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Nanotechnology: What is it and how will it affect us?

A non-technical review of nanotechnology from a Catalan perspective – its potential economic and social impacts and the potential role of public policy.

FUNDACIÓ CATALANA PER A LA RECERCA I LA INNOVACIÓ

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THE ADDED-VALUE OF INDEPENDENCE

As a result of a reorganisation of the activities of the Catalan Foundation for Research and Innovation (FCRI), the Foundation today is a competent and expert instrument capable of providing the necessary elements of analysis and understanding of science and technology issues to the Catalan research and innovation system. We complement the promotion functions of the system and especially those of dissemination of scientific knowledge.

Within the framework of challenges and commitments agreed within the Catalan Agreement for Research and Innovartion (CARI), signed in November 2008, the FCRI plays a structural and independent role, enabling inter-institutional connections to co-ordinate activities and programmes and, consequently, the production of impartial studies to assess needs, research outcomes, regulation and impact.

This capacity for projection and service to the Catalan research and innovation system, which derives partially from the Foundation´s unique public/private nature, enables us to take a position, both legitimate and capable of consensus, in order to co-ordinate analysis and study groups on research development. Over the next few months, actions detailed in the CARI that will change the Catalan research system to make it more efficient and effective, will also shape the FCRI with new characteristics. Nevertheless, the ability to reach consensus and the Foundation's continued impartiality will be preserved in order to continue to provide competent resources for analysis and forecasts.

In early 2008 we launched the ICPDE series of reports. You have in your hands a new report devoted to nanotechnology, one of the most multidisciplinary frontier fields of science and one which at the same time presents numerous challenges to our methods of production, to society, and to people's lives, generating many controversies and questions.

As you will see in these pages, the ICPDE reports aim to ensure that research outcomes, players, resources and international research trends are accessible to society in general as well as R&D&I stakeholders. The FCRI's role as an advisory and foresight institution, along with its other activities, are being developed as a truly neutral perspective which will be enriched with other similar actions, such as the in-depth liaison with the EPTA network (European Parlamentary Technology Assessment), the co-operation with STOA (Science and Technology Options Assessment) as well as with the Parliament's Advisory Council on Science and Technology (CAPCIT), which is responsible for informing and providing advice on science and technology for the Parliament of Catalonia.

The FCRI is becoming a catalyst for new initiatives in the system. It offers a flexible and improved structure which is independent professionally and politically speaking and which is placed at the service of Catalonia. I am absolutely certain that we will achieve maximum benefit within the new research structure in Catalonia.

Joan Comella
Director
Catalan Foundation for Research and Innovation

INFORMATION ON DECISION MAKING... ON NANO?

Last year, Harvard University recommended the book Physics for future presidents, a great sales success, which in plain comprehensible language, dealt with the importance of various physical processes useful for understanding and making decisions on energy sources, to support desicions on research or risks in the space race.

In Barcelona at the same time, the Catalan Foundation for Research and Innovation (FCRI) launched the collection "Scientific Reports on Decision Making (ICPDE) with the same objective: getting relevant information on a technology or a scientific area across to the public in plain but still rigorous language.

Naturally, information is necessary in order to take a position, make decisions between various options or to learn more about a subject in order to form an opinion. This is especially the case in scientific and technological subjects, which we can understand and assess only if we have specialised information, which is often not accessible to everyone. Meanwhile the internet and new technologies also enable us to directly access information, sometimes so much so that it is difficult to differentiate and select what is relevant.

In the face of these needs and serving the purpose of bringing scientific knowledge closer to society, the FCRI launched the ICPDE collection that aims to provide the layman public with information and expert, independent analysis to facilitate decision making and strategic positions in science and technology; to help them to learn about the consequences of new technologies and to foster the development of research and innovation in Catalonia.

Decision making on subjects related to scientific knowlegde requires information on advances and technology and science fields that are relevant for society and which should be included in the political agenda. It is also necessary to learn more about controversies related to the science, their causes and consequences, and relationships with stakeholders.

