in the form of measurement, production, support equipment for packaging and so on, is it more probable that other markets will gather momentum.

[117] Allianz and OECD (2005).
[118] Allianz and OECD (2005), data from the US National Science Foundation 2003.

Figure 11. Growth of a number of markets related to nanotechnology.



Some commentators believe that the electronics market will gather momentum by 2010 and that life science applications of nanotechnology will only reach larger markets after that, since it takes quite a long time to verify the results of medical products[119]. However, in the above diagram the market for biotechnology and pharmaceutical applications gathers momentum before the IT market. The image given by Swedish actors is generally that the biotechnology applications are further on in time. Regardless of the assessment of the development (which may be related to the limitations of various studies) it can be observed that both the electronics and biotechnology fields are expected to be big.

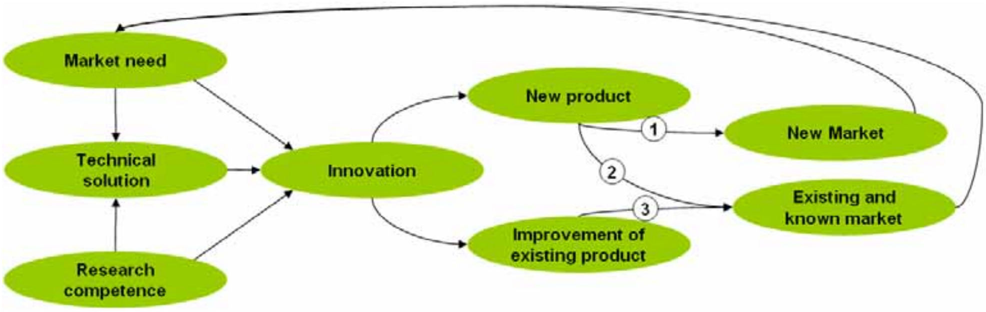
The fact that the Materials field in Figure 11 diminishes in size in terms of economic output can be linked to the fact that growth based on nanotechnology is not anticipated to come from companies producing nanomaterials, but from ones which use these in existing markets[120], such as IT or pharmaceuticals.

3.4.2 Two ways to reach the market

Two types of company are commercialising nanotechnology in Sweden, generally in two different ways. Figure 12 provides a simplified picture of how innovations are generated within nanotechnology and what routes there are to commercialise these.

[119] Allianz and OECD (2005).
[120] Cientifica (2006).

Figure 12. Simplified model of how innovations are created within nanotechnology.



One way is when new participants try to break into markets which already exist but are new to them (1 in Figure 12), in fields with established actors which often posses significant resources[121]. The pure nanotechnology companies have often taken this route, as new companies are often involved. That has often proved difficult due to the markets for nanotechnology applications being immature, or because the large established actors were solving problems using conventional technologies faster than the small actors could find better solutions with nanotechnology. So far, innovations which have taken this route have often been based on research expertise which has been seeking a market need by means of a push-effect. At times, these innovations have been brought out too early and participants have had problems finding a potential market and successfully rousing it. Markets have often been perceived as immature at the same time as nanotechnology has created no better solutions than those found within established industry. Nevertheless, there are successful examples on this route but the innovation process has taken a long time.

Another way of reaching the market is through the launching of new products, or improvements to existing ones, on a market which the industrial actor knows (2 and 3 in Figure 12). These, often large established, companies launch a new product on a market known to them or improve existing products with the aid of nanotechnology. Many believe this is the way in which the major markets and growth will be attained. The larger actprs will be able to present the infrastructure and market knowledge required in order to generate real growth from innovations[122]. In many cases, nanotechnology is only one ingredient in products which are launched and what propels and shapes the market will be specific factors linked to that particular market.

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[121] Cientifica (2006).
[122] Cinetifica (2006).

3.4.3 Significance of the Swedish market

Few actors in the Swedish innovation system for nanotechnology have Swedish clients who are crucial to them. For many actors, the Swedish market is insignificant and the corporate tie to Sweden is through human capital. However, there is a need for Swedish clients as development partners and reference clients in order to enter into international markets. Despite Swedish clients often not being financially strong, they are seen as competent both nationally and internationally. Swedish clients open pathways to more capital-rich international clients. The importance of geographical proximity has also been mentioned as a factor in getting a successful collaboration. However this is far from crucial for everybody.

3.5 Legitimisation

In order to provide innovations which give growth, there must be legitimacy and acceptance for the technology in question. At the same time as there is a great belief in nanotechnology, there are also major news items with adherent uncertainty regarding the development of the technology, but also regarding questions on the environmental and health effects. In order to safeguard the development of nanotechnology innovations, the technology requires legitimacy.

As early as 1959, when Richard Fredman was presenting his visions, the countless possibilities for building structures atom by atom where mentioned[123]. These thoughts inhabited a minor research-bound world until Eric Drexler, with his *Foresight Institute*, provided a more societal, engineering-based perspective. His visions were associated with science fiction and attracted a broader audience but were met with disquiet by some. Since nanotechnology needed to accrue legitimacy for increased research funding, the associations with science fiction were considered problematical and threatening[124]. This split between the visionaries on one hand who were far from always devoted to research, and traditional researchers on the other, is something which is still visible in present-day Sweden[125]. Despite Drexler's ideas being repudiated for some years, they are now read by a broad following and he has contributed to an awakening of thought on the environmental and ethical aspects related to nanotechnology[126].

[123] Fogelberg (2002).
[124] Fogelberg (2002).
[125] Karhi (2006).
[126] Fogelberg (2002).

3.5.1 Environmental and health aspects

There are currently deficiencies in the knowledge surrounding environmental and health risks related to nanotechnological innovation,[127] which may ultimately damage the legitimacy of the field. Participants often connected to environmental and health-related organisations consider that the distribution of funding between nanotechnology research and research into the risks of nanotechnology must be reviewed. Deficiencies in the regulatory framework surrounding nanotechnology are also pointed out. The debate surrounding the risks of nanotechnology was long undeveloped in Sweden but has more recently started to gather momentum, particularly in the media. Researchers are seldom concerned or feel more impeded by the risk aspects surrounding nanotechnology than in other types of research. Nanotechnology researchers are warning that too great an emphasis on the risks of nanotechnology may lead to hostility to the technology. It is difficult to conduct a general risk discussion given the diversity of nanotechnology innovations[128]. The properties of a nanoparticle depend on many things, not just size and material but also structure and combination with other particles. General risk analyses and regulatory frameworks are difficult to produce without requiring a case-by-case analysis of nanotechnological applications.

The EU, OECD, the UN and Greenpeace can be named among the actors currently working on the initial stage of surveying and subsequently regulating environmental and health risks of nanotechnology. One example is the EU project Nanologue, which aims to survey and get hold of the risk aspects involved and avoid a debate based on myths[129]. Despite acting on an international stage, some actors consider that national action also must be taken.

A number of potential risks to health and environment are mentioned in the global debate. Most are connected to toxicological and chemical effects which nanoparticles may have on the human body and our surroundings[130]. A distinction is often drawn on whether the issue is particles, as in powder, or structures bound to a surface. Nanometre-sized particles can enter biological systems and reach the organs of the body through respiratory organs and perhaps even the skin. It is likely that the complexity of materials will make recycling processes more difficult[131]. At the same time,

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[127] IVA (2006).
[128] IVA (2006).
[129] Andersson (2005).
[130] Including Türk et al (2005).
[131] Including Türk et al (2005).

nanotechnology opens the way to create materials which make recycling processes easier.

3.5.2 Ethical and social aspects

In the debate, the ethical and social risk aspects of nanotechnology often have strong connections to general research ethics and social aspects of technological development. There is talk of nanotechnology leading to complex systems which will take away control from the user as it may be more difficult to use and repair products, or that the search for ever more sophisticated solutions will draw the focus and resources away from simpler and cheaper alternatives. Integrity aspects are under discussion since miniaturisation may lead to monitoring applications becoming more efficient. Nanotechnology enables different types of diagnosis methods for human health conditions and sceptics consider that this may impinge upon a person's right to know, or not know, the state of their health. There are also ethical aspects surrounding military applications which may be developed using nanotechnology[132] and an increased knowledge divide between users and developers, and between different regions[133]. The world is being divided between those who have or do not have access to technology and its opportunities, in the form of such things as increased standard of living and access to medical applications.

Despite these threatening clouds being a general feature of technological development, they do pose a specific threat to the development of nanotechnology. They may affect public perception of nanotechnology and thereby its use. However, it is difficult to assess how great a threat this is to the general development of nanotechnology.

