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Policy for a New Industrial Revolution

– a Study of Nanotechnology in the USA

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Foreword

The aim of this report is to provide input to Vinnova (The Swedish Agency for Innovation Systems) and ongoing discussion on technology induced contributions to growth policy, in this case nanotechnology. This is a multidisciplinary area that is expected to create a significant impact on several industry segments including e.g. electronics, pharmaceuticals, energy and transportation. The technology will improve productivity, reduce costs and facilitate the creation of new products. Nanotechnology can be described as a new emerging industrial revolution. There are, however, also several societal issues associated with the development of nanotechnology such as health risks, regulating nanoparticle emissions, privacy implications and environmental concerns.

Because of the opportunities and policy challenges for nanotechnology research and development more than 30 countries have initiated nanotechnology programs for coordination of research, development and commercialization. One of the first programs was the US Nanotechnology Initiative.

The following report gives a general overview of the current initiatives and trends in the USA in the area of nanotechnology. It covers federal and state policies along with activities within the scientific community and private sector. The report has been written mainly by Martin Ahlgren. Helena Jonsson Franchi has written chapter 7 and 8 and John Wallon chapter 8.6.

Östersund, June 2005

Sture Öberg
Director General

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Summary

More than 30 countries have initiated national nanotechnology programs for coordination of multidisciplinary research, development and commercialization. A number of smaller countries such as Switzerland have also created nanotechnology initiatives. The US Nanotechnology Initiative started in 2000 has been a benchmark for several of the other programs. Sweden has not initiated a national initiative, but the European Commission has highlighted the need to increase European nanotechnology R&D funding. The national initiatives have been launched because nanotechnology creates particular policy challenges for funding multidisciplinary research, organizing research, commercialization, health- and environmental impact and education. National nanotechnology initiatives facilitate focus on the multidisciplinary dimension of nanotechnology.

Nanotechnology represents an emerging industrial revolution and is considered by many to be a disruptive technology with the potential to change, create or render obsolete entire business segments. The technology will have an impact on almost all industry segments covering e.g. electronics, pharmaceuticals, energy and transportation. Today there are also already several products on the market that use nanotechnology.

The US 21st Century Nanotechnology Research and Development Act became law in 2003 and institutionalized the federal commitment to nanotechnology. Funding for the federal US multiagency nanotechnology initiative (NNI) was about USD 1 billion in 2004 and accounted for about 8 percent of the National Science Foundation budget. State and local funding was about USD 400 million and venture capital funding about 300 million USD in 2003. About 29 federally funded centers of excellence for nanotechnology R&D and 70 nanoscience and technology centers have been initiated and more than 15 state initiatives have been launched. The leading states are California and Massachusetts. In December 2004 a new federal strategic plan for the NNI was launched. The new plan puts greater emphasis on technology transfer, cooperation with industry groups and societal aspects of nanotechnology.

This study of nanotechnology in the USA concludes that the following factors are important for Swedish growth policy:

- Taking appropriate action for Swedish science and technology policy requires the creation of a nanotechnology forum with members of government, academia and industry to promote dialogue and the development of nanotechnology as a first step. The forum could also provide a coordinated picture about Swedish nanotechnology to the Government. For successful long term nanotechnology R&D, a broad policy perspective is important.

- Public concern and fear of future nanotechnology applications also creates a need for information about nanotechnology for the general public. The importance of its societal implications has increased. Further dialogue

between the scientific community and policy makers is important for the future of nanotechnology, fears and concerns need to be discussed.

- Several organizations are concerned about the potential health and environmental impact of nanotechnology. Some companies also hesitate to launch nanoenabled products because of product liability may lead to litigation. Its possible future impact could be compared to Asbestos. Several policy challenges related to regulation of nanotechnology exist, such as the definition of workplace emission limits and international harmonization.
- Nanotechnology requires expensive R&D equipment, cost of manufacturing is high and the need for multi disciplinary teams adds additional costs. The allocation of capital for commercializing nanotechnology is more difficult than for other high-tech segments. Federal and state initiatives for nanotechnology are considered to be very important for successful commercialization of nanotechnology. Sweden needs further discussion about the government's role.
- Intellectual property is more important for nanotechnology commercialization than for a number of other high-tech areas. Technology in-licensing is driving the commercialization of nanotechnology. Specific firms focusing on technology in-licensing could facilitate the commercialization of university R&D.
- The need for interdisciplinary research and the issues associated with it is one of the most important challenges for the nanotechnology community in the US. The creation of cross-disciplinary networks, partnerships and multidisciplinary collaboration are important aspects of the US National Nanotechnology Initiative.

Sammanfattning

Fler än 30 länder har initierat nationella nanoteknologiprogram för koordinering av multidisciplinär forskning, utveckling och kommersialisering. Även flera mindre länder som t.ex. Schweiz har skapat nanoteknologiinitiativ. USA:s nanoteknologiinitiativ startade år 2000 och har fungerat som förebild för flera andra länders program. Sverige har inte initierat något nationellt initiativ men Europeiska kommissionen har lyft fram behovet av en ökad finansiering av europeisk nanoteknologiforskning. De nationella initiativen har lanserats för att nanoteknologi skapar särskilda policyutmaningar för finansiering av multidisciplinär forskning, organisation av forskning, kommersialisering, hälsa – och miljöpåverkan och utbildning. Ett specifikt nationellt nanoinitiativ underlättar också möjligheten att fokusera på den multidisciplinära dimensionen av nanoteknologi.

Nanoteknologi banar vägen för en framväxande industriell revolution och anses vara en teknologi som har potentialen att förändra, skapa eller slå ut hela affärsområden. Teknologin kommer att på något sätt påverka nästan alla industrisegment omfattande t.ex. elektronikindustrin, läkemedels-, energi- och transportsektorn. Redan idag finns också flera produkter på marknaden som är baserade på nanoteknologi.

USA:s 21st Century Nanotechnology Research and Development Act trädde i kraft under 2003 och lagen institutionaliserade det federala arbetet med nanoteknologi. Finansieringen av det federala myndighetsövergripande nanoteknologiinitiativet (NNI) omfattade ungefär 1 miljard USD år 2004. Finansieringen av nanoteknologi svarar för ca 8 procent av National Science Foundation totala budget. Den delstatliga och lokala finansieringen av nanoteknologi omfattade ca 400 miljoner USD år 2003 och riskkapitalfinansieringen var ca 300 miljoner USD. Ungefär 29 Centers of Excellence och 70 Nanoscience and Technology Centres för forskning och utveckling inom nanoteknologi har fått finansieringen från NNI. De ledande delstaterna är Kalifornien och Massachusetts. I december 2004 lanserades en ny strategisk plan för NNI. Den nya planen skapar ökat fokus på teknologiöverföring, samverkan med industrigrupper och samhälleliga aspekter av nanoteknologi.

Denna studie av nanoteknologi i USA drar slutsatsen att följande faktorer är viktiga för den svenska tillväxtpolitiken:

- För att lyfta upp området nanoteknologi på agendan och underlätta en dialog mellan olika aktörer samt driva på utvecklingen är ett första möjligt steg att skapa ett svenskt nanoteknologiforum med representanter från myndigheter, universitet och näringsliv. Ett nanoteknologiforum kan också erbjuda en samlad bild av svenska initiativ och satsningar inom nanoteknologi till regeringen. För en långsiktigt framgångsrik forskning och utvecklingen inom nanoteknologi är ett brett policyperspektiv av vikt.

- Allmänhetens frågor och oro runt framtida tillämpningar av nanoteknologi skapar ett behov av information om nanoteknologi även till allmänheten. De samhälliga aspekterna har i USA med tiden också fått en allt högre prioritet. Ytterligare dialog mellan forskningssamhället och politiken är av vikt för den framtida utvecklingen av området nanoteknologi. Risker och olika frågeställningar måste diskuteras öppet.
- Många organisationer anser att det finns potentiella hälso- och miljörisker med nanoteknologi. Vissa företag tvekar också runt lanseringen av nanoteknologibaserade produkter på grund av produktansvaret som kan leda till stämningar. Utvecklingen skulle eventuellt kunna likna den för asbest. Det finns flera policyutmaningar relaterade till reglering av nanoteknologi så som definition av gränsvärden för arbetsmiljö och internationell harmonisering.
- Inträdesbarriär för kommersialisering av nanoteknologi är hög. Teknologin kräver dyr utrustning för FoU och kostnaden för tillverkning är hög. Dessutom leder behovet av multidisciplinära team till ytterligare kostnader. Det är svårare att allokera kapital till kommersialisering av nanoteknologin än till andra högteknologiområden. I USA anses federala och delstatliga initiativ vara viktiga för att kunna skapa en framgångsrik kommersialisering av nanoteknologi. I Sverige är det viktigt att diskutera de offentliga aktörernas roll i utvecklingen av nanoteknologi
- Hantering av immaterialrättigheter är viktigare för kommersialisering av nanoteknologi än för flera andra högteknologiområden. En viktig drivkraft för kommersialiseringen av nanoteknologi är att licensiera in teknologi från universitet. Specifika företag som arbetar med att licensiera in teknologi från universitet kan underlätta kommersialiseringen av FoU vid universiteten.
- En av de viktigaste utmaningarna för utvecklingen av nanoteknologi i USA är hanteringen av multidisciplinär forskning. Skapandet av interdisciplinära nätverk och partnerskap samt multidisciplinära samarbeten är också en viktig aspekt av det nationella nanoinitiativet i USA.

1 Introduction

Nanotechnology is considered to be a disruptive technology with the potential to alter, create or render obsolete entire business segments. Disruptive technologies can often shift the global balance of economic and military power. Nanotechnology will have a significant impact on several industry segments including e.g. electronics, pharmaceuticals, energy and transportation. The possible widespread impact arising from nanotechnology represents a new emerging industrial revolution. Solutions based on nanotechnology are expected to improve productivity, reduce costs and facilitate the creation of new products. In some cases represents nanotechnology also an evolution of current technology areas. The definition and scope of nanotechnology is an issue.

From a policy perspective is nanotechnology a tool for economic and business development in a way similar to information technology. Both nanotechnology and information technology are multipurpose technologies. The possible impact of nanotechnology can be compared with earlier shifts in major technology such as electrification and digitalization in society. The US National Science Foundation has stated that "the current pace of revolutionary discoveries in nanoscience and technology is expected to accelerate greatly in the next decade. This will have profound implications on existing technologies and could result in the development of completely new technologies, improvements in health, the conservation of materials and energy, and a sustainable environment" (NSF 2004A).

Nanotechnology is an important area for Swedish growth policy because of its implications for Sweden in several different ways. The multidisciplinary nature of nanotechnology creates policy challenges for e.g. science and technology, education, internationalization, commercialization of research and development, energy, the environment and privacy.

This report provides a broad overview of developments within nanotechnology in the USA including the major federal policy initiatives, but excluding the defense initiatives and some examples of state policy. An overview of industry, commercialization and some other specific policy issues is also provided. The report also describes some specific implications for Sweden based on initiatives and trends in the USA.

The objective of this study is to provide input to Vinnova (The Swedish Agency for Innovation Systems) and for the formulation of policy in Sweden. This study is based on different kinds of reports, conferences and interviews with members of academia, industry and policy thinkers. The report has been written mainly by Martin Ahlgren. Helena Jonsson Franchi has written chapter 7 and 8 and John Wallon chapter 8.6.

2 Background

2.1 Definitions

Nano is a prefix meaning one billionth and comes from the Greek word nanos. A nanometer, nm, is a millionth of a millimeter and a typical atom is about 0.1 nm in diameter. For comparison, a human hair is about 100 000 nanometers thick.

Nanoscience is the study of atoms, molecules, and objects whose size on the nanometer scale is between 1 and 100 nanometers according to the National Nanotechnology Initiative (NNI). One fundamental observation is that physics is different on the nanometer scale. Important properties including electrical, optical and physical can be controlled at the nanoscale. At the nanoscale these properties can be very different from the properties of the same materials at a larger scale (NNI 2003A).

Nanotechnology provides the capacity to control or manipulate materials on the atomic scale and create structures that have new properties and functions because of their size, shape or composition and can be considered as atomic “handicrafts”. Nanotechnology is the combination of the nano dimension and the new properties at the nanoscale, the area represents research and development (R&D) across a number of disciplines such as biology, chemistry and physics. Because of its broad areas of application, it is often more accurate to talk about nanotechnologies than nanotechnology.

It is difficult to define the scope of nanotechnology in more detail (CCST 2004A). Several different approaches to nanotechnology can also be used: “nanotechnology is both old and new, top down and bottom up” according to California Council of Science and Technology (CCST 2004A). The top-down approach is based on continuing to shrink today’s devices and the bottom-up approach is based on self-assembly of atoms and molecules into complex systems (BASIC 2004A).

The most liberal use of nanotechnology encompasses all technology that operates below 1 000 nanometers. The name small tech is also sometimes used to refer to a broader technology segment. Within the nanotechnology community in the US there is an ongoing discussion about the scope of nanotechnology (UCB 2004A, NSTI 2004B). The approach to nanotechnology is an important issue in the formulation of policy. Several large businesses view nanotechnology as the next logical development of existing trends in their industry (CCST 2004A). But different nanotechnology segments can also be linked together by some common principles.

The US National Science and Technology Council describe the possibilities of nanotechnology as: “The emerging field of nanoscience and nanoengineering are leading to unprecedented understanding and control over the fundamental building blocks of all physical things. This is likely to change the way almost everything – from vaccines to computers to automobile tires to objects not yet imagined – is designed and made.” (NSTC 1999A)

2.2 History

Nanoscience has become an important field because of scientific achievements during the last 20 years, the term Nanotechnology was first introduced in 1974 (RAND 1995A). But a speech with the title “There's Plenty of Room at the Bottom” by Nobel Laureate (Physics 1965) Richard Feynman at the California Institute of Technology (CalTech) in 1959 is also often mentioned as a starting point for the evolution of nanoscience. The discovery of the quantum dot in 1980 by Louis Brus of Columbia University was an important early step in the development of nanotechnology. In the early 1980s the scanning tunneling microscope (STM) was invented by IBM-Zurich in Switzerland, the researchers received a Nobel Prize in physics in 1986 for the invention. The scanning tunneling microscope was the first instrument that was able to see atoms. A few years later the Atomic Force Microscope was invented expanding the capabilities and types of materials that could be investigated.