Technology Assessment is a concept that embraces different forms of policy analysis on the relation between science and technology and typically includes policy analysis approaches such as foresight, economic analysis, systems analysis and strategic analysis.

The ICPDE reports are intended for open-minded and dynamic public audiences in Catalonia, from institutions in that make political decisions to institutions enforcing, assessing or explaining those decisions to other citizens.

So, as Director of this FCRI's collection, I am very pleased to present the 2nd ICPDE report "Nanotecnology: what is it and how will it affect us?" that will surely become a useful tool for those in need.

Judit Castellà
Director of Programmes
Catalan Foundation for Research and Innovation

FOREWORD

Sometimes when facts are first presented, they can cause a radical change in perception and help us target problems and opportunities from new perspectives. This is the case of nanotechnology. Richard Feynmann, Nobel Physics Prize winner, gave a talk in an American Physical Society meeting at Caltech (California Institute of Technology), in December 1959, the title of which has since become famous, “There’s Plenty of Room at the Bottom”, where the scientist considered the possibility of direct manipulation of individual atoms and its consequences. These ideas started to be realized in the early 1980’s when Binnig and Rohrer, two researchers at IBM’s research labs in Zurich, designed the first scanning tunneling microscope allowing solid surfaces to be imaged with atomic scale resolution. The scientific community immediately understood the utmost importance of the discovery and they received the Physics Nobel Prize in 1986.

Since then, the expected scientific and technological benefits as well as the social impact of nanotechnology have continued to increase exponentially. The EU and the US have taken the lead, but also developed and emerging countries have been drafting initiatives and communications, and structuring policies to back the development of nanotechnology. Catalonia has not been excluded. Catalonia has endorsed the commitments agreed by the EU in the Lisbon (2000) and Barcelona (2002) meetings that focused on promoting an economic growth model based on knowledge, with nanotechnology as a fundamental part of the scheme. Nanotechnology, as identified in the Research and Innovation Plan for Catalonia 2005-2008, is one of the seven priority technology areas to incentivise the development of appropriate standards of competitiveness in strategic sectors as well as medium-term competitiveness in all producing sectors.

But, what exactly is nanotechnology? Which areas does it cover? What impact has it on the business world? How will it affect the social welfare of people? What potential risks are involved? Answers to these questions should be clear and understandable to help policymakers be aware of nanotechnology’s importance and to immediately design lines of action to convert scientific development into technological and innovative development in the business sector.

This report by FCRI responds in a clear, rigorous and educational manner to these questions. I would stress three important issues. The report compares the impact of nanotechnology on society with the one of the greatest scientific discoveries of the 19th century: electricity. I believe this is an appropriate comparison as it is expected that nanotechnology will become integrated into all human activities. This spirit fits my personal perception that nanotechnology will drive the next industrial revolution. The second point is the impact of nanotechnology on industry. Nanotechnology should be seen as an opportunity to add value by improving technologies but, in addition, the producing sector must be prepared to assimilate new applications based on nanotechnology. The key issue is that many applications do not require sophisticated technologies but rather new ideas. Nanotechnology in many fields is available at an affordable cost. Moreover, there is still time for industry to actively participate in this revolution and the Catalan Agreement on Research and Innovation (CARI) must be the basis of the roadmap. The third issue is the control

of potential risks. Particularly the EU is investing significant effort in this field and, as outlined in the Commission Communications on European strategy on nanotechnology, is fostering proactive policies to safeguard the health and security of citizens.

The document that you have in your hands joins the ICPDE collection. At the end of the text are number of recommendations that I endorse as correct and appropriate. It is not easy to put together a report on such a vast and transversal subject as nanotechnology, and to deal with the disparity of issues that fall within the umbrella of nanotechnology.

In short, this document and the many references presented in the text should help politicians at all levels to underpin their decisions with sound arguments based on a good knowledge of the subject matter, as this document aimed to do and very much succeeds.