3.5.3 Technical uncertainties

In order for the innovation system to fully succeed in safeguarding nanotechnology's opportunities, there must be confidence in its ability to solve problems. The research world is finding confidence relatively weak in established industry, but a change in attitude is being noticed as technologies mature and tangible innovations point to actual possibilities. Standards can make the technology more legitimate by facilitating communication between participants internationally and in the Swedish innovation system. Standards also indicate stability and a common language facilitating the development of technology. In 2004[134], it was felt that standardisation was not needed. The technology was at too early a stage and

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[132] Including Türk et al (2005).
[133] Westman (2005).
[134] Nanoforum (2004b).

the patenting which often underpins standardisation was overshadowed by publication. However, a small number of patents make the standardisation process easier and early standardisation activity can facilitate future work. At the same time, the degree of maturity is different for different fields within nanotechnology, for which reason standardisation work should deal with one area at a time since the standardisation process consumes resources and entails certain intellectual property law complications. There is now an initiative at national and international level for the standardisation of nanotechnology[135].

3.5.4 Visionaries and realists

There is division of opinion regarding what are realistic expectations of future breakthroughs in nanotechnology[136]. The visionary goals of so-called "extreme research" whose goal is virtually to "save the world" are met with certain scepticism by researchers involved in so-called "mainstream research" or "real nanotechnology". Concerning "extreme research", this covers a broad spectrum of varying degrees of realism and visionaries do not merely deal in notions of creating nanobots or supermen.

Despite Swedish researchers keeping to so-called "mainstream research", images are being put about through the media and other channels in Sweden of "extreme research" which influence not only the public at large but also policy actors in the Swedish innovation system. On one hand, such grandiose descriptions of the potential of nanotechnology and rhetoric surrounding a "Third Industrial Revolution"[137] can attract resources and awaken interesting ideas. The next generation of nanotechnology researchers who have not been shaped by conventional thinking are challenged to think big and think creatively. Changes in attitudes and the ability to set unconventional targets can then lead researchers into new fields with far bolder objectives than today's researchers[138]. On the other hand, overly visionary thinking surrounding nanotechnology can arouse fear of change and uncertainty and lead to hostility to the technology. They can also be seen as too unrealistic and thus damage the legitimacy of the field.

The problems of future scenarios which arouse positive and negative attention are not specific to the field of nanotechnology but are often encountered by technological fields in their early stages[139]. However, this

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[135] See Chapter 2.3.1.
[136] Karhi (2006).
[137] Fogelberg (2002).
[138] Karhi (2006).
[139] Karhi (2006).

problem is found to be particularly great in nanotechnology[140]. The exaggerated scare stories being put about are overshadowing the necessary debate on the actual risks of nanotechnology. If the technology does not have legitimacy with the public, nanotechnology cannot generate long-term economic growth. This requires a genuine risk debate, parallel to the development of the technology.

3.6 Resources

Creating innovation and growth requires resources in the form of human capital, financial resources and resources linked to infrastructure.

3.6.1 Human capital

Access to research expertise within nanotechnology is largely considered satisfactory. Sweden has a certain pulling power concerning research expertise from overseas, but it is hard to maintain. A certain degree of insecurity is experienced by researchers in academia due to the resource-consuming research financing system and, from an international perspective, the relatively low salaries of researchers. Still, the current state of access by researchers and level of research and university training is generally considered strong, but with a theoretical emphasis. There is thought to be a sufficient offering of research expertise and university programmes, but a number of participants, particularly small spin-off companies, are finding it hard to find personnel with special skills. These minor participants do not often have sufficient resources to train personnel within desired fields.

In a European context, Sweden has relatively few basic training courses related to nanotechnology[141]. However, there is no comparable data on the number of individuals with undergraduate or graduate training. A major proportion of the European actors within nanotechnology believe there will be a shortage of qualified personnel within a 10-year period[142]. There will be a critical need for engineering know-how and practical skills. However, the most important skills are considered to be interdisciplinary ones. National actors emphasise the importance of people being able to communicate across disciplinary boundaries. Partly due to a lack of movement of people in the system, there is a dearth of such people, particularly in the interface with biotechnology.

[140] IVA (2006).
[141] Nanoforum (2004a).
[142] Nanoforum (2004b).

Given the lack of commercial and entrepreneurial knowledge generally found amongst researchers in the system, it is particularly important for there to be a flow of people between industry and academia. The European Commission amongst others request nanotechnology researchers and engineers with an entrepreneurial outlook[143]. The flow of researchers between industry and academia within natural sciences is generally low[144], which in many cases includes nanotechnology researchers. Where it concerns researchers within engineering, this is generally higher. However, the specific level for nanotechnology is unknown. Amongst European actors, mobility is deemed one of the most important policy questions, followed by that of training. However, there is a flip-side to mobility specifically related to the mobility of people in the case of spin-offs. This way of commercialising research expertise is being increasingly encouraged and participants from academia are experiencing a certain drain of human capital when eminent researchers leave academia to start companies. Some contact with universities remains, but the researchers seldom return to university which may lead to a lack of feedback of researcher-entrepreneurs' experiences to universities.

The number of industrial doctoral students with a link to nanotechnology is currently unknown. Their importance to the development and diffusion of knowledge in the system is yet great, particularly for increasing receiving capacity[145] in industry. Another politically-orientated question which comes up is the underused potential of women[146]. This question is being raised by European actors within nanotechnology[147].

3.6.2 Financial resources

Financial resources are required at a number of stages in the creation of innovations, such as in research and development and in the commercialisation stage.

Financial resources for research and development

The largest research financiers of nanotechnological research and development in the Swedish innovation system invested a total of almost SEK 230 million in 2005 in nanotechnological research, development and demonstration[148]. However, this does not include direct faculty grants and

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143 European Commission (2004).
144 Sandgren and Perez (2006).
145 Ability to take in knowledge from outside.
146 European Commission (2004).
147 Nanoforum (2004b).
148 SEK 14 million for research centres (Appendix C) and some 215 for other types of programme (Appendix D).

commissioned research for academia, industrial investment in research within the field internally and the basic financing which reaches research institutes; it has not been possible to chart this within the scope of this study. Obtaining a complete picture requires a more in-depth survey of the field.

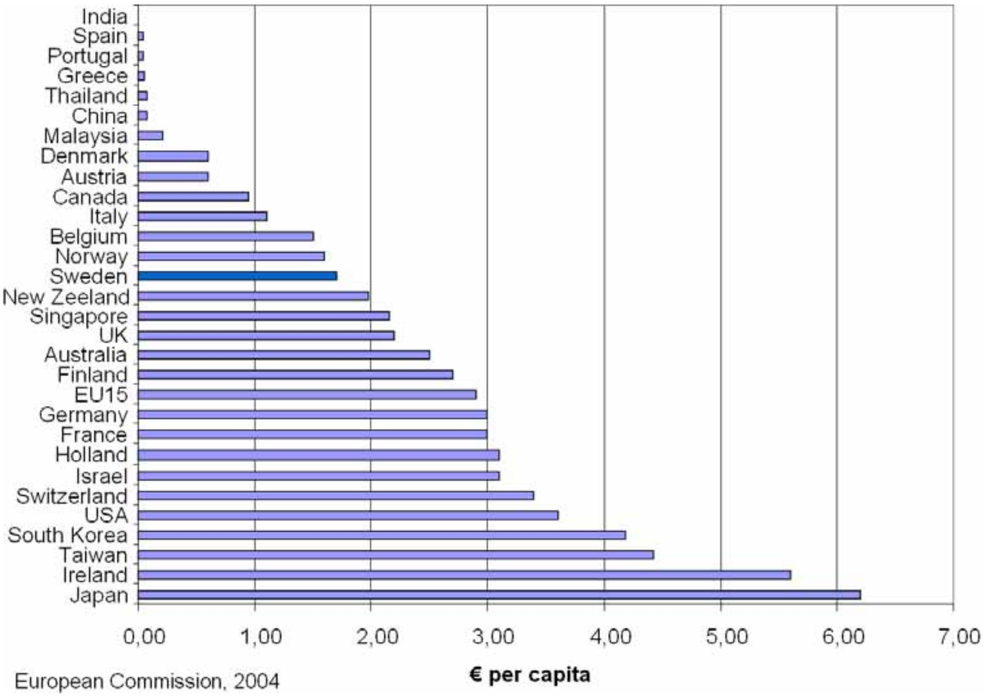
However, an increase in the financing of nanotechnology can be noted amongst the research financiers. For 2007, an investment of over SEK 80 million was anticipated in research centres within nanotechnology, compared with SEK 14 million for 2005.