In 1985 Jim Heath and Richard Smalley discovered a new form of carbon molecule, the buckyball with 60 carbon atoms linked together. The researchers won the Nobel Prize in Chemistry in 1996. Nanotechnology was popularized in Engines of Creation by Eric Drexler, published in 1986. The book is an important document for public discussion about the vision of nanotechnology. Drexler is the chairman of the nanotechnology think-tank, the Foresight Institute. The NEC researcher Sumio Iiljma discovered the carbon nanotube in 1991, a material 100 times stronger than steel with only one-sixth of its weight. In 1999 MIT researcher Paul Alivisatos invented the nanocrystal shape control (NTSC 1999A).

Recently, a number of factors have converged to act as catalysts for the development of more advanced and complex nanotechnology products. Analytical instruments have been significantly improved in recent years. At the same time governments have made research and development of nanotechnology a priority. In 2000 President Clinton launched the National Nanotechnology Initiative and during the last few years interest in nanotechnology from the investment community and media has also increase dramatically. The number of nanotechnology related articles in the popular press has more than doubled between 2002 and 2004 (Lux 2004A).

The definition of nanotechnology is no longer a purely academic concern as more investors become attracted to anything that carries the nanotech label. Merrill Lynch created a nanotechnology stock index in 2004 including a list of about 25 publicly traded companies as e.g. Nanophase, Nanogen and Harris & Harris. The state of nanotechnology today represents a paradox. New products using nanotechnology have been developed and are available. On the other hand understanding of the underlying properties of nanoscale structures is still at a basic level (NNI 2003A). This situation adds to the complexity of understanding the status and trends of the nanotechnology segment.

2.3 Applications

Today there are already a number of products on the market that use nanotechnology such as computer chips from Intel that have features 90 nanometer or smaller and scratch proof paint for cars. Nanoscale materials are also being utilized in a variety of basic applications, such as sunscreens, water repellant fabrics, carbon fiber tennis rackets and antistatic materials. Applications of nanotechnology could significantly improve the performance, cost and functionality of existing products and enable the development of products previously not possible. Nanotechnology will also enable products to be improved. Over the long term it is probable that nearly every component of a personal computer, mobile phone, television and network will include some form of nanotechnology.

At the nanoscale, variations in color can be achieved by varying the size of a nanostructure. This could improve the performance of products, such as displays, solid state lighting and solar cells, while reducing their cost and manufacturing complexity (Nanosys 2004A). When one atom at a time can be altered it may also be possible to repair damaged cells. Nanomedical devices implanted in humans will enable new solutions for disease prevention, diagnosis, control, new generations of medical implants and chip-sized home diagnostic devices (NSTC 1999A, CCST 2004A).

The National Nanotechnology Initiative has funded recent achievements in nanotechnology such as nanotube-based fibers requiring three times the energy to break the strongest silk fibers and 15 times that of Kevlar fiber. Another example is a field demonstration that iron nanoparticles can remove up to 96 percent of a major contaminant from groundwater at an industrial site (NNI 2003A). Pollution reversal through nanotechnology using the concept of a nano robot or NEMS (nanoelectromechanical systems) capable of modifying physical material at the molecular level is a significant long term opportunity (Drexler 1986). Universities such as the University of Southern California’s (USC) Laboratory for Molecular Robotics carries out research within NEMS. Nanotechnology will also enable building materials from atoms “bottom-up” requiring less material and reducing pollution. To illustrate the broad applicability of nanotechnology, some different segments are listed in Table 1.

Table 1. Some nanotechnology segments.

Electronics	**Healthcare**	**Energy & Environment**
Nanoelectronics	Nanobiotechnology	Nano solar cells
Nanophotonics	Nanomedicine	Hydrogen storage
Molecular electronics	Bio-Defense	Nano fuel cells
Nanodisplays	Nanotoxicology	Pollution reversal
Nanosecurity	Nanorobots	
Molecular manufacturing		

2.4 Industry Dynamics

Nanotechnology is interdisciplinary and is expected to have an impact on almost all branches of industry. “This impact will surpass the combined impact of both biotech and information technology" according to Richard Russell, the White House's Senior Director for Technology. Existing industries will have to undergo radical transformation to survive such changes. A dramatic structural revolution that will change products and manufacturing is driven by nanotechnology, it is a “new industrial revolution” according to the California Council on Science and Technology (CCST 2004A). Nanotechnology represents a threat to a number of current business segments. The following exemplifies the impact: “Toshiba could see its USD 1.8 billion (United States Dollar) in annual flash memory sales displaced by nano-enabled alternatives, and nano-fabric treatments could erode the 29 percent of revenue that Procter&Gamble earns from fabric and home care products” according to Lux Research (Lux 2004B). The American National Science Foundation estimates that by the year 2015 the total global market for goods and services within nanotechnology will be worth around USD 1 000 million. The potential for different segments is outlined in Table 2. The revenue growth for nanotechnology will require about 2 million nanotechnology workers in the US (NSF 2003A). Many examples of nanotechnology can already be found in industry today but most of the threats and possibilities lie in the future. The US National Research Council states that “nanoscale science and technology will no doubt emerge as one of the major drivers of economic growth in the first part of the new millennium” (NAS 2002A). Nanotechnology will definitively increase productivity and is expected to create productivity impacts similar to those associated with information technology (CA 2004A).

Table 2. Potential nanotechnology market for different segments.

Sector	**Size 2015** (billion USD)	**Products, e.g.**
Materials	340	Nanostructured catalysts
Electronics	300	Low cost, high performance memory
Pharmaceuticals	180	More efficient drugs
Chemical Manufacture	100	Custom materials
Aerospace	70	Nanomaterials
Sustainability	45	Low cost solar cells
Improved Healthcare	30	Sensors for cancer detection
Tools	20	Atomic modelling and analysis
Total	**1 085**	

Source: NSF 2004A

Nanotechnology is also a new opportunity for states to improve their high-technology position and long term growth. The states invested about USD 400 million into nanotechnology research and commercialization in 2004. The problems within the information technology sector including e.g. off-shoring is of importance for the launch of nanotechnology initiatives. Nanotechnology represents a new paradigm and a new possibility for the creation of successful high technology industries (BASIC 2004A). The nanotechnology revolution is new and the future dominance of any state in the US is not assured.

Nanotechnology initiatives are important for national and regional economic development. Several initiatives have been launched in the San Francisco Bay Area during the last few years to support the development and commercialization of nanotechnology (CCST 2004A).

3 Swedish Nanotechnology R&D

This chapter provides a brief overview of some different Swedish initiatives within policy, academia and industry to promote nanotechnology research, development and commercialization:

Research & Development Funding

- The Royal Swedish Academy of Engineering Sciences (IVA) has previously established a committee on nanotechnology with representatives from academia and industry with the objective of promoting Integrated Projects and Networks of Excellence. IVA estimates total Swedish non defense funding of nanotechnology R&D at SEK 70–80 million, in addition to annual defense funding about SEK 20 million (IVA 2004A).
- The Swedish Research Council provides funding to several nanotechnology related research projects, but nanotechnology is not one of the multidisciplinary research topics for the organization. The Council's annual funding of nanoscience is approximately SEK 20 million. In 2004 the Council also arranged a seminar on the ethical aspects of nanotechnology.
- The Swedish Foundation for Strategic Research's (SSF) annual funding of nanoscience and nanotechnology is about SEK 25 million. The Foundation is managing e.g. the program Bio-X as well as funding for some different nano-projects.
- The Knowledge Foundation (KK-Stiftelsen) initiated in 2004 a two year program to provide firms with know-how for the development of products based on micro- and nanosystems technology, the funding is SEK 15 million. The program is coordinated by Mälardalen University.
- The Swedish Agency of Innovation Systems (Vinnova) has the programs Micro- and Nano-electronics, BioNanoIT and Designed Materials with a focus on nanotechnology (GU 2002A).
- A Swedish five year defense program for nanotechnology was initiated in 2003 with funding of SEK 100 million. The program is managed by the Swedish Defense Research Agency (FOI) but other partners are also working in the program. The program covers seven different projects (FOI 2005A).
- The Knut och Alice Wallenberg Foundation is also funding nanotechnology research in Sweden at e.g. Lund University Nanometer Structure Consortium.
- The NanoNord group at the Nordisk Innovations Center prepared during 2003 a prestudy for a Nordic nanotechnology program. The group published a report in March 2004 including a recommendation for a Nordic Nanotechnology Program with an initial annual funding of NOK 15–20 million and duration of 3–5 years (NanoNord 2004A).

R&D and Education

- Examples of Swedish research centers with nanotechnology research are The Ångström Laboratory, KTH/KI Micro Technology Center, Lund University Nanometer Structure Consortium and the Department for Microtechnology and Nanoscience at Chalmers University of Technology.
- A Master of Science program in Technical Nanoscience was initiated at Lund Institute of Technology in 2003. The program is multidisciplinary and managed in collaboration with e.g. the school of medicine.
- ABB initiated an R&D program within nanotechnology in 2000. The program covers areas of importance for ABB such as electronics, nano-coatings and nano-sensors. Other firms with nanotechnology R&D are e.g. Obducat, Sandvik, Silex Microsystems and Åmic.
- Other examples of commercialization of Swedish nanotechnology related R&D exist such as the creation of the firm Nanoxis based on research at Chalmers University of Technology and QuMat Technologies based on research at Lund University.

Commercialization and Promotion

- To facilitate the commercialization of university R&D in nanotechnology Pronano was established in 2002. Pronano received its major funding from Region Skåne and the City of Malmö. The institute has collaborated with about ten large Swedish firms but the funding for the institute was only secured until the beginning of 2005. Pronano is no longer in operation.
- Some organizations with the objective of promoting nanotechnology have been created such as Center for Nano Science and Technology (CeNano) at Linköping Institute of Technology (LiTH). The mission of CeNano is to strengthen and support competence within nanoscience and nanotechnology at LiTH. NanoNordic and Nanoforum (a European Nanotechnology Gateway) are fora for providing information to the nanotechnology community. Nanoforum is funded by the European Union. The European NanoBusiness Association is a forum for discussion and promotion of education and networking in the European Union.
- In 2000 the Swedish Nano Network was established with funding. The network with most of the members from academia has presented a strategy document for a Swedish initiative in nanotechnology. Today the network does not provide active support for nanotechnology. The Nano Network estimates annual Swedish external nanotechnology funding at SEK 45 million.
- The British Embassies in Sweden and Denmark, the British Council and UK Trade and Investment arranged seminars with local Swedish partners focusing on nanoscience and nanotechnologies in February 2005 at Lund University.

- Nanotechnology in Northern Europe – congress and exhibition is arranged in April 2005. The congress is a forum for scientists and companies to discuss research, development and applications of nanotechnology. The focus is on Mobile Devices, Paper and Printed Electronics and Nanotechnology & Environment.
- Nanotec Forum 2005 – conference and exhibition is arranged in June 2005. Leading scientists and industrial researchers will present their work, covering a wide spectrum of different topics and applications. This year special attention is paid to different aspects of commercialization.

Policy

- In 2002 the group Future for Swedish Industry (The Bennet-Johnsson Group) presented a policy document with proposals for funding different technology segments including nanotechnology. The group proposed a five year national R&D initiative for nanotechnology at an annual cost of SEK 55 million (FI 2002A).
- A number of motions to the Swedish Parliament such as 2002/03:N245 and 2002/03:N237 include proposals for the introduction of some kind of Swedish nanotechnology initiative, but the Chamber voted against the proposals (SP 2005A). The support for particular technology related initiatives was not enough.
- The European Commission adopted the Communication "Towards a European Strategy for Nanotechnology" in May 2004. The objective of the document is to: "bring the discussion on nanoscience and nanotechnology to an institutional level and propose an integrated and responsible strategy for Europe". The document highlights the need to increase European nanotechnology R&D funding. The Council of the European Union discussed the strategy in a session in September 2004. In November 2004 the Single Market, Production and Consumption section of the European Economic and Social Committee adopted a positive opinion on the strategy. In spring 2005 an Action Plan on nanotechnology will be published (Cordis 2005A).
- The Swedish Government submitted the research policy bill Research for a Better Life 2004/05:80 (Prop 2005A) to the Swedish parliament in March 2005. The bill describes that nanoscience and nanotechnology have a large industrial potential and it exists a great need for competence about different aspects of nanotechnology. There is no clear coordinated picture about the nanoscience research in Sweden and a lack of information about the industry R&D within nanotechnology. The bill indicates that there is a need for further information about the area (Prop 2005A, page 78).

4 Federal Initiatives

4.1 International Overview

Governments, corporations and venture capital firms spent about USD 8 billion worldwide on nanotechnology research and development in 2004 (Lux 2004A). The worldwide government nanotechnology R&D has increased approximately seven times in the last six years to about USD 3 billion in 2003 (NSF 2003A). At least 30 countries have initiated national nanotechnology R&D programs including several smaller countries such as Switzerland and the Netherlands. Several states including California and New York also provide significant funding for nanotechnology R&D. The state of New York will spend more on nanotechnology R&D in 2004 than China, India and Israel combined.

Table 3. Worldwide government nanotechnology R&D funding.

Region	1997	1998	1999	2000	2001	2002	2003
USA	116	190	255	270	465	697	862
Western Europé	126	151	179	200	225	400	650
Japan	120	135	157	245	465	720	800
Other	70	83	96	110	380	550	800
Total (million USD)	**432**	**559**	**687**	**825**	**1 535**	**2 367**	**3 112**

Source: NSF 2003A

Japan established a nanotechnology program in 2000 soon after the US National Nanotechnology Initiative (NNI) was launched; the level of funding was increased in 2001. The efforts in Japan to coordinate policies to support commercialization are an important part of the initiative. Because of the focus on product development in Japan, Japanese industry can be earlier than the US on the market with some nanotechnology products. US nanotechnology funding is more focused on fundamental building blocks than the Japanese programs. But increased focus on commercialization is a part of the new strategic plan for the NNI launched at the end of 2004.

Table 4. Ranking of regions for different application areas.

	Medical	Materials	Chemicals	Electronics	Manufacturing
Rank 1	USA (west)	USA (west)	Germany	Japan	USA (west)
Rank 2	USA (east)	USA (east)	USA (west)	USA (west)	USA (east)
Rank 3	UK	Japan	USA (east)	USA (east)	Japan
Rank 4	Germany	Germany	UK	Korea	Germany

Source: 3i 2002A

The venture capital firm 3i carried out a regional ranking of regions for different application areas of nanotechnology in 2002. The survey (3i 2002A) indicates that western USA is the leading region for nanotechnology, with the exception of Germany's leading position in the chemicals segment and Japan's number one ranking in electronics. The survey focused on regions with the most sophisticated nanotechnology developments.