Jordi Pascual
Director
Catalan Institute of Nanotechnology

ABOUT THE AUTHOR

Born in Melbourne, Australia, Boaz Kogon studied biochemistry, information technology and applied mathematics at the University of Western Australia before pursuing a corporate career in agrifoods, working with both small firms and large multinationals with postings in Perth, Auckland and Tel-Aviv. He has recently completed an MSC in the Economics of Science and Innovation at the Barcelona Graduate School of Economics.

He is currently Project Manager at the Institut Catala de Nanotecnologia in Barcelona and also acts as a freelance consultant in marketing & business strategy, primarily in agrifoods and biotech. His previous posts include R&D Manager at AION Diagnostics and General Manager Marketing at Milne AgriGroup both in Perth, Western Australia.

NANOTECHNOLOGY: WHAT IS IT AND HOW WILL IT AFFECT US?

Governments and industry are pouring billions of euros into developing nanotechnology, while the media and consumer goods companies use the word “nano” with ever-increasing regularity. Yet nanotechnology is well understood by very few outside the scientific community even though its impacts, both positive and negative, are likely to affect many aspects of our lives within a decade. This report aims to give the non-scientist a brief yet comprehensive overview of nanotechnology – what it is, what its impacts will be on industry, the economy, the environment and society - and suggests some actions that can be implemented on a regional basis to address the key issues of concern, with particular reference to Catalonia.

KEY WORDS

Nano; nanotechnology; particles; R&D; technology transfer

CONTENTS

E ECUTIVE SUMMARY

Nanotechnology is a general term referring to many different technologies and applications that utilise the peculiar behaviour of matter when it is formed into very small structures (below a few hundreds of nanometres; around 0.0000001m). At this scale, the classical laws of physics give way to quantum laws, often resulting in materials displaying very different properties to those they have in their bulk form.[1] Such changes include colour, conductivity, reactivity and physical strength,[2] amongst others.

Nanotechnology is considered to be so important because it bears all the signs of being a powerful general purpose technology (GPT), similar to electricity, the steam engine and the computer. GPT's are characterised as being applicable to many different sectors of industry, having large impacts on other technologies, and driving significant changes in economic productivity. Whilst extremely positive for productivity over the longer term, GPTs can cause significant disruption and require massive investments in infrastructure when they are first introduced.

Nanotechnology is not just a future vision - many nanotechnologies are already used in products on the market today.[4] However the use of the word "nano" is not regulated, and many products are marketed as "nano" merely because they are small or new, even though the products themselves often do not use any nanotechnologies.[5]

Over the last decade nanotechnology has seen explosive growth worldwide in both advances and investment, similar to that which occurred with genetic technologies in the 1990s. This sudden appearance is due to many reasons, primarily because nanotechnology is the result of convergent technologies (see ICPDE report n. 01 on the NBIC FCRI, July 2008). Its emergence required the prior development of an array of capabilities in many different fields.[6] Key among them; advances in microscopy that have enabled individual atoms to be imaged, advances in scientific theory that enabled the peculiar behaviour of matter at the nano-scale to be explained, advances in synthesis with control over size, shape and assembly, and advances in manufacturing techniques driven by the semiconductor industry that allow nano-scale structures and particles to be easily produced.

Nanotechnology has practical applications in almost every area; medical nanotechnologies[7] offer vastly improved treatments, implants and surgical devices; nano-materials offer stronger and lighter construction materials, corrosion resistant surfaces, even completely new materials integrating biologics with inorganics; nano-electronics offer ever smaller and more powerful computing, flexible video displays and circuitry woven into clothing; nano-particles offer improved cosmetics and catalysts; important applications also exist in energy, household goods, food, the environment, aerospace and the military.

In general, most forecasts describe three broad phases of nanotechnology development:[8]

- *Early stage (next 5 years): nanotechnology is at investigation phase and scientific nowledge is beginning to ta e shape in solid applications*

- *Commercial development (5-10 years): during this period many different applications are e pected to be developed and to begin to be produced on an industrial scale*

- *Widespread use (10-15 years): nanotechnology will be consolidated as an industry and consumers will en oy a wide range of products using nanotechnology. At this point it is anticipated that the worldwide mar et for nanotechnology enabled applications and products could e ceed US   trillion.*

The impact on industry will differ from sector to sector. For some industries, nanotechnologies will offer incremental improvements and these changes may well be easily absorbed within a normal program of continuous improvement. Other industries, however, may require extensive replacement of outdated equipment and infrastructure with potentially disruptive consequences.