Despite that in principle all major national research financiers have invested in nanotechnology, there is no coordination and overview of these investments. This is a prerequisite for larger strategic investments and the focusing of research on key competences.

Sweden invests a lot in R&D; just below 4% of GDP. Only Israel invests more. Despite major resources for scientific fields close to nanotechnology, public R&D investment within nanotechnology is estimated to be at a relatively low level for Sweden (Figure 13). This is regardless of the fact that between 1997 and 2000 Sweden, second to Italy, was the country which increased its R&D investment in nanotechnology the most[149]. Public investments directly attributable to nanotechnology in Sweden in 2003 amounted to approx. EUR 15 million, or approx. EUR 1.7 per capita according to the EU[150]. This is a lower level compared with Germany, Switzerland, the Netherlands and Finland. According to the European Commission, this is below the average level for EU15[151]. According to the European Commission, nanoscience and nanotechnology are not priority fields for public research financiers in Sweden to the same degree as in other countries.

[149] OECD (2003).
[150] European Commission (2004).
[151] However, it should be noted that it is unclear what the European Commission source is and that this is a low figure compared with the calculations made within the framework of this study.

Figure 13. Public financing of nanotechnology per capita 2003.



Within the EU's Sixth Framework Programme, EUR 27 million of a total EUR 566 million for nanotechnology has accrued to Swedish actors[152], a normal achievement for Sweden. In the Seventh Framework Programme, around EUR 3.5 billion has been dedicated to the priorities of *Nano-sciences, Nanotechnologies, Materials and new Production Technologies*. As the name implies, this also includes Materials and Production. Nano is also becoming a part of other priorities. Based on the results of the Sixth Framework Programme, around EUR 2.9 billion can be counted on for projects relevant to nanotechnology, distributed across seven years.

Both industry and university actors regard the resources for research as insufficient. For example, the universities consider their resources too small to attract foreign, and keep domestic, human capital. Companies do not consider that they have economic opportunities to develop their inventiveness in nanotechnology into real knowledge and articulate needs. Actors from institutes have also mentioned a lack of financial resources to develop knowledge in nanotechnology, which has also been highlighted by the universities.

The question of access to resources is complex. Perhaps the problem is not about a lack of financial resources, but a resource-consuming financing system with a lot of administration in conjunction with applications and split resources which are difficult to survey. Furthermore, there is a certain

[152] See Chapter 7.1.1.

conflict in that the system has to unite, coordinate and focus on nanotechnology even whilst many actors feel they are being set against each other through a competition-based financing system. The smaller universities, which may not perhaps be experts at obtaining funding but which have innovative ideas and generate diversity in the system, are sidelined.

European industrial actors have put forward a need to displace the distribution of funds from the current concentration on theoretical research to more technical and engineering-orientated development[153]. However, participants in 2004 will see an increase in total funding to basic research in nanotechnology. Nevertheless, this should be viewed in light of the fact that a majority of participants in the cited study are researchers within academia.

Financial resources for commercialisation

Nanotechnology can chiefly be commercialised in two ways; either through the technology being developed or introduced into existing companies, or through new companies being formed on the basis of research expertise. Concerning the formation of new knowledge-intensive companies, there are a couple of aspects to consider. There is great pressure to rapidly commercialise nanotechnological researcher expertise. In general, nanotechnology requires a lot of time and resources for the development of production methods, packaging, measurement etc. Thus, the verification stage[154] is relatively long. Available venture capital is not considered sufficiently durable to add resources at this stage since an exit is generally a long way off. For university spin-offs, this stage is often conducted in universities where this type of activity is difficult to fund. So, due to difficulties in attracting capital without a company, ideas are only turned into companies when they are mature.

The commercial development is also critical to nanotechnology, as is the pre-seed stage[155]. A lack of capital can be observed here too. This critical phase is supported through ventures such as Innovationsbron, Industrifonden and incubators. However, actors think this is inadequate and that there is not the same involvement from these types of financial actors as from example business angels, of which there are few in Sweden.

A lack of venture capital was also noted in the pre-seed phase for existing companies in Sweden[156]. Swedish actors are less used to risks than their

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[153] Nanoforum (2004b).
[154] In which an idea is packaged and a market analysis and business plan carried out.
[155] In which an idea is supported, checked and protected by means of such things as novelty search, prototype production and patent application.
[156] VINNOVA (2005).

overseas colleagues and state nanotechnology investments on an international level are not matched by private venture capital[157]. Only 1.5 per mille of the American venture capital went to nanotechnology in 2005. In addition, the American capital is tied up in illiquid companies where an exit is considered to be a long way off. Many investors were in a hurry during the beginning of the nano hype and, afraid of missing the boat, invested money in companies despite having insufficient knowledge. Investments have been locked into these companies, since an exit is far off. A few investments have succeeded and the venture capitalists are looking for opportunities to sell technologies on. There is often a problem of misassessment by venture capitalists, which have knowledge about the technology but lack knowledge about the market before going in. The problem is a familiar one from previous discussions relating to difficulties of linking nanotechnology expertise with market knowledge.

The ratios between the European and American venture capital markets are 1:6 for nanotechnology and 1:5 generally[158]. The European actors are less familiar with risk and nanotechnology is still regarded as risky. It has not been possible to chart the investments of Swedish venture capital companies in nanotechnology, but there is a certain amount of activity. For example, the venture capital company Creandum took Nanoxis into its portfolio and FöretagsByggarna has invested in Replisaurus AB. Teknoinvest and Provider Venture Partners have also invested in nanotechnology companies, namely in QuNano. SEB Företagsinvest has the Danish company Capres A/S in its portfolio and Innovationskapital has invested in Åmic and Syntune. Furthermore, there is activity amongst the universities' own venture capital companies such as KTH Seed Capital and LUAB (Lund University's development limited company).

3.6.3 Mobilisation of resources linked to infrastructure

There is a sufficient quantity of infrastructure in Sweden for the nanotechnology field. Major investments have been made recently, for example from the Knut and Alice Wallenberg Foundation among others. In 2002, there was an evaluation of the three laboratories, Elektrum in Kista at KTH, the Ångström Laboratory in Uppsala and Mc2 at CTH[159]. It was confirmed that these had excellent prerequisites in the form of cleanrooms, equipment and personnel for the development of nanotechnology. The cost of establishing these laboratories matched that of high international class. However, the emergence of these laboratories is not the result of a

[157] Cientifica (2006).
[158] Cientifica (2006).
[159] The Royal Swedish Academy of Sciences (2002).

coordinated national plan; rather, they have arisen from a split structure of financing sources. A split structure and excess capacity gives rise to high utilisation costs. A network to coordinate resources does exist, but a continued increased optimisation of utilisation is desirable in order to bring down the costs.

For many of the relatively recently started nanocompanies, verification and reproducibility are two important aspects in order to move ahead in commercialisation. These require costly equipment which is often found in the three cleanrooms. At the verification stage, the utilisation price is manageable, whilst the step up to production is great in terms of both cost and finding suitable suppliers. For these small companies to succeed with their commercialisation requires this infrastructure to be available at a reasonable price, which is not always the case. There are also difficulties in finding suitable suppliers and enabling production in Sweden. This is important, since geographical proximity plays a certain role. The MAX laboratory also has problems with running costs, and it has been noted that operating subsidies must be more than doubled in order for the laboratory to maintain its current position. [160]

3.7 Output

The previous chapter described the prerequisites for the innovation system to generate innovations from a number of angles. But how innovative is the system; how many innovations have been generated?

Information on innovations in the form of product launches or new processes is missing from all types of company, not just nanotechnology ones. Innovations are therefore normally indicated by a company's patenting[161]. An increase in nanotechnology-related patents from Sweden has been established. Measured on an international scale, Swedish patenting activity is medium-sized, both in absolute figures and in relation to the size of the country[162]. Within the framework of this analysis, it has not been possible to make a deeper analysis and follow-up these patents to see which turned into innovations. Nor has it been possible to inspect patents approved after 2001. To truly attempt to identify the number of innovations and the economic value in patents, this is necessary.

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160 The Royal Swedish Academy of Sciences (2004).

161 Since 1996, the European Commission has carried out comprehensive work to measure innovation activities under the name Community Innovation Survey (CIS). Sweden is participating in this work through SCB.