4.2 The Forming of New Science and Technology Initiatives

Several different groups are involved in forming new science and technology initiatives in the US. The Office of Science and Technology Policy (OSTP) is a part of the Executive Office of the President and provides coordination and direction over the agencies. The US National Science and Technology Council (NSTC) was created by President Clinton in 1993 for coordinating research and development (R&D) initiatives and has defined six national priorities that reflect US scientific, military, social, economic and political values and goals. The President's Council of Advisors on Science and Technology (PCAST) has a Nanotechnology Technical Advisory Group that also has a role in the policy formulation process. The Office of Management and Budget (OMB) prepares the budget and has an important role in coordination. Several different industry groups are also important and have significant influence. Congress shapes and provides funding for all federal programs and is quite independent of the President (TPI 2003A). The Committee on Science in the House of Representatives is another important group for science and technology initiatives. There are in total about 10 000 staff members serving the Congress. The Congress is also served by e.g. hearings, the Congressional Research Service and the National Academy of Science.

The process for proposing new science and technology policies is relatively decentralized compared to several other countries, but new policies must be reviewed by OSTP, OMB and the Congress. The National Nanotechnology Initiative (NNI) was formed as a bottom-up initiative. The scientific community argued for federal funding and persuaded some policy entrepreneurs within the White House to develop a plan. The first attempts for coordination of federal nanoscale science and technology began in 1996. President Clinton's deputy assistant for technology and economic policy, Tomas Kalil, established interest in a nanotechnology initiative within the White House. The initiative model was considered to be a successful approach for obtaining high-level support and interest (ST 2005A).

The semiconductor industry with its important political influence gave strong support to the creation of a nanotechnology initiative and helped to establish support in Congress. General support in the Congress for science and technology programs that promise major breakthroughs also facilitated the process. The NNI focus on university research also facilitated the support of the Republicans, who do not generally give support to industry programs (TPI 2003A). Generic programs for federal support of industry R&D such as the Advanced Technology Program[1] (ATP) are not supported by the current White House administration. But specific programs of importance for influential industry groups have been established in some cases.

The multiagency program NITRD[2] has defined 16 grand challenges that are expected to yield significant breakthroughs of importance to mankind as a priority approach for IT R&D. One of the 16 Grand Challenges is Nanoscale Science and Technology. The Nano Grand Challenge contributes to the objectives of the national priorities Leadership in Science and Technology, National and Homeland Security, Health and Environment and Economic Prosperity (NITRD 2004A).

[1] *Advanced Technology Program, a federal program for commercialization, http://www.atp.nist.gov*
[2] *Networking Information Technology Research & Development (NITRD)*

Table 5. NSTC Grand Challenges.

Grand Challenges/ National Priorities	Leadership in Science, Technology	Nation. & Homeland Security	Health & Environment	Economic Prosperity	A Well Educated Populace	Vibrant Civil Society
Knowledge Environments for Science and Engineering	■	■	■		■	■
Clean Energy Production, Improved Combustion	■	■	■	■		
High Confidence Infrastructure Control Systems		■		■		■
Improved Patient Safety and Health Quality			■	■		
Informed Strategic Planning for Climate Change	■		■	■	■	
Nanoscale Science and Technology	■	■	■	■		
Predicting Pathways and Health Effects Polutants	■	■	■	■		
Real-Time Detection to Natural or Man-Made Threats		■	■	■		
Safer, More Secure,…Multi-Modal Transportation System			■	■		
Consequences of … Participation in a Digital Society	■	■	■	■	■	■
Collaborative Intelligence: Integrating Humans …	■	■	■	■	■	■
Generating Insights From Information at Your Fingertips	■	■	■	■		
Managing Knowledge Intensive Dynamic Systems		■	■	■		
Rapidily Acquiring Profiency in Natural Languages	■	■			■	■
SimUniverse: Learning by Exploring	■		■	■	■	
Virtual Lifetime Tutor for All				■	■	■

Source: NITRD 2004A

(Black squares indicating a relation between a Grand Challenge and a National Priority)

The Grand Challenge model shows a relationship between the science and technology initiatives and the policy objectives. The Grand Challenges was formulated by a group of government program managers in 2003 who participate in the government wide NITRD program for information technology R&D. The increased focus on Homeland Security since 2001 is also of importance for nanotechnology. "In science and technology, few things could actually be bigger than nanotechnology in terms of its potential to revolutionize scientific and engineering research, improve human health and bolster our economy" according to Congressman Boehlert, chairman of the House Science Committee (BASIC 2004A).

4.3 The National Nanotechnology Initiative

The US National Nanotechnology Initiative was established in 2001 as an inter-agency and multidisciplinary initiative. The number of participating agencies has grown from 6 to 22, but only ten are funding the NNI. In December 2003 a four year USD 3.7 billion act (21st Century Nanotechnology Research and Development Act) was approved to continue the United States National Nanotechnology Initiative. During 2004 the US government invested USD 961 million in the NNI; this represents an increase of 11 percent since 2003. The funding request for 2005 was USD 982 million a 2 percent increase from 2004 (NSTC 2004A). But the appropriation for 2005 is less than the authorized amount in the 21st Century Nanotechnology R&D Act. The total federal R&D budget for 2005 is USD 132 billion, 53 percent is allocated to the Department of Defense, 22 percent to the Department of Health and Human Services, 8 percent to the National Aeronautics & Space Administration and 7 percent to the Department of Energy (AAAS 2004B).

Table 6. NNI budget by department or agency.

Federal Department or Agency	2000	2001	2002	2003	2004	2005
National Science Foundation	97	150	204	221	254	305
Department of Defense	70	125	224	322	315	276
Department of Energy	58	88	89	134	203	211
National Institute of Health	32	40	59	78	80	89
NIST	8	33	77	64	63	53
NASA	5	22	35	36	37	35
Energy Protection Agency		6	6	5	5	5
Department of Homeland Security			2	1	1	1
Department of Agriculture		1,5		0	1	5
Department of Justice		1,4	1	1	2	2
Total (million USD)	**270**	**467**	**697**	**862**	**961**	**982**

Source: NSTC 2004A

The NNI program represents about 0.8 percent of the total federal R&D budget, but the National Science Foundation (NSF) part of the NNI is approximately 8 percent of the total NSF budget. Nanotechnology is the Bush Administration's highest science and technology priority in the 2004 fiscal year. NNI and Homeland Security R&D have been the fastest growing R&D programs. Nanotechnology will be the largest government-funded basic science program since the Space Program, exceeding even the Human Genome Project (NNI 2003A). The NNI accounts for approximately 4 percent of federal funded basic research. The multiagency networking and IT R&D program NITRD with a funding of more than USD 2 billion in 2004 is larger than the NNI but it includes more than primarily basic science. The R&D funding for Department of Homeland in 2005 is USD 1.2 billion. The NNI has significantly increased funding for the physical sciences. The program has also contributed to an increased interest in nanotechnology within the universities (RAND 2005C).

About two-thirds of NNI funding supports university-based research, about 25 percent government-owned laboratories and about 10 percent for private sector entities. The NNI funds more than 70 nanoscience and technology centers and about 29 centers of excellence (NSTC 2004A). Universities in California, New York and Massachusetts have received most national nanotechnology funding including more than USD 370 million from 2001 to 2003 (Lux 2004A).

The NNI is an interagency initiative covering coordination of funding, research and infrastructure development activities at the individual agencies. The NNI is managed within the framework of the National Science and Technology Council. The NSTC Subcommittee on Nanoscale Science, Engineering & Technology (NSET) prepares the strategic plans for the NNI, coordinates the plans, budgets and programs for the NNI. The National Nanotechnology Coordinating Office (NNCO) serves as the secretariat for the NNI program. The NNCO serves as the point of contact for e.g. government organizations, industry and academia. Outreach in different ways is an important part of the NNI. The NNI has a key role in the creation of cross-disciplinary networks and partnerships. The goals of the NNI are to conduct R&D, develop a skilled workforce, and better understand the social, ethical, health and environment implications of nanotechnology. The goal for the NNI is also to facilitate technology transfer and commercialization (NNI 2003A).

4.4 The Initial Funding Strategy

The NNI funding strategy is based on five modes of investment. The **first investment mode** supports a balanced investment in fundamental research across science and engineering. Specific areas of focus are material structures, nano-biosystems, nanoscale devices, modeling and simulation. A better understanding of the underlying properties of nanotechnology is important for the NNI. The time for transforming basic nanotechnology research into a commercial product is more than five or even ten years (NNI 2003A).

The **second mode** focuses on nine Grand Challenges covering specific R&D areas that are more directly related to applications of nanotechnology. Several different sets of Grand Challenges exist because it is a concept used by several programs. Previously the NITRD Grand Challenges was mentioned. The NNI nanotechnology Grand Challenge areas aim to efficiently accelerate the transformation of science into innovative technologies. The NSTC NSET has played a key role in the definition of the nanotechnology Grand Challenges.

The nanotechnology Grand Challenges are:

1. Nanostructured Materials by Design
2. Manufacturing at the Nanoscale
3. Chemical-Biological-Radiological-Explosive Detection and Protection
4. Nanoscale Instrumentation and Metrology
5. Nano-Electronics, -Photonics, and -Magnetics.
6. Healthcare, Therapeutics and Diagnostics
7. Efficient Energy Conversion and Storage
8. Microcrafts and Robotics
9. Nanoscale Processes and Environmental Improvements

The **third mode** of investment supports centers of excellence that conduct research. The centers conduct broad multidisciplinary research programs. The centers also promote education of researchers and training for industry. Six NSF centers were funded in 2001 and six more centers were funded in 2004.

Table 7. NNI Centers of Excellence.

NSF - NNI Centers of Excellence	**Institution**
Nanoscale Systems in IT	Cornell University
Nanoscience in Biological & Environmental Eng.	Rice University
Integrated Nanopattering & Detection	Northwestern University
Electronic Transport in Molecular Nanostructures	Columbia University
Nanoscale Systems and their Device Applications	Harvard University
Directed Assembly of Nanostructures	Rensselaer Polytechnic Inst.
Nanobiotechnology Science & Technology Center	Cornell University
Center of Integrated Nanomechanical Systems	UC Berkeley
Center for High Rate Nanomanufactoring	Northeastern University
Center for Affordable Nanoengineering of Polymer	Ohio State University
Center on Molecular Function at the Nano/Bio Interface	University of Pennsylvania
Center for Probing the Nanoscale	Stanford University
DOD - NNI Centers of Excellence	
Institute for Soldier Nanotechnology	Massachusetts Inst. Tech.
Center for Nanoscience Innovation for Defense	UC Santa Barbara
Nanoscience Institute	Naval Research Laboratory
NASA - NNI Centers of Excellence	
Institute for Cell Mimetic Space Exploration	UC Los Angeles
Inst. for Intelligent Bio-Nanomaterials	Texas A&M
Bio-Inspection, Multifunctional Nanocomposites	Princeton University
Institute for Nanoelectronics & Computing	Purdue University

Source: NNI 2003A, NSF 2004A

The **fourth investment mode** funds the development of infrastructure, instrumentation, standards, computational capabilities and other research tools necessary for nanoscale R&D. This funding has been used to support the Nanofabrication Users Network (NNUN) covering e.g. Cornell University, Stanford University and UC Santa Barbara. The modeling and simulation Network for Computational Nanotechnology (NCN) is another infrastructure initiative. In 2003 NNI invested USD 70 million to develop the National Nanotechnology Infrastructure Network (NNIN) with 13 universities, including e.g. Harvard and Stanford. NNIN provide support to users from the academic, government and industry research community for research infrastructure needs. NNIN is also an initiative in education and outreach. Research infrastructure funding is also used by Department of Energy (DOE) to create five Nanoscale Science Research Centers (NSRC) e.g. Center for Nanophase Material Science at Oak Ridge National Laboratory and Center for Integrated Nanotechnologies at Los Alamos National Laboratories. The NSRCs are available to all researchers on a merit-reviewed basis.

The **fifth mode** funds research on the societal implications of nanotechnology. NSF has introduced the program Societal and Educational Implications of Scientific and Technological Advances on the Nanoscale covering issues such as e.g. knowledge barriers to adoption of nanotechnology in commerce and educational and workforce needs.

4.5 The 21st Century Nanotechnology R&D Act

In December 2003 the 21st Century Nanotechnology Research and Development Act (the Act) was signed into law (Act 2003A). The Act was accepted in the policy process because it promised jobs and economic development and more projects for government labs and universities in a large number of Congressional districts (ST 2004A). Some Congress members of importance for the introduction of the nanotechnology legislation were Sherwood Boehlert chairman of the Science Committee and Mike Honda from California. The Act authorizes appropriations for fiscal years 2005 to 2008 and states that the President "shall implement a National Nanotechnology Program". But for the funding of the program each year, an appropriation is necessary. The current US budget deficit in combination with other priorities could have an impact on the funding of the program each year. The President's request for the NNI for fiscal year 2006 is USD 1. 05 billion which is below the appropriation for 2005; it is the first time a request for funding has been less than the funding in the previous year.

The objectives, program activities, management and reporting requirements of the National Nanotechnology Program are defined in the Act. In several ways the act is in line with the established strategy for the NNI, but several new goals and program activities are also defined. The Act "institutionalizes the federal commitment to nanotechnology" (ST 2004A) and defines nanotechnology as a governmental priority. The Act also establishes a legal structure for the NNI. The National Research Council (NRC) made a review of the NNI in 2002 to analyze different aspects of the NNI (NAS 2002A). The review finds that "the leadership and investment strategy established by the NSET has set a positive tone for the NNI". But the review also makes ten different recommendations. A proper balance between short-term and long-term funding is recommended, revolutionary ideas need sustained funding. New mechanisms for accelerating ideas into applications and increased support for industrial partnerships are recommended. The review also recommends the creation of programs for new instruments for nanoscience and support for the development of an interdisciplinary culture within the NNI. An integration of the societal implications of nanotechnology into different aspects of the NNI is also recommended. Several of the major changes for the NNI defined in the 21st Century Nanotechnology R&D Act are in line with the recommendations in the NRC review.

The objectives defined in the 21st Century Nanotechnology R&D Act are establishment of goals and priorities for Federal nanotechnology research, investment in nanotechnology R&D programs and interagency coordination. Several different program activities are defined such as (Act 2003A):

- "Establishing of interdisciplinary nanotechnology research centers."
- "Establishing a network of advanced technology user facilities."
- "Centers to the greatest extent possible, be established in geographically diverse locations and encourage the participation of Historically Black Colleges."
- "Ensuring United States global leadership in the development and application of nanotechnology".
- "Advancing the United States productivity and industrial competitiveness through stable, consistent, and coordinated investments in long-term scientific and engineering research in nanotechnology."
- "Accelerating the deployment and application of nanotechnology research and development in the private sector, including startup companies."