It should be noted that nanotechnology is not always expensive to implement. Once methods of production are known and commercialised, they may involve simple upgrades or refinements of existing processes. Therefore some industries will progress naturally to using nanotechnologies without requiring major investments.

Impacts on the environment have the potential to be both positive and negative.[9] Many nanotechnologies will improve efficiencies (use less energy and materials) and reduce polluting by-products. Nanotechnologies may also be used to monitor the environment and correct problems such as oil spills and control disease outbreaks. However some nano-materials, in particular nano-particles, may prove to be toxic and difficult to contain, thereby posing risks to human and environmental health. The current lack of strong regulation and control in this area is a major cause of concern[10]for the general public.

The impact on society is expected to be profound[11]with many facets of everyday life affected and significant quality of life improvements. There are however a number of serious social issues developing; some nanotechnologies such as sensors and robots may pose significant challenges to privacy rights, the potential inequalities from those with access to nanotechnologies and those without may give rise to tensions, nanotechnologies potentially increase the risk posed by malevolent individuals or terrorist organisations, and the unknown health risks to both workers, consumers and the environment is probably society's most pressing concern. Whilst important, it should be noted that these concerns are not unique to nanotechnology, as similar concerns exist for most new technologies.

The initial driver behind the global advance in nanotechnology was public funding and it still plays a major role. The EU leads the world in public investment, with the EC

and member states investing over US 2 billion per year since 2005, followed by the US   US 1.7 billion, Japan   US 1 billion and the rest of the world combined   US 0.7 billion.[8] This is reflected in scientific output, with the EU producing   40   of peer reviewed scientific literature related to nanotechnology over the last decade.

However private investment in nanotechnology (which now exceeds global public funding) has been lagging in the EU compared to the rest of the world. Private investment in the US exceeds US 2 billion and Japanese investment US 1.7 billion, yet European industry is investing only US 1 billion per annum. This lack of involvement by industry is reflected in the number of patents granted and products brought to market, with the US[12] and Japan clearly doing better than Europe, which produces only some 12   of nanotechnology products currently on the market.

Spain, like most other advanced countries, has seen tremendous growth this decade in nanotechnology related R&D. In the year 2000, fewer than 100 scientists nationwide were dedicated to nanotechnology, now that number is well over 1000 with many more scientists in diverse fields involving aspects of nanotechnology in their work.[1]

Nevertheless, Spain's investment in nanotechnology is well behind many other countries of similar, and even smaller size, both on a total and a per capita basis. Furthermore the general European problem with technology transfer appears to be even more acute in Spain.[14]

Within Spain, Catalonia has the largest number of nanotechnology groups after Madrid, with a dedicated Institute of Nanotechnology as well as a number of other institutes and research groups heavily involved in nanotechnology.

A large number of reports have been written in recent years on the various technological, industrial and social issues surrounding nanotechnology.[15,16,17] Most favour strong action in public policy to invest in basic research while encouraging and stimulating technology transfer and the development of commercial applications; regulate health and safety issues, and develop international labelling and measurement standards; address workforce needs by establishing multi-ldisciplinary training and education schemes, supported by more general public education on nanotechnology.

An addition to these general objectives, regions such as Catalonia could also consider how best to focus limited resources. Other small regions and countries are attempting to create individual niches in technological and industrial capabilities in order to attain leadership in one or more sectors. Catalonia has significant existing strengths in certain industries and technologies, such as biosciences, that could be leveraged in this way.