162 Meyer (2005a).

Another indicator of the system's output is the number of industrial actors, since it is they who finally commercialise the innovations. The possibility of creating innovations probably increases with the number of companies, despite the fact that a few companies actually ought to be able to generate many innovations and vice versa. A growth in the number of actors has been observed and their activity has increased in comparisons between the surveys in this study and other studies. An increase has been noted amongst both the small nanotechnology companies and the major actors.

However, Sweden has proved to be somewhat poorer at bringing forward industrial actors than at researching and patenting. In two international surveys, Sweden came in 15th place in regard to the number of industrial actors in nanotechnology[163]. However, the number of actors has not corresponded to the total of 85 companies identified in this study.

It can be confirmed that industrial actors have developed a number of products, despite no reliable inventory having been taken of the number of products. Nor is there any cohesive international comparison which would be able to put the Swedish number of innovations into perspective. Further analyses are required in order to assess the system's total output.

[163] Nanovip.com (2006), Allianz and OECD (2005).

4 Conclusions and measures

The Swedish nanotechnological innovation system is taking shape. Participants are beginning to gather around the field and innovations based on nanotechnology are beginning to reach markets. There are opportunities for Swedish actors to take a major role in the development of nanotechnological innovations, but there are obstacles along the way.

The following chapter commences with a summary of the weaknesses identified in the system and, on the basis of these, deduces obstacles to the creation of innovations. Based on these, proposed measures are identified to reduce obstacles in the system. The chapter concludes with a final discussion.

4.1 Obstacles to the creation of nanotechnology innovations

Based on the aspects relating to the driving forces, nanotechnological knowledge base, commercialisation, market, legitimacy and resources as discussed in Chapter 3, obstacles to the creation of nanotechnology innovations can be identified. The following diagram summarises the strengths and weaknesses which have been identified. A number of obstacles give rise to these weaknesses. The relationships between these are represented by arrows in the figure. Obstacles have then been categorised by how critical they are considered to be to the system, based on the size and number of weaknesses they have caused in the innovation system, plus how specific the obstacle was to the actual nanotechnology innovation system. In Chapter 2.1, it was also mentioned that certain aspects are more important given the stage of the system. The most critical obstacles have been noted in a darker colour and the less critical in a lighter one.

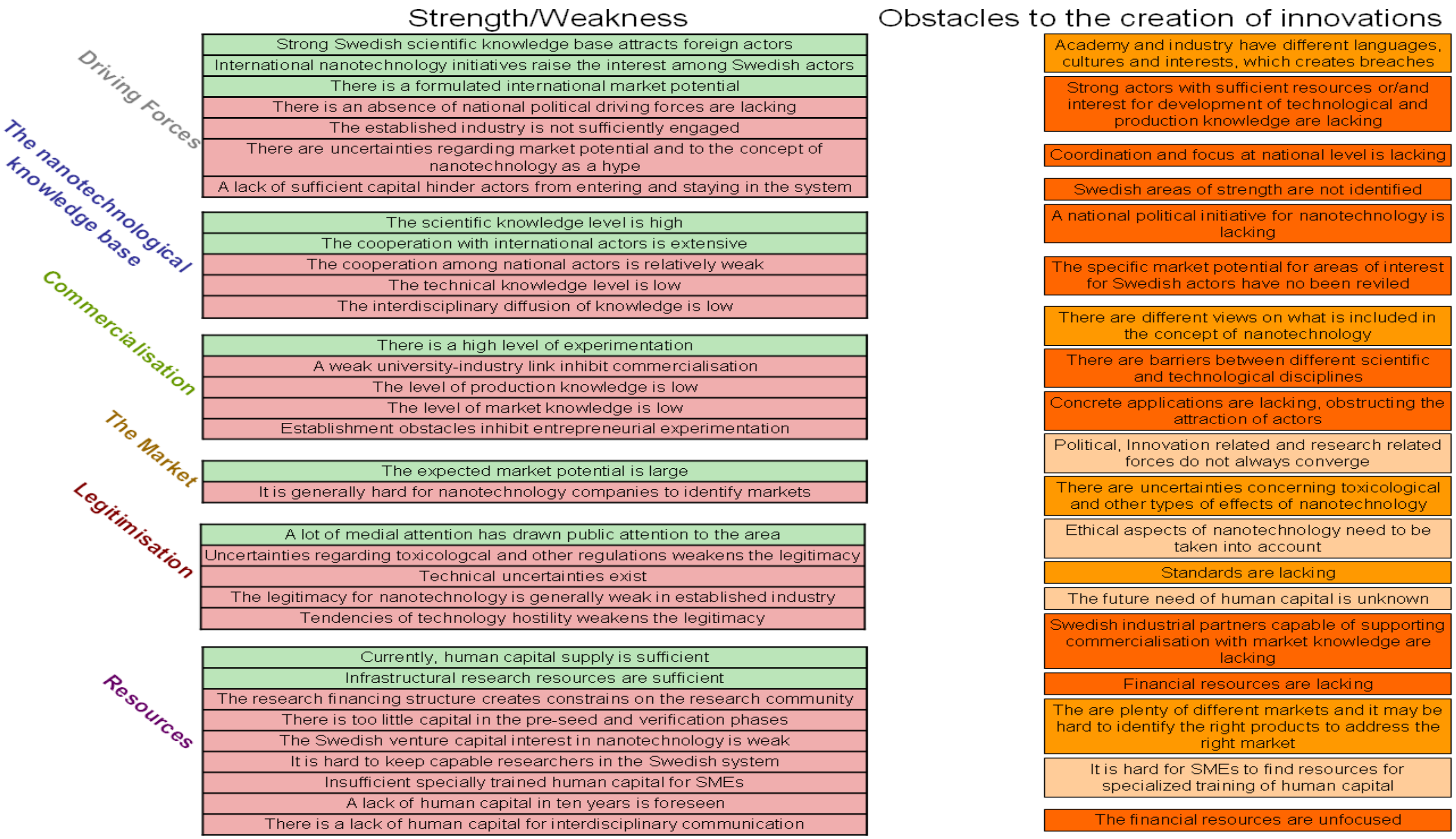


Figure 14. Strengths and weaknesses in the system and the obstacles associated with the weaknesses.

Weaknesses related to driving forces for nanotechnology are due to the lack of national political interests, uncertainties in the market and nanotechnology as a technology, muted enthusiasm from industry and insufficient capital. Obstacles which give rise to this are largely down to an inability to point out the possibilities of nanotechnology. The market potential for specific fields which may be of interest to Swedish actors has not been explained and too few concrete applications of nanotechnology have been developed in Sweden. Nor do Swedish actors have a unified picture of what is included in nanotechnology, or a national initiative such as the US's *Nanotechnology Initiative*.

The nanoscientific knowledge base is strong, whilst the technical side is weaker. Collaboration between different groups of research actors within nanotechnology is low, as is the interdisciplinary diffusion of knowledge. A weak link between academia and industry due to differences in culture and interests, plus the lack of strong actors with sufficient resources and interest to develop technical knowledge prevent development of the technical knowledge base. A lack of coordination between the Swedish actors is creating obstacles to collaboration between the research groups. Interdisciplinary barriers in language and working methods are hindering the interdisciplinary dissemination of knowledge.

The differences in culture and interest between academia and industry prevent not only the development of technical knowledge but also make commercialisation more difficult. This, combined with the lack of strong actors with sufficient resources and interest, is preventing the development of production-related knowledge. The differences between academia and industry also prevent the development of commercial and market-related knowledge. The fact that the market potential of specific fields of interest to Swedish actors has not been surveyed also prevents the development of market knowledge, as does the lack of Swedish industrial partners who would be able to support the commercialisation.

It has proved difficult to identify suitable markets for pure nanotechnology companies. This is chiefly due to the lack of Swedish industrial partners who would be able to support the commercialisation with market knowledge, plus there are too few concrete applications for nanotechnology. The fact that the market potential of specific fields of interest to Swedish actors has not been clarified also plays a role.