The act also stipulates that the NNCO shall perform several studies such as a technical feasibility study of molecular self-assembly and a study on the responsible development of nanotechnology.

The 21st Century Nanotechnology R&D Act also states that a strategic plan shall be developed and updated every 3 years and a new strategic plan (NSTC 2004A) for the NNI was published by NSTC in December 2004.

The goals of the NNI are defined in the strategic plan (NSTC 2004A) as:

- "Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology."
- "Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefits."
- "Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology."
- "Support responsible development of nanotechnology."

4.6 The New Strategic Plan

The NNI strategic plan for the coming 5 to 10 years, launched in December 2004, (NSTC 2004A) puts greater emphasis on technology transfer and cooperation with industry groups. The plan is based on 17 nanotechnology workshops sponsored by the NNI with experts from academia, industry and government in combination with the ongoing missions at the agencies, the National Research Council review of the NNI and the requirements defined by the 21st Century Nanotechnology R&D Act.

The plan defines major categories of investment or Program Component Areas (PCA) based on the defined goals. The PCAs are critical for accomplishing the NNI goals. Each PCA can include both basic research and development of applications. The PCAs is also intended to provide a means for informing the stakeholders about the funding distribution and facilitate the coordination of activities.

The PCAs are:

- “Fundamental nanoscale phenomena and processes”
- “Nanomaterials”
- “Nanoscale devices and systems”
- “Instrumentation research, metrology, and standards for nanotechnology”
- “Nanomanufacturing”
- “Major research facilities and instrumentation acquisition”
- “Societal dimensions.”

Table 8. Illustration of the relation between the NNI goals and the PCAs.

PCAs and NNI Goals	**World-class research**	**Technology transfer**	**Education and infrastructure**	**Responsible development**
Fundamental Nanoscale Phenomena and Processes	■ (black)		■ (grey)	
Nanomaterials	■ (black)			
Nanoscale Devices and Systems	■ (grey)	■ (black)		
Instrumentation Research, Metrology, and Standards		■ (black)		
Nanomanufacturing		■ (black)	■ (grey)	■ (grey)
Major Research Facilities and Instrumentation	■ (grey)	■ (grey)	■ (black)	
Societal Dimensions			■ (grey)	■ (black)

Source: NSTC 2004A

(Black squares indicating PCAs critical to goal and grey for PCAs of primary relevance.)

The research activities can be divided into three different categories according to the plan. Single investigator research allows NNI to support a broad range of research areas with higher risk. Multi-investigator research including multidisciplinary teams is a core part of the NNI. Research centers typically costing more than USD 2 million per year over 5 to 10 years are also an important part of the NNI for larger research groups.

The strategy for the **first goal** ("Maintain a world-class research and development program aimed at realizing the full potential of nanotechnology.") in the strategic plan (NSTC 2004A) is based on the following strategies:

- "Sustain funding for exploratory research leading to the discovery and development of new ideas."
- "Continue to invest in research in the enabling disciplines and in the synergistic research at the intersection of the many disciplines encompassed by nanotechnology."
- "Focus on specific areas of opportunity in which the NNI encourages R&D." E.g. Integration of physical and biological sciences, new instrumentation and tools and science of self-assembly.
- "Establish focused R&D objectives within each of the PCAs. Develop interagency collaborative projects and partnerships with industry."
- "Initiate programs to foster creation of scientific and engineering platforms for precompetitive applications of nanotechnology." E.g. nanotubes for integration in electronic devices.
- "Promote awareness of, and engagement in, international R&D activities by US-based researchers."

The **second goal** of the NNI is facilitation of technology transfer. A range of approaches is used to support this goal including support of meetings between academia and industry, establishment of facilities that are available to researchers from all sectors, utilization of the Small Business Innovation Research[3] (SBIR) to support early-stage nanotechnology solutions and participation in standards development. Programs for multidisciplinary research teams including industry and university researchers will also be supported. The programs include e.g. Opportunities for Academic Liaison with Industry (GOALI) and Partnerships for Innovation (PFI). Manufacturing research is also a particular focus area for commercialization and it is supported by the NSTC Manufacturing Interagency Working Group.

The PCAs is a new approach compared to the Grand Challenges, the PCAs underlie almost all of the former Grand Challenges. Particular application areas such as energy and healthcare may include multiple PCAs. Some of the Grand Challenge areas were very broad and some more specific. The new plan no longer refers explicitly to the Grand Challenges, but nanotechnology applications that address the agencies' missions are still very important according to the plan. The partici-

[3] *Small Business Innovation Research, a federal program requiring ten federal departments and agencies to reserve a part of their R&D funds for award to small business.*

pating agencies have an interest in the application areas of Aerospace, Agriculture, National Defense & Homeland Security, Energy, Environmental Improvement, Information Technologies, Medicine & Health and Transportation & Civil Infrastructure (NSTC 2004A). In general the new strategic plan for the NNI is less specific in terms of application focus. The PCAs is a more generic framework. But particular specific application segments are a part of the strategy for e.g. the first goal of the NNI.

4.7 National Science Foundation

The National Science Foundation[4] (NSF) provides programs on collaborative research and education in the area of Nanoscale Science and Engineering (NSE). NSE is one of six priority areas for NSF. The previous NSF priority area Information Technology Research is planned to be cancelled in 2005, at the same time the funding for NSE is planned to be increased by 20 percent. The goal of the NSE programs is to support fundamental research and be a catalyst for synergetic science and engineering research. The NSE program during 2005 focuses on eight high-risk/high-reward research and education themes. The eights areas are linked by the general goal of achieving systematic control of phenomena at the nanoscale, exploiting new phenomena and functions and applying them in areas of national interest. The research areas include (NSF 2004A):

- Biosystems at the nanoscale
- Nanoscale structures, novel phenomena and quantum control
- Nanoscience devices and system architecture
- Silicon Nanoelectronics and beyond
- Nanoscale processes in the environment
- Multi-scale, multi-phenomena theory, and simulation at the nanoscale
- Manufacturing processes at the nanoscale
- Societal and educational implications of advances at the nanoscale.

During 2005 the program will provide support for Nanoscale Interdisciplinary Research Teams (NIRT), Nanoscale Exploratory Research (NER) and Nanoscale Science and Engineering Centers (NSEC). NIRT encourages teams to address research and education where a synergistic blend of expertise is needed to make significant contributions. NSEC will address major opportunities and challenges in nanoscience, engineering and technology. During 2005 the NSEC will focus on manufacturing processes at the nanoscale and societal and educational implications of science at the nanoscale. The University California (UC) Berkeley Center of Integrated Nanomechanical Systems (COINS) is one of six NSEC.

[4] *National Science Foundation, a federal agency to promote science with an annual budget of about 5 billion USD.*

The Berkeley-based center with researchers also from Stanford University and California Institute of Technology (Caltech) is unique because of its specific focus on mechanics at the nanoscale.

NSF also provides support for the program Nanotechnology Science and Engineering Education (NSEE) during 2005. This program supports learning and teaching in nanoscale science and engineering in graduate- and undergraduate education. A special challenge and opportunity within nanoscale science and engineering is restructuring teaching at all levels to include NSE concepts and nurturing the scientific and technical workforce. NSF also considers that successful development and application of nanoscience and technology will require careful consideration and analysis of associated social and ethical aspects (NSF 2004A).

4.8 Department of Energy

The US Department of Energy (DOE) Office of Science supports nanotechnology through its Materials Sciences subprogram. The program supports basic research and focuses on materials that improve the efficiency, economy, environmental acceptability, and safety in energy generation, conversion, transmission, and use. Efficient Energy Conversion and Storage is one of the NNI grand challenges. Nanoscience and nanotechnology present exciting approaches to assure a secure energy future according to DOE (DOE 2004B). Nanotechnology could be a way of reducing the need for oil from the Middle East (UCB 2004A).

The Department of Energy's Office of Science is going to build five new Nanoscale Science Research Centers. Today world-class facilities available to the scientific community to synthesize process and fabricate nanoscale materials and structures do not exist; DOE is going to fulfill that need (DOE 2004A). The centers will be located at DOE's Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge and Los Alamos and Sandia National Laboratories. Each center will be housed in a new laboratory building. The centers will provide researchers with state-of-the-art capabilities to explore, fabricate and study nanoscale materials.

The first DOE nanoscience center is the Center for Nanophase Material Sciences (CNMS) at Oak Ridge National Laboratory. The construction of a new building for the center started in 2003. CNMS will focus on providing unique opportunities to understand nanoscale materials and phenomena in a highly collaborative and multidisciplinary environment. In May 2004 building started on the new Center for Integrated Nanotechnologies (CINT) at Los Alamos (LANL) and Sandia National Laboratories (SNL). The center is funded with USD 76 million.

A NNI sponsored workshop in May 2004 (DOE 2004B) defined nine research targets in energy-related science and technology in which nanoscience is expected to have the greatest impact, the following are some examples:

- "Scalable methods to split water with sunlight for hydrogen production."
- "Highly selective catalysts for clean and energy-efficient manufacturing."
- "Harvesting of solar energy with 20 percent power efficiency and 100 times lower cost."

- "Solid-state lighting at 50 percent of the present power consumption."
- "Super-strong, light-weight materials to improve efficiency of cars, airplanes, etc."
- "Low-cost fuel cells, batteries, thermoelectrics and ultra-capacitors."

4.9 National Institutes of Health

The National Institutes of Health[5] (NIH) formally started its nanomedicine initiative in May 2004 by soliciting comments from the scientific community to help shape the research project with the purpose of developing new tools to improve human health. The initiative could last a decade and seeks to catalog molecules and understand molecular pathways and networks. Nanomedicine is one of nine initiatives that make up the NIH roadmap, a long-term plan for improving and accelerating biomedical research. Unlike many research projects, NIH is not predetermining specific areas of study, instead NIH is calling for proposals.

The goals of the NIH Nanomedicine Roadmap Initiative are to obtain a comprehensive set of measurements on molecules and assemblies of molecules and to use that knowledge to drive the design and development of new nanomachines and technologies to improve human health.

Much of the initial research will take place at three or four Nanomedicine Development Centers (NMDC) to be established by the initiative. NIH will award about 20 grants for concept development plans and will select the centers from those plans by September 2005. The centers will be staffed by teams of scientists from many different areas, such as biologists, mathematicians, biochemists and engineers. There are also other nanomedicine projects under way at NIH that are not related to the roadmap initiative and are aimed at producing more immediate results.

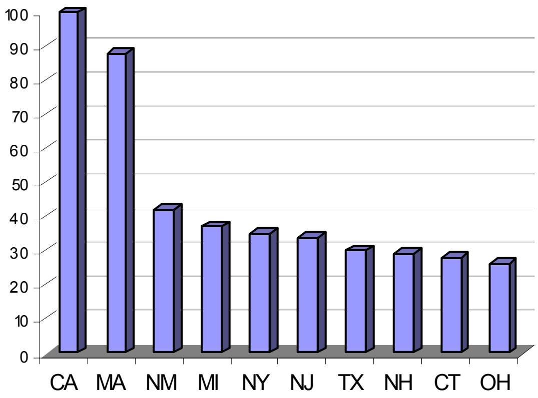
[5] *The National Institutes of Health, a federal agency for conducting and supporting medical research with an annual budget of about USD 27 billion.*

5 State Initiatives

5.1 Introduction

According to Small Times Magazine (SmallTimes 2005A), which each year ranks the top ten states in nanotechnology, California was the state leader in the USA 2004, followed by Massachusetts, New Mexico, New York, Texas, Illinois, Pennsylvania, Michigan, Connecticut and Ohio.

Figure 1. Top ten states in nanotechnology in the USA 2004.



Source: SmallTimes 2005A

The six variables measured on a score between 100 and 1 were:

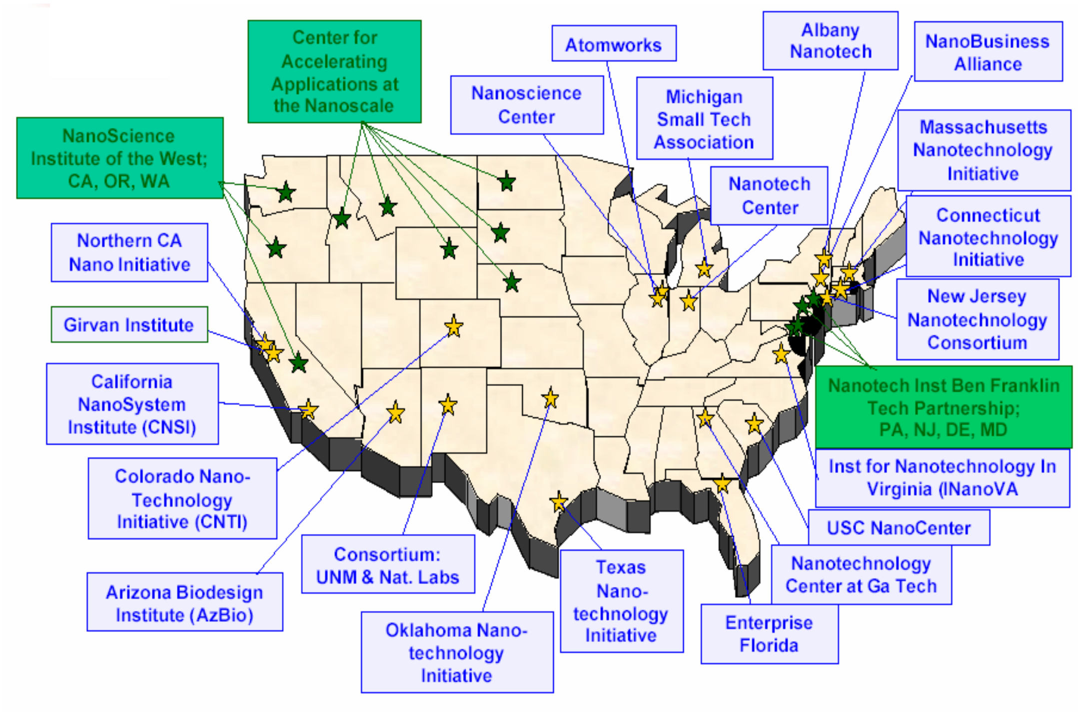
- *Research (20 %).* Measures the amount of research activity in a state as well as its resources.
- *Industry (20 %).* Measures the amount of micro and nanotechnology business that exists in the state.
- *Venture capital (20 %).* The amount and number of private financing deals in a year.
- *Innovation (20 %).* Includes patenting and success at attracting federal funding for commercializing products.
- *Work force (10 %).* Examines the quantity and quality of the labor pool.
- *Costs (10 %).* Encompasses salaries, commercial rents and other factors that affect business costs.