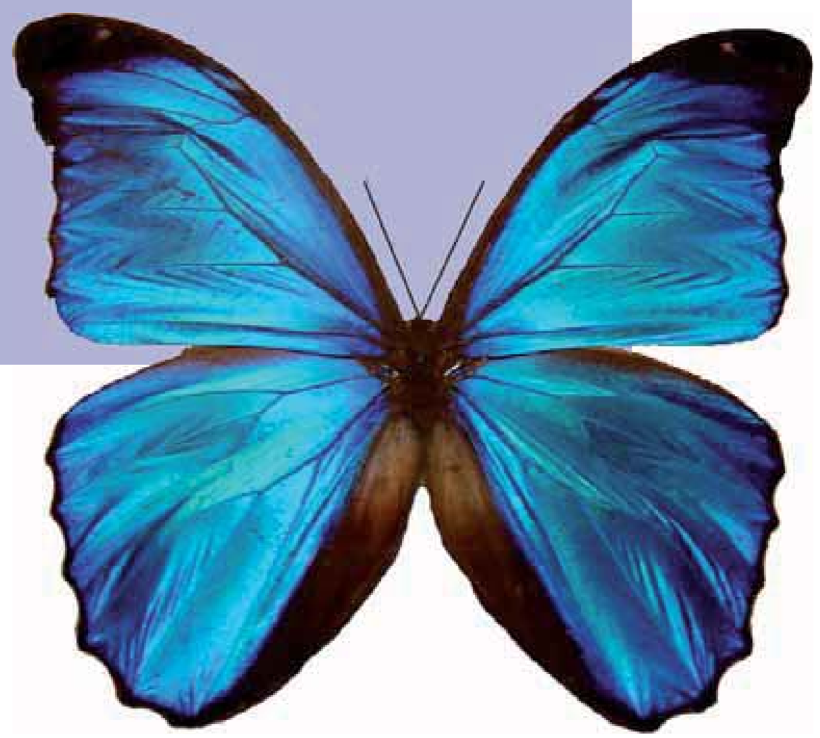
INTRODUCTION

Nanotechnology refers to any technology that makes use of the peculiar properties of matter that begin to manifest when matter is structured at a scale below around 100nm (0.0000001 metres). Nano-effects are not new – they are widely present in nature, for example the carbon nano-particles in the soot of fires and the brilliant colours of butterfly wings produced by the nano-structured surface of their scales.

N N EC N IN N RE - utterfly ings

The colours of a butterfly are not formed by pigments, such as the colours of our eyes and the dyes used to colour our clothes, but rather by controlling and manipulating light via complex nano-structures.

Butterfly wings are covered by thousands of tiny scales, each of which are nano-structured in specific ways that cause only certain colours of light to be reflected at specific angles. These types of nano-structures are called photonic crystals and are found in many other natural examples, including the iridescent colours of a peacock's feathers and the mysterious colours of opal stones.



Photograph of a blue morpho butterfly(Morpho menelaus) by Gregory Phillips, free available at http://commons.wikimedia.org/wiki/File:Blue morpho butterfly.jpg, under GNU license

However what is new is our ability to observe, manipulate and control matter at the nano-scale and to do so in commercial quantities. A powerful convergence of new tools, capabilities and understandings are enabling scientists to not just observe, but also manipulate and form particles and structures at the nano-scale.

The science is also rapidly being commercialised into a vast array of new particles and devices with practical applications,[18] ultra-sensitive sensors that can detect contaminants and pathogens, microscopic motion sensors for security applications, medicinal particles that can deliver drugs directly to tumours, surfaces that stick (or don't stick), integrated lab-on-a-chip' devices that can provide instant test results for at-home diagnostics. The list is endless.

The first wave of commercial products has already arrived, with over 807 on the

market worldwide,[4] including everyday items such as toothpastes, cosmetics, tennis rackets and socks. To date these are fairly simple in both technology and function, yet with over 420 companies in 21 countries publicly proclaiming they are developing nano-technology related products the number and complexity of nanotechnologies is expected to explode, with forecasts[8,15] of 1 trillion in sales by 2015.

However along with benefits come dangers. Many of the nano-particles and nano-materials being developed do not exist in nature and their peculiar properties could pose serious health and environmental hazards.[19] There is concern that if nano-industries are not properly regulated then the public may develop a distrust of the technology resulting in a similar backlash as occurred with genetic engineering technologies. The EC has acknowledged this concern and is acting to increase research and improve legislation in appropriate areas.