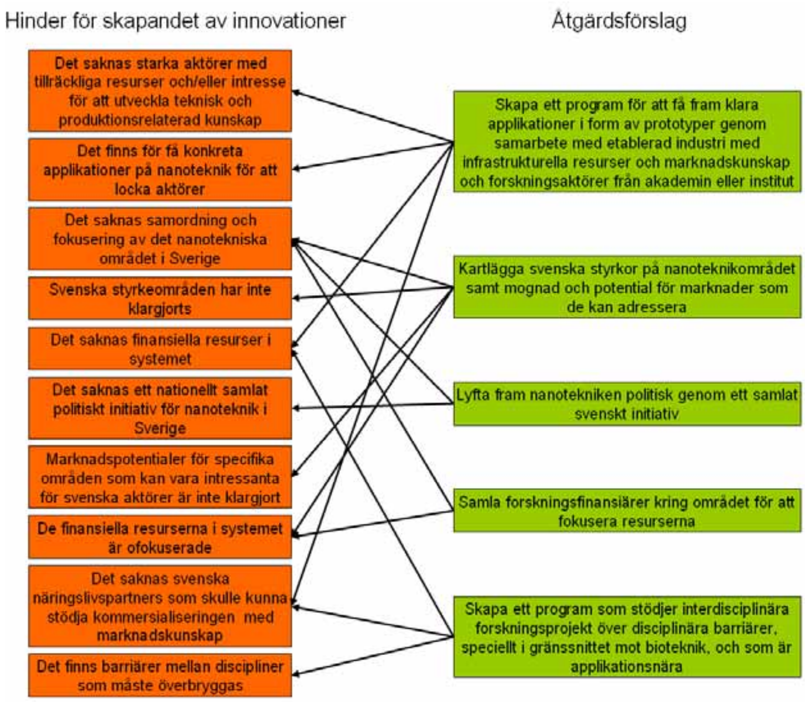
Uncertainties relating to toxicology and other regulations are hampering the legitimacy of nanotechnology. There are also uncertainties relating to technical aspects, which are partly due to the early stage of the system and the lack of standards, but also the need for strong actors with sufficient resources and interest to generate and develop stability around the technical knowledge. A paucity of concrete applications has resulted in a general weakness of nanotechnology with existing industry. Uncertainties regarding ethical aspects and the effects of nanotechnology have created certain hostile tendencies towards nanotechnology.

There is a lack of financial resources in the system. Amongst other things, there is too little capital in the verification and pre-seed phase, plus a generally lukewarm interest from venture capital. This is because the market potential of specific fields interesting to Swedish actors has not been clarified, and there are too few concrete applications of nanotechnology. The lack of financial resources for research, combined with unfocused resources in the system is creating stress on research practitioners and making it difficult to keep researchers with cutting-edge knowledge in the country.

4.2 Proposed measures

Of the obstacles to the creation of innovations which have been identified, 10 are particularly critical to nanotechnological innovations. Based on these 10, five proposed measures are presented which can reduce these obstacles. These are presented in Figure 15.

Figure 15. Proposed measures and how they address the most critical obstacles.



The proposed actions are very much a summary to show how some obstacles to the generation of innovations within nanotechnology could be removed.

A programme for clear nanotechnology applications

By creating a research and development programme in which established industry (which has infrastructural resources and market knowledge) together with research actors from universities and institutes produces clear applications, it is possible to highlight the opportunities which nanotechnology presents. Thus, the legitimacy of the technology increases and more participants are attracted and can add knowledge to the system. Concrete applications may interest existing strong actors who have resources to develop technical and production-related knowledge, as well as industrial partners who can support commercialisation with market knowledge.

Survey of Swedish areas of strength and potential markets

A picture of Swedish potentials can be gained by conducting a sound survey of Swedish strengths within the nanotechnology field. A survey of markets in regard to maturity and growth potential will then give a picture of the possibilities for nanotechnology. By matching Swedish areas of strength with market potentials, the fields in which Sweden has good opportunities to generate growth through nanotechnology innovations are identified. These become priority fields around which Sweden can muster and provide an opportunity for coordination and focusing of Swedish resources.

A combined Swedish initiative to nanotechnological development [164]

Through national actors taking a joint Swedish initiative, nanotechnology can be highlighted politically and coordinated. It is important to include all participants in this work and for there to be political involvement, so as to gain support right up to departmental level. This will increase the legitimacy of the field and generate driving forces which increase the activity of the innovation system and thus the capacity to generate nanotechnological innovations.

Gathering research financiers around nanotechnology

The generic nature of nanotechnology has meant that efforts within the field have been split. By gathering research financiers around nanotechnology, financial resources can be focused in the system and coordinated around nanotechnology, which can create advantages. It will also reduce the stress on research and development practitioners arising due to the split financing structure. By focusing resources on priority fields, it is possible to build up Swedish areas of strength within nanotechnology which can hold up against international competition.

[164] An initial step has been taken through IVA's work with a Swedish nanotechnology strategy.

An interdisciplinary application-driven research and development programme

The interdisciplinary nature of nanotechnology requires collaboration across disciplines; something which can be difficult. There are barriers between different scientific and technical disciplines which are hard to bridge. There is also a need for people with the capacity to work across these barriers. These obstacles can be bridged by creating a programme which supports interdisciplinary research projects across barriers, especially in the interface of biotechnology (which has proved particularly hard). It has also proved important to work closely with applications early on, for which reason the research should be application-driven.

4.3 Final discussion

There are major international expectations that nanoscience and nanotechnology will create new applications and innovations and thereby major growth. The field is increasingly attracting large private and public investments in many parts of the world, but Sweden has acted less robustly regarding the production of nanotechnological innovations and political interest in the field has been relatively unenthusiastic.

The generic nature of nanotechnology has made it hard to discuss from a general perspective concerning research, industry and markets. Therefore, nanotechnology should be considered based on a number of research fields, industrial sectors or markets. Herein probably lies one of the explanations for the lack of focus surrounding Swedish nanotechnology. For, despite no overall nanotechnology investments having been made, nanotechnology is well disseminated within various research fields.

Swedish nanoscientific and nanotechnology research is maintaining a high international level within the number of fields; a result of the investments, albeit split, which have been and are being made within fields relevant to the development of nanotechnology. Concerning the more technically-orientated activity, Sweden has not proved so strong. There is a growing industry within nanotechnology in Sweden, but there is clear potential for improvement. The Swedish innovation system surrounding nanotechnology applications is in its construction stage. Increasing numbers of participants are joining in and interest amongst established industry is increasing, which is necessary if more nanotechnological innovations are to be generated. The established industrial participation in the development of nanotechnological innovations is critical, given that they possess production, markets and commercial knowledge.

Sweden’s has good potentials to lead in nanotechnological fields but to meet international competition, it must rally its efforts and prioritise within the field.

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Rao, Venkat; *The Royal Institute of Technology*

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Appendices

Appendix A: Comparison of institutes' and universities' fields of activity within nanoscience and nanotechnology[165]

	University	Field of activity
Universities	**CTH/GU**	• Nanolithography and visualisation (scanning tunnelling microscopy) • Manipulation of nanoparticles and nanoclusters • Nanocatalysis • Nano-optics • Theoretical aspects of nano-structured material • Fullerenes and nanotubes • Quantum computers
	Halmstad University	• Nanoelectronics
	University of Kalmar	• Molecular motors for nanosystems engineering and biomedical applications • Nanomagnetism
	The Karolinska Institute /Stockholm University	• Medicine, biotechnology, life science
	KTH	• Semiconductor technology, photonics and nanomaterial • Multifunctional nanoparticles for drug delivery
	Linköping University	• Functional materials • Molecular electronics and biotechnology • Visualisation (atom force microscopy, scanning tunnelling microscopy) • Nanomagnetism • Nanostructures in semiconductors (quantum dots and threads) • Self-organising surfaces • Fullerenes and nanotubes
	LU	• Nanothreads, quantum threads (nanothreads) • Quantum dots • Nanomagnetism • Nanolitography för life science applications • Carbon nanotubes
	Luleå University of Technology	• Surface chemistry and materials engineering
	Mid Sweden University	• Sensor field and electronic production • Visualisation (electron microscopy)
	Mälardalen University	• Molecular electronics, nano biology and nanotechnology instruments
	Umeå University	• Nanomaterials • Nanomagnetism • Fullerenes, nanostructures in carbon

165 The comparison is very much an outline and the information compiled from various sources, including articles, interviews and the two reports: *Evaluation of the Swedish Condensed Matter Physics*, The Royal Swedish Academy of Sciences (2005) and *Små funktionella komponenter baserade på Mikro- och Nanosystem [Small functional components based on micro and nanosystems],* Söderkvist, J, Vogel, O, (2004).