The state of California was the leader in the first four of the variables mentioned above. California has more than twice as many companies involved in nanotechnology as Massachusetts. But in terms of business density, i.e. the proportion of micro and nanotechnology companies within a state's overall number of businesses, Massachusetts beat California.

5.2 State Policy

The federal Government provides nanotechnology research funding to the states mainly through the National Nanotechnology Initiative (NNI) and the Small Business Innovation and Research (SBIR) program. Many states have some kind of nanotechnology program or project. A major part of them are existing programs that have been adapted to appeal to NNI funds and private investment.

Figure 2. Examples of current regional, state and local initiatives in nanotechnology in the USA.



Source: Roco 2003A (The highlighted boxes represent multi-state initiatives.)

Only a handful of states have established a long-term policy framework and coordinated investment approach aimed at the nanotechnology sector. This is expected to change in the next few years, mainly because of the large amount of federal funds set aside for nanotechnology, combined with the promise of potential jobs and economic growth. (Barbour 2003A, CCST 2004B)

Incentives offered to nanotechnology businesses are mostly the same as those offered to any businesses. Initiatives in the states mainly start out of university nanotechnology, entrepreneurs, foundations and regional/economic development organizations, which raise interest on a regional and national level, arrange networking events (academia, investors and industry) and lobby for research funding. Some states are supporting the development of technology parks at their universities, levering state funds to attract additional industry funding and utilize university based programs with a statewide strategic focus on nanotechnology. Other states are trying to foster collaborative opportunities, supporting consortia and workshops etc. (RSNI 2003A).

Table 9. Examples of state funded programs[6]

State	Program	Financial Commitment
California	California Nanosystems Institute	$100 million/4 years
New York	Albany Nanotech	$50 million, $400 million/5 years
Illinois	NanoScience Center	$63 million
Pennsylvania	Nanotechnology Center	$37 million
Georgia	Center at Georgia Tech	$25
Indiana	Nanotechnology Center	$5
Texas	Nanotechnology Center	$0.5 million/2 years
South Carolina	NanoCenter	$1 million

Source: Roco 2003A

5.3 California

California is positioned to be the leading state in the USA in adopting and benefiting from nanotechnology, mainly due to the state's preeminence in cutting edge technologies, venture capital, hi-tech industries, and entrepreneurial spirit. The state of California attracts approximately 40 percent of all venture capital, more then any other state. In 2003 the nanotechnology industry in California attracted USD 480 million in venture capital. Another proof of California's competitive advantage is that almost 20 percent of all nanotechnology articles published nationwide came from institutions in the state (CCST 2004B).

Some of the most respected universities and research labs in the country are located in the Bay Area (San Francisco), Los Angeles and San Diego. These institutions include University of California Berkeley, Stanford, Caltech, University of California Santa Barbara, the University of Southern California, University of California Los Angeles, University of California Davis, University of California Santa Cruz, NASA Ames, Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory. Small Times magazine has identified the Bay Area in particular as having the highest concentration of research and industry capabilities in nanotechnology, and it is also known as being the center of early development in semiconductors and biotechnology. Southern California has a strong science and engineering base equivalent to the San Francisco Bay Area. The region is strong in manufacturing, biotechnology, medical devices and telecommunications.

California has several federally funded nanoscience facilities, including the Stanford Nanofabrication Facility (part of the National Nanotechnology Users Network funded by the National Science Foundation) and the Molecular Foundry (part of the Lawrence Berkeley National Laboratory and the University of California at Berkeley and funded by the Department of Energy). These facilities are not directly funded by the state, but their operations receive indirect subsidies through their respective private sponsors (Stanford) and public sponsors (the University of California at Berkeley)

[6] *400 million USD in state venture capital funding, www.albanynanotech.org/About/overview.cfm*

California Council on Science and Technology

Founded by the California State Legislature and the Governor in 1988, the California Council on Science and Technology (CCST)[7], is a partnership of industry, academia and government that identifies ways that science and technology can be used to improve California's economy and quality of life.

In 2004 CCST released a report on the opportunities and challenges facing California in nanoscience and nanotechnology at the request of the Committee for the 21st Century, the California Technology, Trade and Commerce Agency and the Semiconductor Industry Association (CCST 2004B).

Some of the report's recommendations to the state policy makers are:

- **Education.** Invest in education and workforce training.
- **Economic policy.** Re-engineer outmoded *s*tate tax incentives that address the needs of emerging industries, examining siting for nanomanufacturing in California, and facilitate commercialization by encouraging collaboration between industry and the academy.
- **Social and Environmental Issues.** Establish nanoethics centers in higher education and multi-agency government teams to identify essential health, environmental, and other impacts of nanotechnology.

Some of the challenges for California, according to the report, are the need to streamline the technology licensing process and to develop a skilled and adequate workforce to support the nanotechnology industry. Another recommendation is to consider a state-wide R&D strategy comparable to the federal government's NNI to promote and invest in nanotechnology.

The mission of CCST is to:

- Identify the long range research requirements for sustaining the state's economic development and competitiveness.
- Provide direction for new scientific and technological activities.
- Stimulate the technology transfer linkage between the university research setting and the private sector.
- Analyze public policy issues and formulate policy recommendations in the areas of science and technology.
- Establish an organizational structure for the development of collaborative public/private sector initiatives targeted to spur research and development activities, innovation and growth of new science and technology based industries and jobs.

[7] *California Council on Science and Technology, http://www.ccst.us*

CCST is a non-partisan, impartial, non-profit corporation which offers expert advice to the state and provides solutions to science and technology-related policy issues. CCST consists of an independent assembly with up to 30 member of corporate CEOs, academics, scientists, and scholars of the highest distinction.

California NanoSystems Institute

Public/private partnerships play an important role in advancing nanotechnology by combining public sector funding and research capabilities with the private sector. One example of this is the California NanoSystems Institute (CNSI)[8], created in 2000 as a joint venture of the University of California at Los Angeles (UCLA) and the University of California at Santa Barbara, which has encouraged alliances between the public sector and private companies, such as HP, IBM and small biotech firms, in order to foster flows of knowledge between different players in the innovation process.

CNSI initiated by the state of California in 2000 received an initial funding of USD 100 million from the state as one of four California Institutes for Science and Innovation (CISI). The USD 100 million is required to be matched by USD 200 million in additional funds from private donations and new research grants. The Institute will facilitate a multidisciplinary approach to develop the information, biomedical, and manufacturing technologies that are expected to dominate science and the economy in the 21st Century. The aim of CNSI is to become a world-class intellectual and physical environment that supports collaboration among California's university, industry and national laboratory scientists.

The main objectives of the CNSI are to:

- "establish a world-renowned center for nanosystems R&D
- develop commercial applications of CNSI's technology
- educate the next generation of scholars in nanosystems R&D
- promote regional development through commercial use of nanotechnology and
- generate public appreciation and understanding of nanotechnology."[9]

Some examples of short and long term applications of R&D at the institute are:

- "highly efficient solid-state white lighting for light-bulb replacement
- photonic structures and devices for 'beyond Newton' approaches to optical switching, optical multiplexing, and light manipulation
- next generation information technologies for memory and computation, including molecular electronics, spintronics, photonics, and quantum computing
- development of efficient and rapid pharmaceutical screening approaches.
- development of ultra-early medical diagnostic tools for detecting the molecular errors in human physiology that eventually leads to disease." [10]

[8] *California Nanosystems Institute at UCLA and UCSB (www.cnsi.ucla.edu and www.cnsi.ucsb.edu)*
[9] *http://www.cnsi.ucla.edu*
[10] *http://www.cnsi.ucla.edu*

CNSI has been successful at creating industry/university partnerships. Approximately 30 high-tech businesses (complete list in Appendix 1) are currently industry affiliates to the Institute. In exchange for financial contributions, industrial affiliates participate in planning the overall strategic and research direction of CNSI, and have the opportunity to place researchers at CNSI to work with academic researchers on pre-competitive topics. The Institute's Board of Trustees will include representatives from the industry partners, and the Board will evaluate the Institute's leadership on the results of its industrial collaborations.

The Northern California Nanotechnology Initiative

The Northern California Nanotechnology Initiative (NCnano) was initiated in 2003 and is a regional economic development program which aims to build the" world's leading nanotechnology cluster in Northern California". The major goals are to bring USD 6 billion in nanotechnology investment and grant money to Northern California and to create 150,000 new jobs in the region by 2007. NCnano will also facilitate a multidisciplinary approach to develop the biotechnology, molecular electronics, advanced materials and manufacturing technologies that are expected to dominate science and the economy in the 21st century by bringing together universities, research labs, businesses, venture capital, local and regional governments, and entrepreneurs (NCnano 2005A).

5.4 Massachusetts

In Massachusetts, nine of the state's universities are involved in nanotechnology R&D, including Harvard University, the Massachusetts Institute of Technology (MIT), and the University of Massachusetts. Two of the nine National Nanotechnology Initiative "Centers and Networks of Excellence" are located at Massachusetts universities (Harvard University and MIT). The aim of these networks is to provide opportunities for interdisciplinary research and collaboration. In 2003, Massachusetts firms using or developing nanoscale technologies attracted more than USD 120 million, second only to California (USD 480 million). The most recent state budget included USD 2.4 million for a tech transfer center at MIT and USD 20 million to support research centers in nanotechnology and other emerging technologies (NSTI 2004A).

The Massachusetts Nanotechnology Initiative

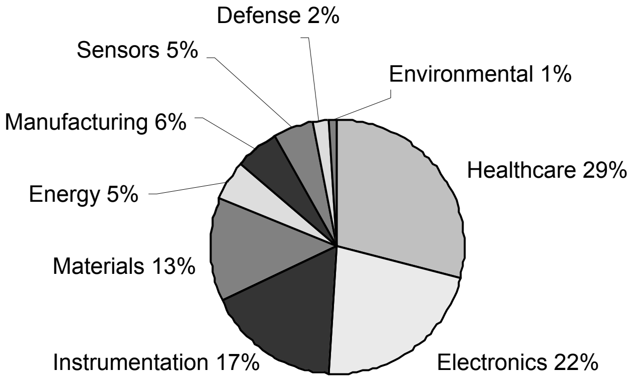
The Massachusetts Nanotechnology Initiative (MNI) was launched in January 2003 after recognizing the importance of nanotechnology to the state's innovation economy. MNI is a project of the Massachusetts Technology Collaborative (MTC)[11], the state agency for tech-based economic development, and the Nano Science and Technology Institute (NSTI)[12], an interdisciplinary consultancy. The aim of the project is to "to foster research, new ventures and new job creation from the Commonwealth's rich base of nanoscale science and engineering".[13]

[11] *Massachusetts Technology Collaborative (MTC), http:// www.mtpc.org*
[12] *Nano Science and Technology Institute (NSTI).*
[13] *http://www.mtpc.org/mni*

The four economic development goals are to:

- promote Massachusetts-based nanotechnology companies
- strengthen industry/university relationships to facilitate technology transfer
- engage policy makers, state and federal officials on opportunities in nanotechnology and
- create opportunities for new and early stage companies to network with venture capitalists and established industry players.

Figure 3. Massachusetts companies using or developing nanoscale technologies (2004)



Source: Massachusetts Technology Collaborative and Nano Science and Technology Institute (NSTI 2004A)

In 2004 the MTC/MNI released a strategic assessment (NSTI 2004A) titled "Nanotechnology in Massachusetts" of the state's position in nanotechnology, complete with state specific recommendations. The report highlights nine major industries where nanotechnology has the potential to have a disruptive impact, namely: materials, instrumentation, electronics, healthcare, defense, sensors, energy, manufacturing and environment. The report also assesses major challenges and opportunities for the state's high tech entrepreneurs, companies and universities in nano-scale research and development. The report shows that Massachusetts is experiencing a surge in nano-scale technology R&D and economic development. In 2004, there were close to 100 companies using or developing nano-scale technologies in Massachusetts. More than half of these firms are located within the healthcare and electronics industries. These industries reflect the region's historic strengths in both the life sciences, computer hardware and software industry clusters.

The MTC report provides a summary with the following recommendations for regional policy makers:

- extend nano-enabled productivity gains from established industries into the growth of new industries;
- create nano institutes;
- retrain professionals;
- establish different forums to discuss and exchange ideas;
- educate academics about entrepreneurship; and
- educate the business community about nanotechnology.

The report also suggests that in order to assess the region's long term strength in nanotechnology, the technology transfer process from the universities and research institutions to small firms, need to be more efficient and closely monitored.

6 Non-Governmental Organizations

There are a vast number of organizations and collaborations focusing on, promoting and engaging the nanotech industry in the USA. The major states usually have some kind of effort on the state level and sometimes even on the regional level. These organizations usually focus on developing and strengthening the nanotechnology sector in their state/region through a collaborative effort between academia, industry and policy makers.

This chapter will highlight a few of the more well known , and non-governmental organizations, that are significant players in the nanotechnology industry in the USA, and that have not been mentioned in other parts of this report. Organizations focusing solely on research related matters will not be included in this chapter.

The NanoBusiness Alliance[14] is considered the first industry association founded to advance the emerging business of nanotechnology and Microsystems. The mission is to represent a collective voice for the emerging small tech industry and develop a range of initiatives to support and strengthen the nanotechnology business community, including:

- Research and Education: Develop white papers, surveys, forecasts and industry directories.
- Public Policy: Develop position papers, analyze legislation, provide expert testimony to federal, state and local political leaders and regulators, and aid in the development of regional nanobusiness centers.
- Public Awareness, Public Relations, and Promotions: Launch public awareness campaigns via the media, Internet and other appropriate outlets; promote industry leaders and emerging technologies.
- Forums/Panels: Educate financial and business leaders, as well as the public at large; develop opportunities for nanobusiness people to interact and network.
- Industry Support: Partnership/business development, job banks, mentoring, message boards and capital access initiatives.

The Advisory Board of the Alliance is headed by the leaders of the nanotechnology community and is chaired by former House Speaker, Newt Gingrich, and venture capitalist, Steve Jurvetson, of Draper Fisher Jurvetson. The board also includes leaders from HP, IBM, GE, AGFA, Deloitte & Touche, the NNI and others. The Alliance is headquartered in New York City and also has offices in Washington, D.C. and Denver, CO. The Alliance has hubs and affiliate offices underway in Texas, Chicago, Colorado, and San Francisco/Silicon Valley. To help drive city, state, and regional development, the Alliance has launched an initiative to establish NanoBusiness Alliance hubs to serve as local catalysts to fuel understanding, discussion, and planning of area specific nanobusiness development. The aim of the NBA Hubs is to bring together business people, researchers, government officials,

[14] *NanoBusiness Alliance, http:// www.nanobusiness.org*

corporations, service industry leaders, start-ups and others to develop the growth of area-wide nanobusiness.