Also at issue for policy makers is how to assess in which domestic industries nano-technology is likely to be important for maintaining competitive advantage and to ensure that resources in R&D and technology transfer are adequately deployed to ensure that local industries do not become obsolete.[20] This is of particular concern in Europe, which seems to be lagging behind other regions in commercialising the results of its research.

The aim of this paper is to provide a broad overview of major recent developments in nano-technologies at both the research and commercialisation levels, highlight those issues which have been identified as being of concern to the public, and provide recommendations as to which public policies might be reviewed to address the needs of the public, industry and academia.

MAIN DISCUSSION

W S OE OO Y

Definitions of nanotechnology vary, but the common theme is that it includes any technique that either manipulates matter at the nanometre scale or that makes use of the peculiar properties of matter that occur at that scale.[21]

The word “nano” itself originates from the Greek word meaning “dwarf”[2] and in scientific measurements means “one billionth”. Therefore 1 “nanometre” means 1 billionth of a metre. To give some perspective, the width of a human hair is around 80,000 nanometres. A DNA strand is about 2nm wide. A million nano-particles could fit on the dot of an i’.

The fundamental contrast[22] between nanotechnology and the older micro-technologies used in computer chips, is that the downsizing process has broken through a critical barrier; beyond it, the laws of classical Newtonian physics don’t always apply and different laws described by uantum physics dominate.

Any material reduced to the nano-scale can therefore behave very differently than it does in its bulk form. For example, electrically insulating materials can become conducting, insoluble substances soluble, colours can change or become transparent.

Nanotechnologies come in many forms:[2]

- *Nano-particles are particles of any material that are smaller than around nm. These often occur naturally for e ample in the smo e from fires and the ash from volcanoes. They have been produced accidentally by human activities for e ample in the e haust of car engines and they are now increasingly being manufactured deliberately for e ample nano-si ed titanium dio ide particles in sun creams to protect the s in from U radiation .*

- *Nano-tubes are tubular structures usually composed of carbon atoms which have a diameter in the nanoscale typically several nanometres across. They can e hibit e traordinary strength and uni ue electrical and thermal properties ma ing them potentially useful in many applications in electronics optics and other fields of materials science as well as potential uses in architectural fields.*

- *Nano-electronics[24] when defined by scientists usually refers to electronic circuits and devices that ma e use of the special properties of matter at the nanometre scale for e ample atom-si ed transistors that can be switched with ust one electron . Although most computer chips produced in the last few years carry millions of transistors that are smaller than nm and therefore could strictly be called nanotechnology because these functions in much the same way as their larger predecessors they are not generally considered to be truly nanotech but rather ust nano-si ed versions of traditional micro-electronics.*

  However because transistor si es are now approaching the scale at which nano-effects come into play they are reaching the physical limit of miniaturisation. The huge investment currently being made in nano-electronics is therefore aimed at developing the ne t generation technology leading contenders include molecular electronics and optical switches that will enable computing power and miniaturisation to eep progressing past the physical limit of current microelectronic technologies.

- *Nano-materials are standard materials such as metals plastics and composites which incorporate nano-particles or nano-surfaces. Including small amounts of nano-particles in a substance can dramatically change its properties for e ample leading to lighter and stronger construction materials. Thin surface layers of nano-structured materials can li ewise dramatically change surface properties ma ing the materials scratch resistant easier to clean or even capable of converting solar energy to electricity photovoltaics .*

- *Nano-medicine is the application of nanotechnology to medical applications. This could include the use of nano-si ed devices such as sensors and implants nano-structured coatings on surfaces e.g. to avoid the body re ecting mechanical implants or nano-si ed particles to improve drug delivery.*

  Importantly nanotechnologies potentially offer tools that will help in the development of theranostics the ability to combine diagnosis and therapy. For e ample several companies are developing nanoscale devices to be in ected into the body that could identify a cancer and act immediately by releasing a drug directly at the cancer site.