	Uppsala University	• Biotechnology, life science and interdisciplinary theory tools • Nano and biomagnetism • Nano-structured material • Nano-optics • Fullerenes and nanotubes
	Örebro University	• Theoretical aspects of electromagnetic nanoparticles

	Institute	Field of activity
Industrial research institutes	**IVF**	• Solar cells and displays
	Acreo	• Biochips and optical systems • Materials for semiconductor components • Quantum dots
	Imego	• Biosensors, microsystems and sensor systems based on optical and magnetic elements.
	SP	• Measurement of nanoparticles and services
	KIMAB	• Nanoparticles and surfaces
	Stfi-Packforsk	• Nanotechnology applications for the forestry industry
	Trätek	• Nanotechnology applications for the forestry industry
	YKI	• Surface structures at nanometre level
	Sicomp	• Nano-structures in polymer materials

Appendix B: Scientific activity and excellence within nanotechnology (1996-2001)[166]

The 10 most active Swedish universities	Number of publications	Number of citations	Number of publications amongst the 10% most cited	Number of citations per publication	Number of citations per publication normalised[167]
CTH	460	720	10	1.5652	1.35
LU	432	1163	10	2.6921	1.61
UU	354	878	13	2.4802	1.60
GU	299	505	6	1.6890	1.35
KTH	223	394	3	1.7333	1.14
LiU	217	522	9	2.4055	2.36
KI	107	795	10	7.4299	2.12
SU	54	110	1	2.0370	0.87
Umeå U	54	222	2	4.1111	1.28
Luleå TU	27	92	2	3.4074	3.53

Actors, excluding universities with more than five published articles	Number of publications	Number of citations	Number of publications amongst the 10% most cited	Number of citations per publication
YKI. Institute for Surface Chemistry	65	224	2	3.45
Pfizer (Pharmacia)	43	274	4	6.37
AstraZeneca	31	95	1	3.06
Biacore	25	88	2	3.52
FOI. The Swedish Defence Research Agency	15	13	0	0.87
Imego	7	0	0	0.00
The National Institute for Working Life	7	0	0	0.00
ABB	5	4	0	0.80

[166] Noyons et al (2003), from the database http://studies.cwts.nl/projects/ec-coe/cgi-bin/izite.pl?show=home
[167] Normalised in regard to the scientific field's general citation frequency.

Appendix C: Centres of Excellence in Sweden within nanotechnology, Lennart Stenberg, VINNOVA 2006

Name	Uni-versity	Period	Total grants[168]	Type of centres and financiers
NANOWIRES for Fundamental Materials Science and Quantum Physics and for Applications in Electronics, Photonics and in Life-sciences	LU	2006-2010	22	Centres of Excellence in R&D, Swedish Research Council
Nanowires for emerging nanoelectronics and life-science applications	LU	2006-2010	34	Strategic research centres, Foundation for Strategic Research
Strategic Research Center for Nano Science	LU	2004-2008	40	SRC in Microelectronics, Foundation for Strategic Research
Nanoscience and Quantum Engineering	LU	2007-2016	87	Linné, Swedish Research Council, Formas
Strategic Research Center for Nanodevices and Quantum Computing (NANODEV)	CTH	2004-2008	30	SRC in Microelectronics, Foundation for Strategic Research
Engineered quantum systems	CTH	2007-2016	100	Linné, Swedish Research Council, Formas
Functional Nanoscale Materials	LiU	2007-2016	70	VINN Excellence Center, VINNOVA
Materials Science for Advanced Surface Engineering, MS²E	LiU	2007-2010	45	Strategic research centres, Foundation for Strategic Research
Linköping Linnaeus Initiative for Novel Functional Materials (LILi-NFM)	LiU	2007-2016	80	Linné, Swedish Research Council, Formas
Hierarchic Engineering of Industrial Materials	KTH	2007-2016	70	VINN Excellence Center, VINNOVA
Uppsala Berzelii Center for Basic and Applied Research in BioNanoTechnology	UU	2007-2016	100	Swedish Research Council and VINNOVA

In 2005, two centres were financed with an average of SEK 14 million for that year. The corresponding figures for 2007 were 11 centres and SEK 80.4 million.

[168] SEK millions.

Appendix D: National finances within nanotechnology, and the EU through FP6

The activities of financiers are classed according to type of financing; financing of research (R), development (D), demonstration (Dn) and/or training (Tr). Financing of Centres of Excellence are not included in this table, but are described in Appendix C. In many cases, programmes listed in the table touch on other fields such as microtechnology and other bio and materials engineering, which are not strictly nanotechnology. Nanotechnology projects are probably also financed in programmes which are not labelled as nanotechnology programmes. This means it is difficult to estimate how much is being invested in the field per year. Proceeding from the programmes listed in the following table, we arrive at approximately SEK 215 million as at 2005 invested by these financiers in nanotechnological research, development and demonstration. It is worth mentioning that the Knut and Alice Wallenberg Foundation made major investments in the field this year.

This excludes what is invested by industry in the field, which has not been possible to determine within the constraints of the study. Nor are academic faculty appropriations included, or any investments made from other smaller financiers such as the Swedish National Space Board, Swedish Environmental Protection Agency, Vårdal Foundation, Riksbankens Jubileumsfond etc. However, it can be confirmed that these have not made large investments.

The information comes from the research financiers’ websites and annual reports.

Financier		Programme	Type	Period	Total funding
International	**European Commission**	Support for research and development within the Six (FP6) and Seventh (FP7) Framework Programme.	R/D	FP6 (2002-2006)	Swedish actors in FP6: EUR 27.4 million[169]
				FP7 (2007-2013)	Total budget nanotechnology [170]: EUR 3.5 billion
	Nordic Innovation Centre	Eight Nordic projects in which the aim is to commercialise existing research [171].	D/Dn	2006 - 2007	Approx. SEK 12 million
State agencies	**VINNOVA**[172]	**BioNanoIT:** a programme for research, development and demonstration which links life sciences with micro/nanoscience and IT.	R/D/Dn	2002-2007	SEK 45.6 million so far
		Micro and nanosystems: a programme for research, development or demonstration.	R/D/Dn	2002- [173]	SEK 90 million
		Designed material incl. nanomaterial: opportunities testing and concept verification for R&D-orientated companies.	D/Dn	2006-2007	Approx. SEK 20 million
		Multidisciplinary BIO[174]: collaborative projects between Japanese and Swedish researchers.	R/D	2004-2008	SEK 12 million
	Royal Swedish Ac. of Sciences	Competitive funding for basic research.	R	Ongoing	Approx. SEK 10 million/year[175]

[169] For contracts signed in FP6 up to 24/1/06.
[170] Nano-sciences, Nano-technologies, Materials and new Production Technologies
[171] A number of previous individual projects have been financed, as have broader initiatives such as *Nordic NanoTrade* and *NANONORD*.
[172] A number of individual projects have also been financed outside the constraints of these programmes.
[173] A new programme is planned within the field and in 2004, the Agency provided SEK 100 million in support for suitable industrial research within IT/telecom aimed at nanotechnology and microelectronics. The stated sums are based on projects financed up to and including 2005.
[174] In combination with SSF, SEK 12 million from each financier.
[175] SEK 40 million annually (forskning.se 28/5/06), around 30 to the Centres of Excellence in R&D within nanotechnology excluded from the list.

Financier		Programme	Type	Period	Total funding
	Formas[176]	**Multidisciplinary BIO**[177]: Collaborative project between Japanese and Swedish researchers	R/D	2004-2008	SEK 12 million
	The Swedish Energy Agency	**Grätzelsolceller**: research project, KTH and IVF.	R/D	2006–2008	SEK 17 million
		ÅSC programme, Ångström Solar Center[178] R/U	R/D/Dn	1998-2005	SEK 75 million
	FOI	**Military nanotechnology programme:** from research to demonstration.	R/D/Dn	2003-2008	SEK 100 million
Foundations	**SSF, Foundation for Strategic Research**	**Nano-X:** postdoctoral programme within applied nanoscience and nanotechnology	R	2006-2010	SEK 80 million
		A number of research centres and individual projects such as Nanochemistry at KTH, CARAMEL at CTH, NANOPTO at LiU etc. Total 22.	R	1996-2006	Over SEK 400 million
	The Knowledge Foundation	**minST, Micro and nanosystems technology:** programme for training smaller Swedish companies within micro and nanosystems technology.	D/Tr	2004-2006	SEK 15 million
		Seven other projects, research and researcher training.	R/D/Dn Tr	2001-	SEK 11.6 million
	Knut and Alice Wallenberg Foundation	Funding for postdoctoral studies in interdisciplinary micro/nanoscience.	R/Tr	2004	SEK 50 million
		Investment in research and equipment within nanoscience.	R/D	2004 / 2005	SEK 124 million/SEK 70.8 million
		NANOSCIENCE center in Lund.	R/D	2003	SEK 10 million
		Neuronanoscience Centre in Lund.	R/D	2005-2010	SEK 40 million
	MISTRA	**ÅSC programme**, Ångström Solar Center[179]		1998-2005	SEK 75 million

176 No other direct nanotechnology programmes, but nanotechnology projects have been financed under broader programmes related to environment, land-based industries and spatial planning.
177 In conjunction with VINNOVA, SEK 12 million from each financier.
178 In conjunction with Mistra, SEK 75 million from each financier.
179 In conjunction with the Swedish Energy Agency, SEK 75 million from each financier.