The National Academy of Science is a private non-profit society. The Academy often advises the federal government on science and technology issues and carries out different studies requested by the White House administration. The main operating agency of the Academy is the National Research Council established in 1916. The Council made a review of the National Nanotechnology Initiative in 2002 (NAS 2002A). The review was requested by the White House and served as an input to the 21st Century Nanotechnology R&D Act and the definition of the new strategic plan for the NNI. The implementation of several of the recommendations in the review shows that the Council is an important organization for nanotechnology policy formulation. The Council will also support the NNCO with some studies defined by the 21st Century Nanotechnology R&D Act (Act 2003A).

BASIC (Bay Area Science and Innovation Consortium), a subsidiary program of the Bay Area Economic Forum in San Francisco, is an action-oriented collaboration of the region's major research universities, national laboratories, independent research institutions, and research and development-driven businesses and organizations.

The goal is to:

- Develop innovative collaborative programs providing solutions for critical national and regional challenges
- Advocate for the Bay Area at the regional, state, and federal levels for economic, policy and business issues and opportunities impacting research and development and
- Demonstrate the critical linkage between the Bay Area's infrastructure and its economic vitality.

BASIC is sponsoring a series of *Scientific Futures* reports which highlights local achievements and prospects in new evolving areas of scientific research that have the potential to stimulate new waves of scientific and commercial success in the Bay Area. BASIC is co-sponsored by the Bay Area Council and the Association of Bay Area Governments. The Board of Directors is chaired by Robert T.J. Morris at IBM Global Services and has members from major universities and research institutions and businesses in the area.

Foresight Institute[15], founded in 1986, is a membership supported, non-profit, educational organization (think tank) based in the Bay Area in northern California. The Institute focuses on nanotechnology and the goal is to "guide emerging technologies to improve the human condition" and that nanotechnology is being developed safely and beneficially. Foresight publishes a quarterly newsletter, the *Foresight Update*, to provide information about both technical and non-technical developments in nanotechnology. Foresight Institute also arranges sponsored conferences on molecular nanotechnology.

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[15] *Foresight Institute, http://www.foresight.org*

Foresight Institute is one part of the Foresight family of organizations founded to help prepare for nanotechnology and other future technologies considered important. The two other organizations are:

- *The Institute of Molecular Manufacturing* is a non-profit research organization founded to promote research in nanotechnology and molecular manufacturing. The goal of the organization is that nanotechnology be developed faster.
- *The Center for Constitutional Issues in Technology (CCIT) is* a non-profit California corporation created to pursue public policy issues arising from the emergence of new technologies.

The objectives of **the Nano Science and Technology Institute** (NSTI)[16] are to promote and integrate nano and other advanced technologies through education, technology and business development. NSTI accomplishes this mission through its offerings of consulting services, continuing education programs, scientific and business publishing and community outreach. NSTI produces the annual Nanotech conference and trade show, one of the most comprehensive international nanotechnology conventions in the world. NSTI also produces conferences on BioNano and Stem Cell Strategies. NSTI was founded in 1997 as a result of the merger between various scientific societies, and is headquartered in Cambridge, Massachusetts with additional offices in California and Switzerland.

[16] *Nano Science and Technology Institute, http://www.nsti.org*

7 The Nanotechnology Industry

7.1 Leading Companies

In some ways nanotechnology represents a new industry, but mostly it is a means of improving different existing industry segments. There are about 800 companies in the US that have announced nanotechnology R&D plans including approximately 700 startups. There are approximately seven times more US nanotechnology companies than in any other country; Germany is number two in terms of number of nanotech companies and Switzerland number three (ST 2004A). Of the 30 companies included in the Dow Jones Industrial Average Index 63 percent are funding nanotechnology R&D (Lux 2004A).

Several firms provide nanotechnology products already today. Sunscreen is enhanced with titanium dioxide from Nanophase, stain-resistant clothing by Nano-Tex, Wilson Double Core tennis balls are using nanomaterials (nanocomposite coatings) from Inmat and sunglasses have nanocoating from Nanofilm. Nanocomposites a lightweight material used in e.g. General Motors cars are provided by the firm Southern Clay. But because of the extensive interest in nanotechnology several firms are trying to take a position within the area. Some firms have also changed their company name to include nano. Table 10 lists some of the firms working with nanotechnology.

Table 10. Some leading nanotechnology firms in the USA.

Large firms	Focus areas
IBM	Several focus areas
General Electric	Several focus areas
Hewlett-Packard	Several focus areas
Motorola	Several focus areas
DuPont	Several focus areas
Other listed firms	**Focus areas**
Harris & Harris	A nanotechnology focused venture capital firm
Nanophase	Nanocrystalline materials innovator and manufacturer
NVE	Develops devices using spintronics, MRAM patents
Headwaters	Energy e.g. nanocatalyst applications
Veeco Instruments	Instrumentation for e.g. nano research
Nanogen	Molecular diagnostic tests
Arrowhead R&D Corp.	A diversified nanotech commersialization firm
Immunicon	Magnetic nanoparticles for cancer diagnosis
Lumera	Nanoscale polymers
Smaller firms	**Focus areas**
Nanosys	High performance inorganic nanostructures
Catalytic Solutions	Has developed a unique catalytic coating
Quantum Dot	Solutions for biomolecular detection
Molecular Imprints	Lithography systems & technology for manufacturing
Carbon Nanotech.	A producer of Buckytubes, IP from R. Smalley.

7.2 Commercialization Timeline

Several nanotechnology enabled solutions are available on the market and a study by Apax has shown that two thirds of nanotechnology companies are near term market opportunities (Apax 2004A). Nanotechnology has the first impact on industry segments such as chemicals and specialty materials for e.g. stain and scratch-resistant products. The top nanotechnology companies in terms of revenue are in the segments specialty chemicals, pharmaceuticals and semiconductor equipment (Lux 2004A). Nanoscale features have already today had a negative impact on the market for some existing solutions and business segments such as the cleaning industry. Nanotechnology properties for stain proof materials reduces the need for cleaning in some cases.

Table 11. Nanotechnology Commercialization Timeline

0 to 5 years	5 to 10 years	10 to 15 years
Flat-panel displays	Drug delivery	Nanoelectronics
Nanosensors	Smart drugs	Spintronics
Nanofluids	Adaptive materials	Quantum computing
Nano-reinforced materials	Nanomemory	Intracellular machines
Nano-filled coatings	Bio materials	Artificial organs
	Bio sensors	Nano solar cells
		NEMS-based devices

Source: (CCST 2004A, UCB 2004A, NNI 2002A, NAS 2002A)

Segments with a rather short time to market are nanotechnology tools and diagnostics. The demand for tools to work at the atomic scale is increasing. The increasing demand for atomic and molecular modeling, measurement and analysis products is an early phase in nanotechnology development. Nanotechnology tool providers such as e.g. Veeco Instruments and FEI Company benefit from corporate and government R&D spending. New software and algorithms for testing, visualization and simulation at nanoscale will also emerge. The US market for nanotech tools is estimated to increase about 30 percent per year and reach about USD 900 million in 2008 and USD 2.7 billion in 2013 (BW 2004A).

The integration of nanotechnology into information technology begins with new solutions for memory and storage. The manufacturing of magnetic nanoparticles for hard disks and tape media is already an industry. The commercialization of results of the NNI has started within e.g. nanoscale imprinting (NSTC 2004A). Nanoscale solutions for life science start with e.g. solutions for cancer diagnostics and therapeutics. The firm Immunicon provides products within this segment. Nano-enabled solar cells are providing better and better performance enabling cost-efficient energy production.

7.3 Electronics

The electronics industry is well on the way to moving from micro- to nanoelectronics but traditional lithographic methods of fabrication cannot be scaled from micro to nano dimensions without problems. Conventional photolithography is unlikely to survive beyond 45 nanometer. By 2010 chips will achieve a scale where silicon circuits no longer function well. The semiconductor industry depends on nanotechnology to extend the limits of current solutions (CCST 2004A). Further CMOS scaling creates several different issues. If the miniaturization of electronics is to proceed, new methods will be needed. Nanotechnology will enable new technology platforms such as e.g. nanoimprint lithography. Motorola in partnership with Molecular Imprints are working with this approach. The technology has also several cost advantages compared to photolithography (NanoMarkets 2004B). A next generation method of manufacturing process several years from commercialization is called nanoscale self-assembly which adopts a bottom-up approach aggregating nano particles. General Electric and Hewlett-Packard are other firms making substantial investments in the field of nanoelectronics.

IBM is collaborating with Stanford University on high-performance, low-power components to help build smaller and faster electronic devices. The partner's latest research in the field of "spintronics" could lead to reconfigurable logical devices, room-temperature superconductors and quantum computers in the next five years.

Defense Advanced Research Projects Agency (DARPA) launched a new multi-million-dollar program for research in quantum computing during 2004 for very fast super computers. Quantum computers could yield exponential improvements in processing speed and create new possibilities for several application areas. But it could take 20 years or more to build functional quantum computers.

Nanomemories and nanodisk drives will become commercialized as early as 2005. Today, one penny will buy a little over a Megabyte of storage but within two or three years this could increase by several orders of magnitude to one Gigabyte. More than 40-times improvement in data storage and retrieval can be achieved. Current work by IBM, Hewlett Packard and some startups could ultimately transform the economics of storage so that a penny could buy a Petabyte of storage. The concept of pervasive computing is supported by firms such as IBM and Motorola and will require high capacity and low-power consuming non-volatile memories e.g. MRAM (NanoMarkets 2004B). MRAM could be one very important nanotechnology enabled product. With MRAM the need to boot up computers will be eliminated. A nanotechnology memory company is ZettaCore which replaces the chemistry of today's memory with its own molecule that has advantages over a silicon transistor according to ZettaCore. Nanomemory could emerge as one of the first significant markets for nano-engineered products (NanoMarkets 2004B).

Nanosensor technology remains mostly in the development phase but is in some cases close to commercialization. The firm Cyrano Sciences has demonstrated nanosensor technology for detection of very low levels of chemicals. Molecular Nanosystems is close to the introduction of a nanotube based gas sensor and will extend its technology to genomic applications. There are different nanosensors including conventional sensors that use nanomaterials such as carbon nanotubes and quantum dots as the sensing material and nanosensors that utilize nanoelectronics to reduce size and cost (NanoMarkets 2004C).

Plastic electronics is another nanotechnology platform that could be used for several different products. Plastic electronics includes the use of conductive polymers and will create new opportunities because of low production costs also for small-volume manufacturing. The possible products include low-cost RFID tags and flexible displays (NanoMarkets 2004C).

7.4 Healthcare

Nanotechnology offers many important opportunities for the biotechnology- and pharmaceutical industry. National Science Foundation estimates that half of all drugs will be made with nanotechnology by 2010 (NSF 2004A). Nano-enabled drugs have the possibility to quickly affect the target and improve dosing efficiency, firms such as e.g. Elan Pharmaceuticals have R&D within this field. Nanomaterials as buckyballs can be used for improving drug delivery. Nanotechnology will also improve R&D productivity for the drug industry in general because of e.g. more efficient test methods. The National Cancer Institute has initiatives within nanotechnology including e.g. biosensors for cancer detection. Researchers at the California Institute of Technology are also working on solutions based on nanosensors for cheaper and more convenient cancer tests. The firm Immunicon uses patented magnetic nanoparticles in systems to collect and analyze rare cells from blood. Its initial products focus on cancer diagnostics. Immunicon's products could cut the time and sample size required for cancer diagnostics (NanoMarkets 2004D). Other firms with solutions for tests based on nanotechnology are e.g. Quantum Dot. The nanosubstance quantum dots (materials with a width of a few atoms) could be used to diagnose diseases. Early indicators of diseases such as proteins and other substances in the body are difficult to detect with current technologies. Also other countries have leading nanotechnology firms. The Australian nanotech firms Starpharma and pSiVida, the UK firm Skyepharma and the French firm Flamel Technologies are examples of firms that have made progress for nano-enabled life science products.

7.5 Energy

Nanomaterials will have broad energy implications. Perhaps the greatest impact for nanotechnology within energy will come in the areas of energy generation and utilization (NNI 2002A). Scientists from the firm Nanosolar are designing low-cost solar electricity cells that could make solar power competitive with conventional energy sources. Nanosolar uses a nano-engineered material that "self-assembles" into tiny solar cells that convert sunlight into electricity. The firm raised USD 6.5 million during 2003 from U.S. Venture Partners, Benchmark Capital and other investors. Other solar cell firms are e.g. Solar Cells.

Clean energy technologies are considered to be a growing market for products that generate revenue without harming the environment. Nanomaterials also have applications for sustainability including catalysis for dealing with emissions such as

CO_2 (carbon dioxide). Nanomaterials for catalysts will also have significant impact on the petroleum and chemical processing industries. New solutions for hydrogen storage for fuel cells will also be possible.

7.6 Materials

Nanotechnology will enable new materials with new properties as improved performance, prolonged lifetime and increased strength. Areas of application, for example, are within coatings, catalytic converters, manufacturing and medical techniques. The near-term commercial applications of nanomaterials are within nanoperticle-reinforced materials and nanoparticle-filled coatings. Nanoparticle-filled coatings can be used to create e.g. scratch proof surfaces and are used by automakers already today (UCB 2004A). The chemical industry including firms such as Dow Corning and DuPont created a Chemical Industry R&D Roadmap for Nanomaterials By Design in 2003 and delivered it to the NNI Coordination Office. The roadmap was prepared by the industry collaboration Chemical Industry Vision2020 Technology Partnership.

The potential for the nanotechnology platform carbon nanotubes is huge and this new class of materials has a strength-to-weight ratio more than 600 times that of high-strength steel. U.S. sales were estimated at USD 200 million 2003, but are projected to hit USD 1 billion by 2007 and USD 4.5 billion by 2012. One firm providing solutions for carbon nanotubes is Xintek. The solutions from the firm use the physical properties of carbon nanotubes for field emission for e.g. X-ray tubes. Another nanotechnology platform is buckyballs, scientists think they could eventually be used in chemical sensors, fuel cells, drug delivery, cancer medicines, and smart materials. Carbon Nanotechnologies is one of the world's leading producers of buckytubes. The company was founded in 2000 and has worldwide licenses from Rice University for several technologies developed by the 1996 Nobel Laureate Richard Smalley.