- *Nano-robotics[25] is the development of tiny machines which could be used for medical applications e.g. tiny robots to scrub your arteries free of cholesterol deposits but could also be used for many other purposes as environmental sensors to repair and clean machines and homes or even to construct other machines.*

  Although wor ing nano-robots are still very far from being developed the concept is of concern to many people as such machines could cause significant damage if designed maliciously or allowed to run out of control.

- *Nano-sensors are nano-si ed devices that measure physical chemical or biological properties and relay the information in a way which is useful for humans. For e ample they could be dispersed throughout a manufacturing plant and report on any lea s of dangerous chemicals or they could be used in public places to detect dangerous diseases e plosives or poisons. Commercial* *nano-sensors are at the early stages of development although it is envisaged that these will be available much sooner than nano-robots.*

S E MP E Electron and to ic orce Microscopes

Microscopes using light have been used for hundreds of years to enable scientists to study microscopic structures. However light based microscopes have a fundamental limit of about 1000 times magnification.

In the 1920s it was discovered that electrons travelling at high speed behave like light, and that furthermore magnetic and electric fields could be used as lenses to focus and direct them. Dr Ernst Ruska at the University of Berlin combined these characteristics and built the first Transmission Electron Microscope (TEM) in 19 1. For this and subsequent work on the subject, he was awarded the Nobel Prize for Physics in 1986.

Recently electron microscopes have undergone dramatic improvements. Modern day electron microscopes can achieve magnifications up to 1 million times with a resolution of 0.1nm – powerful enough to see individual atoms.

Another form of microscopy called scanning probe microscopy was developed in 1981 by Gerd Binnig and Heinrich Rohrer (for which they also shared the 1986 Nobel Prize for Physics). Scanning probe microscopy uses a sensitive tip to directly interact with the surface of sample to build a -D image of the sample surface.

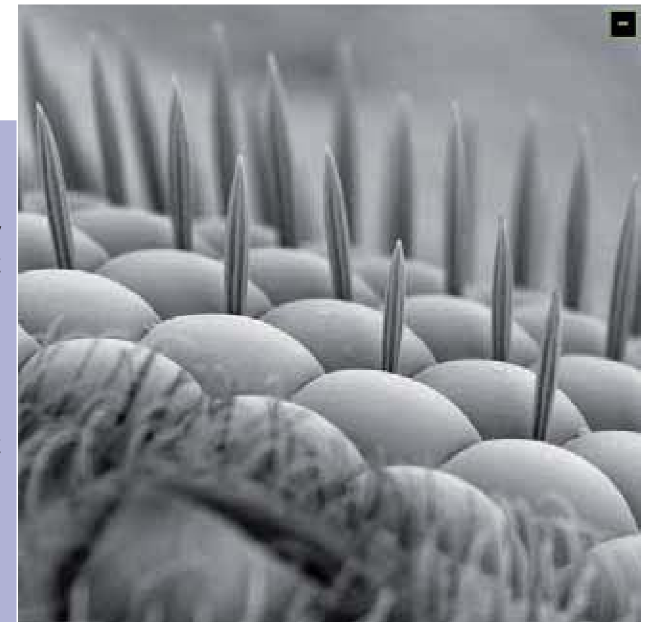
A number of different scanning probe systems have since been developed, including the Atomic Force Microscope (AFM) which has been particularly useful in the development of nanotechnologies due to its ability not only to measure surfaces but to also manipulate atoms and molecules on the surfaces of samples.