Appendix E: Projects in FP6 coordinated by Swedish actors

Acronym	Title	Coordinator	Participants
CANEL	Carbon-based nanoelectromechanical devices	Chalmers University of Technology	4
NANOBIOMAPS	Imaging mass spectrometry for nanoscale mapping of biological cells and tissues	SP Swedish National Testing and Research Institute	6
AMNA	Addressable Molecular Node Assembly - a Generic Platform of Nano-scale Functionalised Surfaces Based on a Digitally Addressable Molecular Grid	Chalmers University of Technology	4
NODE	Nanowire-based One-Dimensional Electronics	Lund University	12
NANOSTAR	Nano-Structured Ferrolectric Films for Tuneable Acoustic Resonators and Devices	Chalmers University of Technology	6
NANDOS	Nanophotonic and Nanoelectronic Devices from Oxide Semiconductors	Göteborg University	7
EMISHIELD	A Novel Gasket and Seal System used for EMI Shielding Using Double Percolation of Carbon Nanotube Technology to Improve Safety, Profitability and Productivity for SMEs	Roxtec International AB	8
BIOSCOPE	Self-reporting biological nanosystems to study and control bio-molecular mechanisms on the single molecule level	Lund University	9
NANOFOREST	A nanotechnology roadmap for the forest products industry	Stfi-Packforsk AB	4
NABIS	NANOBIOTECHNOLOGY WITH SELF-ORGANISING STRUCTURES	The Royal Institute of Technology	6
NANOCUES	Nanoscale surface cues to steer cellular biosystems	Chalmers University of Technology	7
NANOQUANT	Understanding Nano-Materials From the Quantum Perspective	The Royal Institute of Technology	10
CANEL	Carbon-based nanoelectromechanical devices	Chalmers University of Technology	4

Appendix F: bibliometric indicators[180]

Figure 16. World production of nanotechnological publications 1994-2000 and 2001-2004, data Thomson ISI 2005[181].

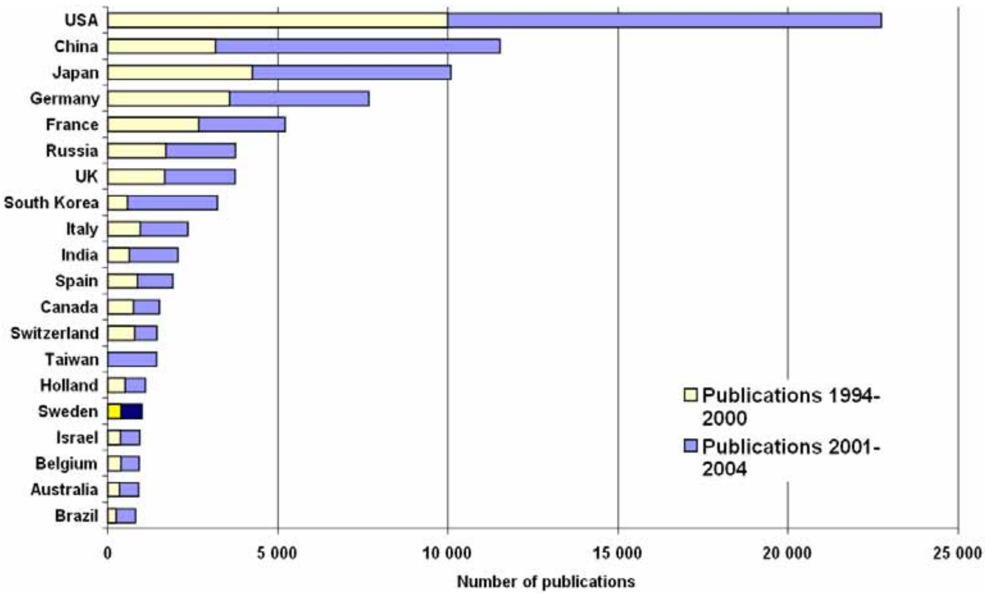
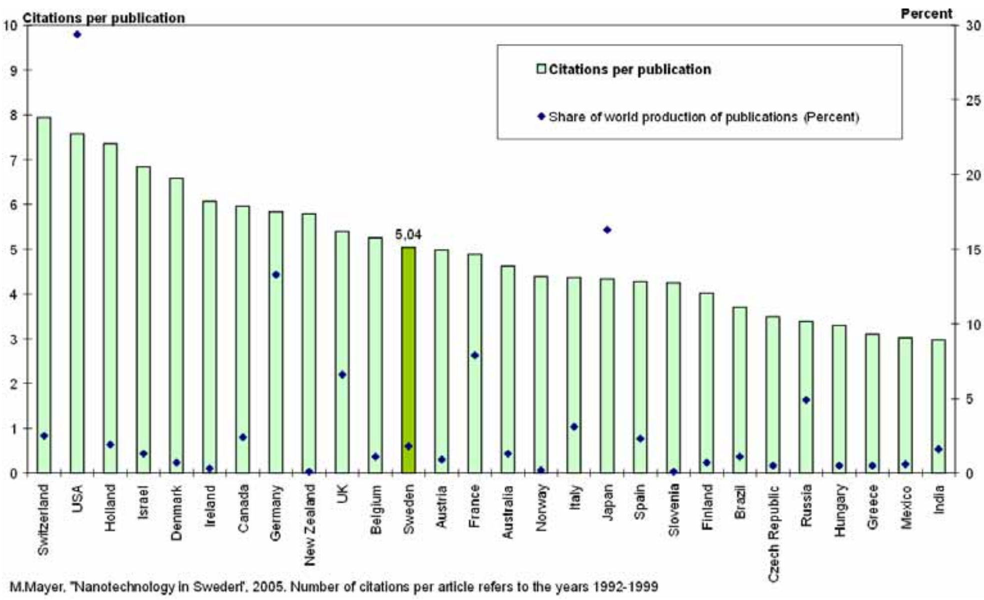


Figure 17. Number of citations per published article and number of published articles of the total world production for a selection of countries, 1992-2001 (number and percentage).



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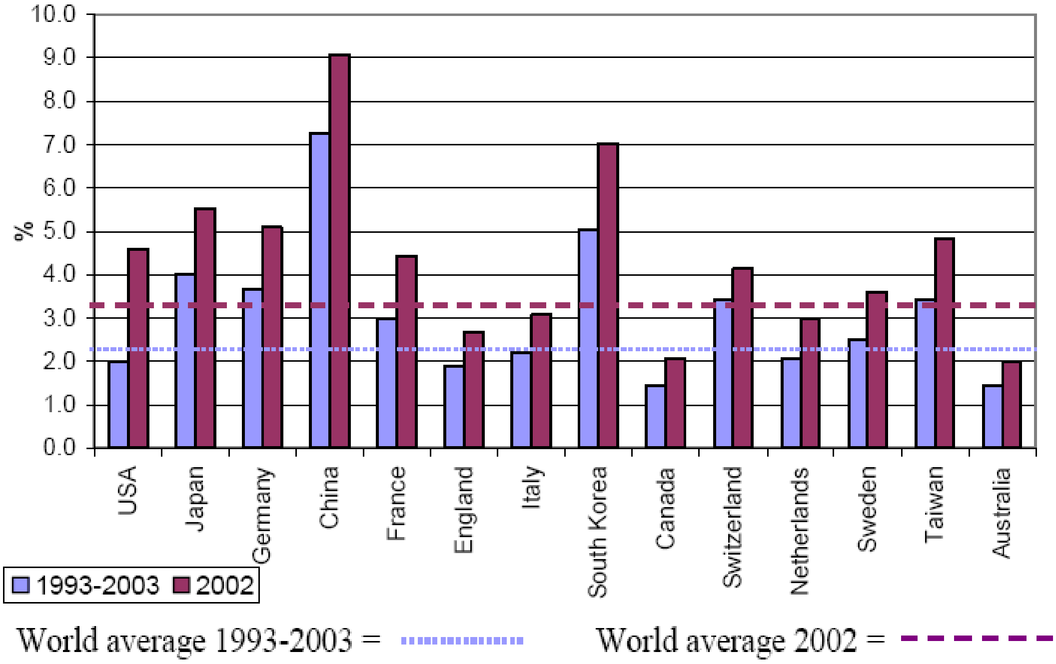
[180] Differences in the results relate to different timespans and differences in search methods.