Some different trends in the development of nanomaterials have been identified. Bionanomaterials includes the integration of organic materials with nanoscale inorganic and polymeric materials. Nanocomposites are a class of materials with improved functionality based on the integration of nanoscale components into the materials. The third class of materials is functional nanostructures based on bottom-up nano manufacturing to create new nanoscale structures. (RAND 2004B)

8 Commercialization

8.1 Entry Barriers

Recent discussions regarding commercialization of nanotechnology, is whether nanotechnology differs from other high-tech areas. Nanotechnology is different to other high technology areas because of e.g. the multidisciplinary nature including nanoapplications for information technology, biotechnology and materials. But within each nanotechnology segment, the challenges covering management, customers and competitive edge are common to other high-tech areas. However, nanotechnology firms face much higher technical barriers than many other technology companies. There are several entry barriers such as the need for equipment for atomic force microscopes at a cost of about between USD 0.1 and 1 million each (CCST 2004A). The high cost of research and manufacturing equipment will be a restriction for development and commercialization. The cost of nanotechnology manufacturing is also very high for several applications. The need for multidisciplinary research teams also creates additional costs. Nanotechnology firms also need to have a strong intellectual property platform (Forbes 2002A).

High entry barriers make nanotechnology different from e.g. information technology. Funding for nanotechnology could in general be more difficult than for other emerging technology areas. The funding issues indicate that the need for federal and state funding could be critical for nanotechnology commercialization. Most nanotechnology start-up firms are based on university intellectual property, few successful firms are started by independent entrepreneurs (CCST 2004A). This also indicates that federal and state initiatives are important for successful nanotechnology commercialization.

Nanotechnology is still mostly a technology in search of products and investors with research performed by government funded universities and companies looking for new products. Nanotechnology startups are in general still too technology driven and not sufficiently business driven. "Formidable challenges remain in the areas of fundamental understanding, device design, system design and architecture, manufacturing, and system integration and deployment before the potential of nanotechnology becomes a reality" according to National Science Foundation (NSF 2004A).

8.2 Intellectual Property

Intellectual property (IP) is a central issue for most emerging nanotechnology firms. IP is more important for nanotechnology commercialization than for several other high-tech areas (CCST 2004A). The business for several of the leading nanotechnology firms is based on university IP. The number of nanotechnology patents per year in the US increased from 350 in 1998 to 700 in 2001. The US are leading in terms of number of nanotechnology patents (about 2 900) and Japan (about 700) is number two (ST 2004A). Nanotechnology will lead to particular challenges for intellectual property including e.g. if an atom can be patented. Most nanotechnology patents are generated by universities, government labs and large companies. The highest number of research articles between 1991 and 1999 within nanotechnology were published by universities in Los Angeles followed by San Francisco Bay Area, Boston, New York, Philadelphia and Chicago. The four leading research regions are also at the top in terms of number of nanotechnology firms (CCST 2004A).

Northern California Nanotechnology Initiative is developing a nanotechnology intellectual property database to facilitate commercialization of nanotechnologies. The database includes sources from hundreds of top R&D institutions from around the world. The U.S. Patent and Trademark Office are also working to improve the ability to search and examine nanotechnology-related patents. The agency has established a nanotechnology classification project. The American National Standards Institute (ANSI) has established a Nanotechnology Standards Panel and a framework for standards within the area of nanotechnology.

Some of the leading nanotechnology firms such as e.g. Nanosys have a strategy based technology in-licensing from leading universities and have over 250 patents. Nanosys has licensed IP from universities such as Harvard, Massachusetts Institute of Technology (MIT), University of California Los Angeles (UCLA) and UC Berkeley. Some nanotechnology companies have also a business model entirely based on IP-licensing to other companies, this is particularly common for segments such as e.g. displays and storage (CCST 2004A). The IP plan and relationships with universities is particularly important for start-ups seeking venture financing (MintzLevin 2004A). Several firms are also trying to acquire broad patents for nanotechnology to create an attractive IP-position.

8.3 University – Industry Relationships

Industry funding of US university research in general has increased from 3 percent to about 8 percent or USD 2 billion in thirty years. The income from licensing has also increased substantially for several universities during the last ten years. The average licensing income for universities is about 2.7 percent of the total revenue, but several universities have the ambition of increasing this revenue stream (GMU 2005A). Licensing revenue from particular medical innovations is an important revenue stream for some universities. The US university system is dynamic and very responsive to new trends and is able to take advantage of new opportunities such as e.g. nanotechnology and Homeland Security. The universities see a first mover advantage. Some of the structural features of the US university system important for the governance are: “lack of centralized and national control, reliance on external sources of research funds, entrepreneurial faculty members and high personal mobility” (TPS 2002A). The tradition of sponsored research is also important for the responsiveness of universities to changing external needs. In California Stanford University and California Institute of Technology (CalTech) are successful in commercializing the IP, but the universities in the UC system have some problems with the commercialization process. University-industry relationships are particularly important for nanotechnology because of high entry barriers and the because they are at an early stage of development. Industry also needs to use the research facilities for nanotechnology at the universities. Because of the broad scope of nanotechnology, different kinds of partnering are important for business development (ST 2004C).

Several firms interested in nanotechnology have created R&D joint ventures with different academic centers including e.g.:

- MIT*s Institute of Soldier Nanotechnology is collaborating with DuPont and Raytheon.
- Stanford's Nanocharacterization Laboratory is collaborating with FEI Company.
- Albany Nanotech program, the State of New York receives funding from e.g. IBM, Sony and Sematech (NSTI 2004A).
- The Semiconductor Industry Association supports nanotechnology research at UC Berkeley Gigascale Silicon Research Center and UC Los Angeles Functional Engineering Nano Architectonics Focus Center (CCST 2004A).

8.4 Access to Capital

Venture capital firms in the US invested about USD 300–900 million or about 2–5 percent of total investments of USD 19 billion in nanotechnology firms during 2003; which can be compared to about 40 percent in information- and communication technology (ICT) firms (MoneyTree 2004A, NSTI 2004A). The size of the investments depends on what is included in the segment nanotechnology. Because of the high risks associated in general with nanotechnology investments, early stage angel investments are an important source of funding. About 40 percent of nanotechnology venture funding has gone to electronics and semiconductors and about 40 percent to nanobiotechnology. Californian firms received about 50 percent of total US nanotechnology venture capital funding in 2003, second was Massachusetts with a share of about 13 percent (NSTI 2004A). There are about ten venture capital (VC) firms in Silicon Valley that have funded nanotechnology companies e.g. Draper Fisher Jurvetson. Some of the other specific nanotechnology VC firms are Venrock, Harris and Harris, NexGen and Apax Partners. Access to capital is important for commercialization. In Silicon Valley the first round of venture financing is about five months faster than the US average (PPI 2003A).

About 55 percent of worldwide nanotechnology startups are based in the US. The top receivers of nanotechnology venture funding are the firms Catalytic Solutions, Nanosys, Quantum Dot, Molecular Imprints and Frontier Carbon. Together the five firms have raised about USD 250 million since 2001, representing about 20 percent of total nanotechnology venture funding. Venture funding in nanotechnology have been rather concentrated. In 2004 the firms, Immunicon, a developer of magnetic nanoparticles for cancer diagnosis and, Lumera, a developer of nanoscale polymers went public through IPO (Initial Public Offering) (Lux 2004A). But Nanosys withdrew its IPO in August 2004 because of limited demand from the capital market. The cancelled Nanosys IPO was a major issue for the nanotechnology community in 2004. Several members of the nanotechnology community are referring to a possible nanotechnology hype in USA. The true value of nanotechnology might get lost in the hype according to some analysts (Dallas 2004A).

The National Science Foundation has invested about USD 10 million per year in Nanotechnology firms since 2000 using the SBIR (Small Business Innovation Research) and STTR (Small Business Technology Transfer) programs. In 2003, 55 firms received SBIR/STTR Phase 1 funding and 11 firms received Phase 2 funding from NSF. The major product areas for the SBIR/STTR funding are carbon nanotubes, nanofiber and nanoparticle composites, nanofilter membranes and nanocrystalline coatings (NSF 2003B).

8.5 Commercialization Organizations

Arrowhead Research Corporation (ARC) is a company in the field of nanotechnology commercialization and is listed on the NASDAQ stock exchange (ARC 2004A). Arrowhead Research Corporation funds research at universities in pioneering scientific areas, primarily nanotechnology, in return for exclusive rights to commercialize technologies, intellectual property and patents developed as a result of this research. ARC also provides capital to other entities engaged in development and commercialization of nanoscale solutions. ARC has exclusive rights to 33 U.S. patents issued. ARC provides financial, administrative and strategic resources. The firm has agreements with the e.g. the California Institute of Technology and three of its faculty. ARC has created the firm Aonex Technologies to commercialize an ultra thin crystal film technology, Insert Therapeutics, to commercialize a proprietary drug delivery system, and Nanokinetics to commercialize various nanoscale applications. Nanokinetics will focus on the transition to mass production of market-ready nanotechnology products. Another nanotechnology R&D and commercialization organization is Applied Nanotech, a subsidiary of the firm Nano-Proprietary. Advance Nanotech is a UK and US based firm specializing in the acquisition and commercialization of nanotechnology. Independent commercialization organizations are an alternative approach to creating commercialization organizations within the universities. Specific firms with focus on technology in-licensing can facilitate the commercialization of university R&D.

8.6 Incubators

Incubators are a common tool to promote start-ups and support early stage companies. Hackett and Dilts define an incubator as follows (Hacket 2004A):

“A business incubator is a shared office-space facility that seeks to provide its incubatees (i.e. client-companies) with a strategic, value-adding intervention system (i.e. business incubation) of monitoring and assistance”.

In North America alone there are about 1 000 incubators of which approximately 37 percent are focused on supporting high-tech companies. One trend in the incubator industry is that the proportion of high-tech incubators is increasing. Another is that most high-tech incubators nowadays are mixed-use incubators, which means they host companies representing more than one sector. Biotech and IT are two leading sectors promoted so far in these incubators (ITPS 2004A). However, due to the great impact nanotechnology is expected to have on the economy and society as a whole, there is today an ongoing discussion within the incubator-industry whether or not establishing specific nanotechnology incubators is a good idea. For instance in Chippewa Valley in Minnesota a feasibility study (Gunderman 2005A) was conducted to find out if a nanotechnology-incubator should be started in the area. The study resulted in several reasons not to, one being that although nanotech-research is impressive, there is still a lack of commercial applications in the field. Cost is another important factor, the specialized equipment needed is very expensive ranging between USD 10–100 million. The study also says that finding a good management team for the nano-incubator would be both expensive and difficult. In the end the estimated cost per job is too high and thus a mixed-use technology incubator is what the feasibility study suggests for the Chippewa Valley. The same reasoning are more probably viable in other places and nanotech-incubators are therefore regarded as premature by many. However a lot of mixed-use technology incubators are already today allowing nanotech-companies in their facilities. One of them is the University of Central Florida Technology Incubator (UCFTI) which was named the incubator of the year in 2004 (ITPS 2004A). So even though pure nanotechnology incubators still aren't common, some nanotech-companies are already being incubated.

The California NanoSystems Institute (CNSI) is the result of a joint effort by the University of California, Los Angeles (UCLA), and the University of California, Santa Barbara (UCSB). CNSI aims to be a world-renowned center for nanosystems R&D and furthermore want to develop commercial applications of their own technology. In order to do this CNSI are at present building a facility in which they will operate incubator labs. The objective with these incubator labs is to transform research into the development of marketplace products. This will be done through collaboration with California industry (CNSI 2005A). The CNSI's plan for a nanotechnology incubator indicates that the phenomena will be more common in the future.

9 Other Issues

9.1 Health and Societal Implications

Nanotechnology provides great opportunities but the field is complex and it is important to consider the risks. The 21st Century Nanotechnology R&D Act states that an American Nanotechnology Preparedness Center for coordination and collection of studies on societal, environmental and legal impacts shall be established. The act also states that a research program for different societal concerns shall be established (Act 2003A). The focus on societal issues is significant because of earlier experiences from controversial technologies, such as some biotechnology segments. The NSTC NSET[17] has also created a special working group (Nanotechnology Environmental and Health Implications Working Group) with representatives from agencies that support nanotechnology and those with regulatory responsibility.

Little data exists on the impact nanomaterials in large quantities will have on the environment. Research on the societal and health implications of nanotechnology lags significantly behind scientific development (CCST 2004A, Woodrow 2004A). Several organizations are concerned about the potential toxicity of nanoparticles and are warning of pollutants from nanotechnology and some are calling for a moratorium on the release of nanoparticles in commercial products until further research has been performed. The US Environmental Protection Agency (EPA) has also announced that it is considering regulating nanomaterials due to increased concerns that these products could have health and environmental risks. At least four other agencies have programs for studying health risks (NSTC 2004A). A discussion about workplace safety guidelines for nanomaterial manufacturers is also ongoing (ST 2005A). Researcher have also found that fish exposed to nanoparticles suffered brain damage (CRN 2005A, ST 2004B). But nanotechnology also has the potential to eliminate many wasteful industrial processes and reduce future pollution, and Molecular Nanotechnology is also expected to play a role in the cleaning up toxic pollution in the environment (BASIC 2004A). The University California Davis has a center for Nanomaterials in the Environment.

The controversy has highlighted a need for federal research into the environmental and health effects of nanomaterials. The EPA (Environmental Protection Agency) has launched a USD 4 million research project that will study the toxicology of manufactured nanomaterials. NSF has funded the Center for Biological and Environmental Nanotechnology at Rice University (CBEN 2005A). The Nano-Center at the University of South Carolina has programs focusing on e.g. public dialogue. A dialogue between the scientific community and policy makers is important for the future of nanotechnology, fears and concerns need to be discussed (CCST 2004A). The California Council on Science and Technology has recommended the creation of nanoethics centers at some universities to work with social

[17] *National Science and Technology Council Nanoscale Science, Engineering, and Technology Subcommittee*

and ethical issues of nanotechnology. Addressing societal issues of nanotechnology is an important area for the National Nanotechnology Initiative (NSF 2001A). Several US universities with a nanotechnology program have some kind of education which also covers the societal aspects of nanotechnology.