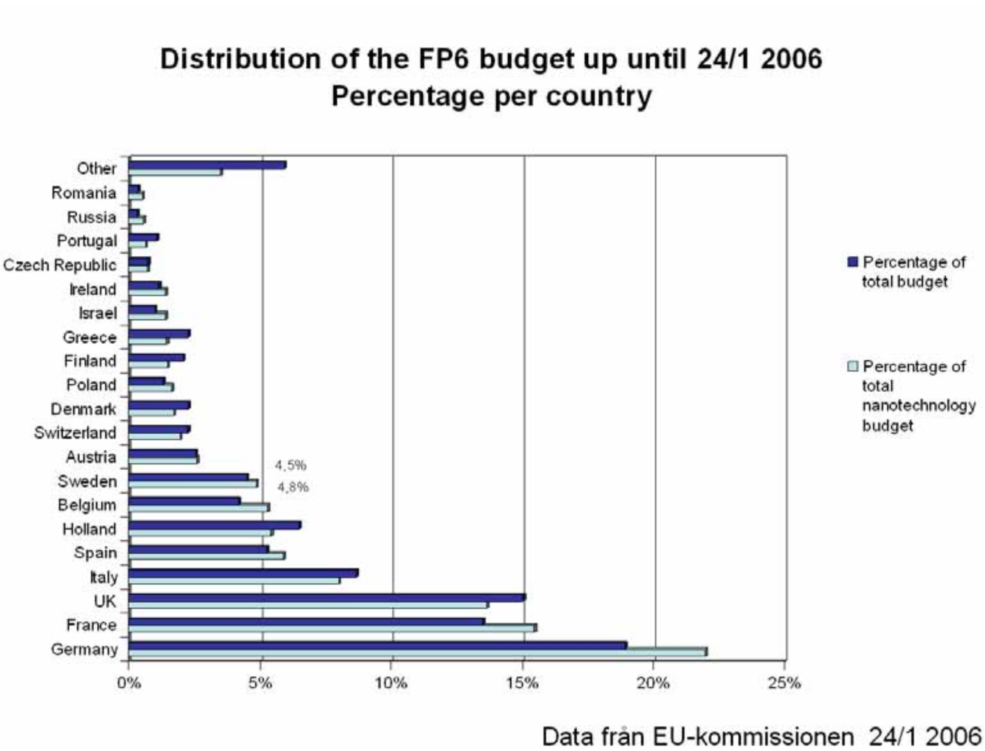
[181] Data commission and published by the Engineering and Physical Sciences Research Council (2005). http://www.epsrc.ac.uk/CMSWeb/Downloads/Other/NanotechnologyThemeday2005.doc#_Toc118883223

Figure 18. Percentage of the number of countries' publications which are nanotechnology-related, from Warris (2004).



Appendix G: Distribution of funding across participating countries within the Sixth Framework Programme

Figure 19. Distribution of funding within the Sixth Framework Programme.

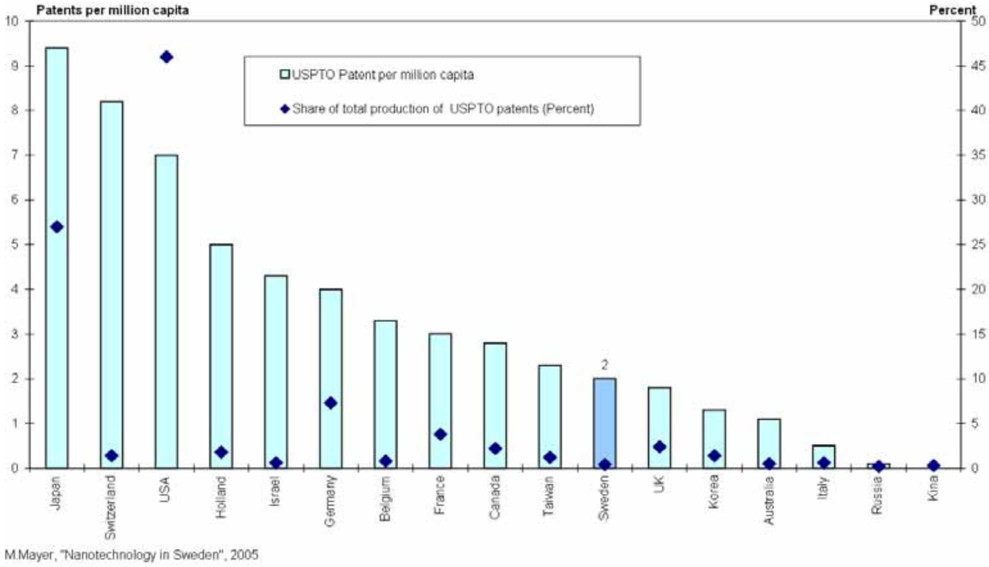


The distribution of competitive funding within the EU's framework for research and development can be seen as an indicator of scientific quality in research[182]. This covers far from just scientific research, but also technical developments involving companies. However, the research groups from universities dominate amongst the participants. Since 55% of the budget for the Sixth Framework Programme is contracted, around EU 566 million has been allocated nanotechnology-related projects. Of these, Sweden has received EUR 27 million. The following diagram shows the distribution of the EUR 566 million across the primary countries.

[182] However, participants' ability to write good applications and enter into successful collaborations affect the results, which does not directly bear upon the participant's scientific quality.

Appendix H: Patenting activity

Figure 20. Number of nanopatents (USPTO) plus number of patents of the total stock of nanopatents (USPTO), 1992-2001 (number and percentage).



VINNOVA´s publications

April 2008

See www.VINNOVA.se for more information

VINNOVA Analysis

VA 2008:

01 VINNOVAs Focus on Impact - A Joint Approach for Impact Logic Assessment, Monitoring, Evaluation and Impact Analysis

02 Svenskt deltagande i EU:s sjätte ramprogram för forskning och teknisk utveckling. *Only available as PDF*

03 Nanotechnology in Sweden - an Innovation System Approach to an Emerging Area. *For Swedish version see VA 2007:01*

VA 2007:

01 Nanoteknikens innovationssystem. *For English version see VA 2008:03*

02 Användningsdriven utveckling av IT i arbetslivet - Effektvärdering av tjugo års forskning och utveckling kring arbetslivets användning av IT. *For brief version in Swedish and English see VA 2007:03 and VA 2007:13*

03 Sammanfattning - Användningsdriven utveckling av IT i arbetslivet - Effektvärdering av tjugo års forskning och utveckling kring arbetslivets användning av IT. *Brief version of VA 2007:02, for brief version in English see VA 2007:13*

04 National and regional cluster profiles - Companies in biotechnology, pharmaceuticals and medical technology in Sweden 2004. *Only available as PDF. For Swedish version see VA 2005:02*

05 Nationella och regionala klusterprofiler - Företag inom fordonsindustrin i Sverige 2006

06 Behovsmotiverade forskningsprogram i sektoriella innovationssystem. *For English version see VA 2007:15*

07 Effekter av den svenske trafikksikker-hetsforskningen 1971-2004. *For brief version in Swedish and English see VA 2007:08 and VA 2007:09*

08 Sammanfattning - Effekter av den svenska trafiksäkerhetsforskningen 1971-2004. *Brief version of VA 2007:07, for brief version in English see VA 2007:09*

09 Summary - Effects of Swedish traffic safety research 1971-2004. *Brief version of VA 2007:10, for brief version in Swedish see VA 2007:07.*

10 Effects of Swedish traffic safety research 1971-2004. *For brief version in Swedish and English see VA 2007:08 och VA 2007:09*

11 Svenskt deltagande i sjätte ramprogrammet. *Only available as PDF*

12 The role of Industrial Research Institutes in the National Innovation System

13 Summary - User-driven development of IT in working life - Evaluating the effect of research and development on the use of information technology in working life. *Brief version of VA 2007:02, for brief version in Swedish see VA 2007:03*

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VINNOVA´s mission is to promote sustainable growth
by funding needs-driven research
and developing effective innovation systems

VERKET FÖR INNOVATIONSSYSTEM – SWEDISH GOVERNMENTAL AGENCY FOR INNOVATION SYSTEMS

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