Interest in the health impacts of nanotechnology is to a large extent driven by industry in the US including such companies as 3M and DuPont. The product liability relating to possible health impacts could lead to litigations. The uncertainty creates some hesitation in launching products including nanomaterials. Health implications of nanoparticles could eventually be compared to other “small particles” such as Asbestos. There are also several challenges related to the regulation of nanomaterials including the definition of different recommended nanoparticle emission limits. The National Institute for Occupational Safety and Health is working on workplace safety guidelines. The Woodrow Wilson Institute published a case study on Nanotechnology & Regulation in 2003 (Woodrow 2003A). Future international harmonized regulation of nanoparticle emissions is also an issue (RAND 2005B). From a business perspective, specific environmental regulations in e.g. California could be a barrier to development. Business concerns over regulating nanotechnology have increased in the last few years.

The Center for Biological and Environmental Nanotechnology (CBEN) at Rice University has formed the International Council on Nanotechnology (ICON), a collaboration between academic, industry, regulatory and non-governmental interest groups. ICON will work to assess, communicate, and reduce potential environmental and health risks associated with nanotechnology. The ICON organization is supported by industry, non-profit foundations, and governments. Based at Rice University in Hourston, the ICON is currently an affiliates program of the United States National Science Foundation’s Center for Biological and Environmental Nanotechnology (CBEN). Its membership extends beyond CBEN to include other national and international centers with an interest in its mission. All nanotechnology stakeholders, from non-governmental organizations to industry, participate in the organization’s governance and activities.

ICON’s mission is to assess, communicate, and reduce nanotechnology environmental and health risks while maximizing its societal benefit through:

- Science and engineering research into the environmental and health impacts of engineered nanostructures.
- Social science research into public acceptance of new technology, and the role that regulation and government policies can and should play.
- Collaborative policy activities that develop international standards for engineered nanostructure, terminology, safety guidelines, and best laboratory practices.
- Public communication and outreach that tracks all relevant technical data on nanotechnology’s risks and presents this information in a format accessible to non-specialists.

Privacy implications of nanotechnology are also of importance according to organizations such as RAND and the California Council of Science and Technology. Widespread distribution of invisible sensing devices could create privacy issues. Today usage of RFID is a policy issue in e.g. California. The implications of nanotechnology for Homeland Security are also a policy issue. Molecular nanotechnology weapons are difficult to control and could be hard to keep out of the hands of terrorists according to the Center for Responsible Nanotechnology (CRN 2005A). The possible military use of nanotechnology is a possibility, but also an issue. The US Department of Defense (DoD) funds a new class of weaponry that uses energy-packed nanometals (nanoenergentics) to create powerful, compact bombs.

9.2 Organization

The multidisciplinary nature of nanotechnology creates several particular organizational challenges for policy, academia and industry. The creation of interdisciplinary partnerships is a very important task for the nanotechnology community. To achieve the full potential of nanotechnology, universities must form partnerships among schools of science, engineering and business (NNI 2002A). Nanotechnology requires an integrated understanding of and collaboration between field such as e.g. biology, biotechnology, physics, chemistry, material science, computer science, mechanical engineering and electrical engineering. Researchers from different faculty have different approaches to nanotechnology research creating some interesting challenges. The multidisciplinary issues associated with nanotechnology are one of the most fundamental challenges for the creation of a successful nanotechnology policy. The National Nanotechnology Initiative fourth mode of investment has funded several initiatives to facilitate multidisciplinary research.

There are different approaches to the setup of nanotechnology research centers. The centers can be driven by demand for nanotechnology research by other faculty; a center with this approach is e.g. the University of California, Irvine (UCI) Integrated Nanosystems Research Facility (INRF). In this case the nanotechnology research center is a resource with nanotechnology knowledge and research infrastructure. The INRF facility is available for industrial partners as well. The centers can also have their own application agenda and a more nano-centric approach. The UCLA California NanoSystems Institute (CNSI) is working on e.g. nanosystems research and commercialization. The University of Southern California (USC) has created a Center for Interdisciplinary Research to foster creative new ideas that do not fall within disciplinary boundaries. The center sponsored e.g. applications of nanoelectromechanical systems (bioNEMS) in 2004. New buildings for nanotechnology centers are also often one important part of the different initiatives.

Nanotechnology does not fall very easily into the organization of several large companies today. The companies also have different approaches to nanotechnology research. Centralized nanotechnology programs are implemented at 42 percent of the companies and an equal proportion have decentralized activity without coordination according to a study made by Lux Research (Lux 2004B). Within some industries, nanotechnology only represents a process innovation leading to incremental improvements of current processes. But in several cases, nanotechnology also creates new products that can be recognized by end customers.

9.3 Education

Nanotechnology is an important part of the educational system in the US and there are about 200 academic nanotechnology programs. Several of the programs have been established as multidisciplinary initiatives. Support of education is also one of the goals in the strategic plan for the NNI. Some of the federal programs are NSF Research Experience for Teachers, Research Experience for Undergraduates and NSF grants to support nanoscale education course development. The University at Albany in New York has awarded the world's first Ph.D. degree in nanoscience in 2004 according to the school. The New York's nanotech efforts revolve around the Albany Nanotech Center. Earlier degrees were tied to other science disciplines. Education in nanotechnology needs to be improved at all levels and school children must also learn about nanotechnology during K-12 education to develop the nanotechnology workforce of the future (NNI 2002A). The California Council of Science and Technology recommends the establishment of a nanotechnology workforce training initiative together with invited industry partners, since in 5 to 10 years California will have a shortage of qualified nanotech workers (CCST 2004A).

The possible health effects of nanotechnology in combination with public concern and fear about future applications creates a need for information about nanotechnology for the public as well. The California Council on Science and Technology states that "keeping the public informed about nanotechnology is particularly important" (CCST 2004A).

10 Conclusions and Policy Recommendations

This study of nanotechnology in the USA concludes that the following implications are important for Swedish growth policy:

Policy

- **Consider a Swedish nanotechnology forum.** To be able to take appropriate action for Swedish science and technology policy, the creation of a nanotechnology forum with members of government, academia and industry to promote dialogue and the development of nanotechnology is a first possible step. In Sweden is nanotechnology to a large extent still only an issue for the research community. This study of nanotechnology in the USA shows that there is several different policy issues associated with a sustainable development of nanotechnology. General purpose technologies as information technology and nanotechnology have implications for several parts of the society and can require some kind of government governance. Because of the need for a broad policy perspective, more than 30 countries have initiated national nanotechnology initiatives. For successful long term nanotechnology R&D, is a broad policy perspective of importance covering areas such as societal issues, outreach, education and commercialization. One initial objective for a Swedish forum could be to establish a Swedish nanotechnology strategy whitepaper including a roadmap. The forum can be a platform for a broad dialogue about nanotechnology.
- **Establish a national nanotechnology program.** Several smaller countries such as Switzerland have also created nanotechnology initiatives. Nanotechnology initiatives are a way to improve the high technology image of a country. In the beginning of 2004, the HelsinkiNano initiative was launched. Nanotechnology is multidisciplinary research with implications for areas such as information technology and biotechnology. But nanotechnology requires new approaches to be able to create e.g. the necessary interdisciplinary research cooperation and commercialization. Nanotechnology creates particular policy challenges for funding multidisciplinary research, commercialization, health- and environmental impacts and education. Swedish organizations with responsibility for R&D funding can face problems today in allocating funding to nanotechnology because it is not considered to be a specific scientific segment. This problem indicates that successful funding of nanotechnology could require national initiatives with a multidisciplinary approach. A particular nanotechnology initiative will facilitate a focus on the multidisciplinary dimension of nanotechnology.
- **Outreach and societal implications are important.** Public concern and fear about future nanotechnology applications creates a need for information about nanotechnology also for the public. The new strategic plan for the NNI is also creating greater focus on the societal implications. A dialogue between the scientific community and policy makers is important for

the future of nanotechnology; fears and concerns need to be discussed. Also the research community needs a better understanding about the risks associated with nanotechnology.

- **A possible need for regulation.** Several organizations are concerned about the potential health and environmental impact of nanotechnology. Some companies also hesitate to launch nanoenabled products because of the risk of product liability leading to litigations. The possible future impact could be compared to Asbestos. Several policy challenges related to regulation of nanotechnology exist such as the definition of workplace emission limits and international harmonization.
- **A dynamic science and technology (S&T) policy process.** The US Nanotechnology Initiative was formed by a bottom-up policy process initiated within the scientific community. Nanotechnology is in several ways a complex area with broad implications for several policy areas. In the USA the Nanotechnology Initiative is one of only three multiagency R&D initiatives. A dynamic S&T policy process requires the combination of top-down initiatives because of e.g. major external chocks such as the 9/11-terrorist attacks and also bottom-up initiatives.
- **The importance of public-private partnerships.** Public-private partnerships play an important role on the state and regional level in advancing nanotechnology by combining public sector funding and research capabilities with the private sector. Examples of recommendations to policymakers for keeping California in a leading position in nanotechnology in the future are the creation of a state version of the Nanotechnology Initiative (NNI) and focusing different efforts on education, economic policy, societal and environmental issues, as well as streamlining the technology licensing process.

Research & Development

- **Several initiatives for nanotechnology.** Funding for the US multiagency nanotechnology initiative (NNI) represents approximately 1 percent of federal R&D or about USD 1 billion in 2004. However, nanotechnology funding is about 8 percent of the National Science Foundation budget. State and local funding is about USD 400 million and annual venture capital funding about USD 300 million. The NNI funding request for 2005 represents an increase of 14 percent compared to the funding in 2003. About 29 federally funded centers of excellence for nanotechnology R&D and 70 nanoscience and technology centers have been initiated, and more than 15 state initiatives have also been launched.
- **Lack of research infrastructure.** Research infrastructure facilities available to the scientific community to synthesize processes and fabricate nanoscale materials and structures are a bottleneck for nanotechnology research today. A fundamental part of US nanotechnology initiatives is the creation of new R&D infrastructure that can be used both by academia and industry.

- **High priority for funding of interdisciplinary research.** The need for interdisciplinary research and the issues associated with it is one of the most important challenges for the nanotechnology community in the US. The creation of cross-disciplinary networks and partnerships and multidisciplinary collaboration is an important aspect of the US National Nanotechnology Initiative.
- **Nano-tools and nano-based diagnostics are possible Swedish segments.** Development of software based nano-tools for e.g. simulation and visualization is a segment with low entry barriers and with an existing market demand. The specific importance of tools for nanoscience R&D is also recognized by the new strategy for the NNI. Nano-based diagnostics is another segment that could be one focus area for a Swedish nanotechnology initiative.

Commercialization

- **Federal initiatives important for commercialization.** Nanotechnology requires expensive R&D equipment, cost of manufacturing is high and the need for multi disciplinary teams adds additional costs. The allocation of capital for nanotechnology commercialization is more difficult than for other high-tech segments. Federal and state initiatives for nanotechnology are very important for successful commercialization of nanotechnology. The new strategic plan for the NNI published in 2004 also puts greater emphasis on technology transfer.
- **Intellectual property (IP) issues are particularly important.** IP is more important for nanotechnology commercialization than for several other high-tech areas such as information technology. Very few independent entrepreneurs are commercializing nanotechnology. For nanotechnology technology in-licensing is driving commercialization. Specific firms with a focus on technology in-licensing could facilitate the commercialization of university R&D.

Industry

- **Important long term impacts on industry dynamics.** Nanotechnology is considered by many to be a disruptive technology with the potential to change, create or render obsolete entire business segments. Disruptive technologies can rapidly shift the global balance of economic and military power. Nanotechnology will create an impact on almost all industry segments including e.g. electronics, pharmaceuticals, energy and transportation. The possible productivity impacts of nanotechnology may be similar to information technology.
- **Too high expectations are a threat.** Interest in nanotechnology has increased tremendously during the last few years in the US and created a situation with short term expectations that in some cases are too high. This could pose a threat to long term development.

Appendix

US Nanotechnology Companies

Firms	Focus areas
Nanofilm	Ultrathin polymer coatings for eyewear
Inmat	Nanocomposite barrier coatings
InnovaLight	Develops solid-state lighting solutions
Nanostellar	Develops Platinum Nano-Composite Catalysts
NanoDynamics	Manufacturer of nanomaterials
NanoString Technologies	Bar coding system for single molecules
ZettaCore	Molecular electronics for ultradense memory systems
Nanomix	Nanotubes for sensors and displays
Kovio	Nanoparticle-based printable electronics
Aryx	IP in the area of retrometabolic drug design
Accelrys	Scientific software applications
General Nanotechnology	Developer of nanotechnology tools
GlimmerGlass	Micromirror-based switching technology
Polyfuel	Engineered membranes for fuel cells
NanoGram	Technology enabling the manufacture at nanoscale
Chlorogen	Chloroplast transformation technology
Nanopharma	Therapeutics based on glycomimetic technologies
Nantero	Carbon nanotubes for next-generation semiconductor devices
Materials Modification	Solutions based on nanocrystalline metals and ceramics
Nanogate	Easy-clean nanocoating, a German-based firm
Micro Emissive Displays	Ultra-miniature quality screens, a UK-based firm
Oxonica	Nanomaterials with 38 patents, a UK-based firm

Source: Web sites for each company.

California Nanosystems Institute Industry Alliance

Accelrys
Affymax
Agilent Technologies
Agility
Amgen
Applied Epi
Ceres, Inc.
Concorde Microsystems, Inc.
Cree, Inc.
CTI, Inc
Ericsson Datacom
Terry & Carolyn Gannon Fund
Hendry Telephone Products
Hewlett-Packard
T. Milton & Marilyn Honea
Intel Corporation
Eric Roger Kanowsky
LeadScope, Inc.
Los Alamos National Laboratory
Medea
Oracle
Rockwell Scientific
Sequenom
SGI
Silicon Valley Bank
Sputtered Films, Inc.
Starbuck, Tisdale & Associates
Stradling Yocca Carlson & Rauth
Sun Microsystems
Veeco Metrology Group

Source: CNSI, January 2005.

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The Swedish Institute for Growth Policy Studies (ITPS) is a Government Agency responsible for providing policy intelligence to strengthen growth policy in Sweden. ITPS primarily provides the Government Offices, Members of the Swedish Parliament, other state authorities and agencies with briefings based on statistical material, policy papers and key analyses. Business policy and regional development policy are areas given high priority.

Changes in policy should be based on:

- Statistic data and analyses of the structure and dynamics of industry
  – to obtain an up-to-date view of future challenges and opportunities.
- Evaluation of results and effects of policy measures and programmes
  – to provide benchmarks and learn from measures implemented earlier.
- Policy intelligence in order to look outwards and ahead
  – what issues are likely to come on the growth policy agenda in the future?

These represent the principal missions of ITPS

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