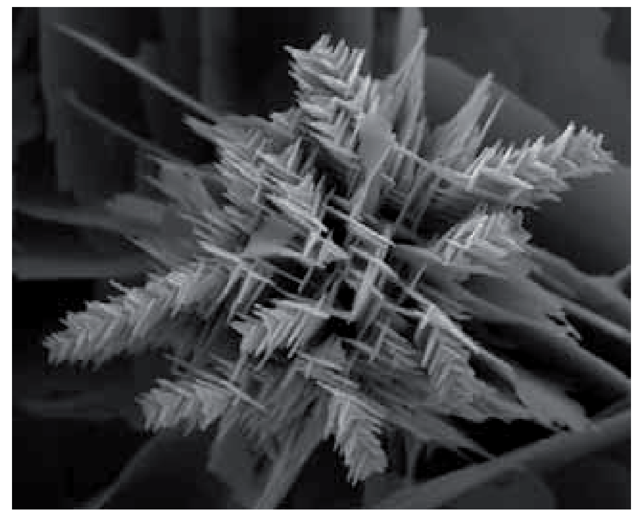
The AFM is significantly cheaper and able to operate in much less stringent environments than electron microscopes and is able to image almost any type of surface, including polymers, ceramics, composites, glass, and biological samples.

These tools enable scientists to push the boundaries of discovery and exploration, facilitating breakthroughs in pharmacology, biotechnology, forensics, pathology, materials science, semiconductor manufacturing and data storage.

Photographies available at http://www.fei.com/Resources/image gallery.aspx; http://www.fei.com/uploadedImages/Resources/image gallery/images/others/fly eye.jpg and http://www.fei.com/resources/nanoscale-bug.aspx. FEI Company.

- *Nanotoxicology is the study of the to icity of nano-materials. ost concerns in regards to to icity relate to nano-particles although nano-structured surfaces and nano-medical devices also have potential to cause harm. Some nano-particles are potentially dangerous due to specific properties such as small si e large reactive surface area or the difficulties in eeping them from spreading into the invornment.*





W Y S O E O O Y OR

Nanotechnology is considered by many to be extremely important because it shows all the signs of developing into a General Purpose Technology (GPT).

"General Purpose Technology" is a term used by economists to describe great leaps of innovation that can affect entire economies, usually at a national and eventually global level. Past examples include the development of writing, steel, the steam engine, railroads, electricity, telecommunications and computers.

GPTs are characterized by:

- *Pervasiveness: they are used in many downstream sectors*
- *Technological dynamisms: they inrease the potential of an economy to support continous innovation in industry and science and*
- *Innovational complementarities: they provide improved capabilities in many other technical areas thereby increasing the productivity of research and development in many sectors.*

As a result of these impacts, GPTs have profound effects on the economy. Not all of these effects are good – although GPTs can lead over the longer term to huge increases in productivity and economic growth, in the shorter term they can create significant disruption. Existing infrastructure, equipment and work skills can become outdated, meaning that companies close down, workers need retraining and governments are forced to make significant investments in upgrades. (A classic example is the introduction of the steam engine and railroads).

Sometimes the introduction of a GPT can create social concerns even before problems arise. When computer technology first started to become widespread there were fears that people would become redundant and computers would take their jobs. There was some truth to this, as many manual jobs became obsolete, so people were forced to retrain to become computer operators and programmers. However the feared negative impacts were largely not realised.

It is too early to say definitively whether nanotechnology will be a major GPT, but it shows all the early signs – it theoretically makes possible more efficient manufacturing and communication, it impacts on virtually every major industry, from computers to textiles to medicine, and it facilitates scientists in furthering many other fields of knowledge by providing them with more powerful experimental tools.[26,27]

hen is Nano not Nano ?

Ever more consumer products are being branded with “nano” which to the average consumer conveys an image of new and/or small and/or high-tech. A classic example is Apple’s iPod Nano music player which has achieved worldwide success.

Yet in many instances, as with the iPod Nano, the product does not truly contain nanotechnology. At least in the iPod case it is true that the computer components inside do have features at the nano-scale, although these are no different to those found in your PC, and would not qualify as nano-technology according to the definitions given in this report.

This form of “false” advertising is of concern to many. Advocates of nanotechnology fear that if products marketed as nanotechnology under-perform or are found to adversely affect health or the environment, then nanotechnology as a whole will unjustly suffer.

Consumer groups are also concerned, fearing that companies will take advantage of the complexity of nanotechnology and mislead consumers into thinking a product has the features associated with nanotechnology when in fact it does not.

Below are two real examples where such situations have already occurred:

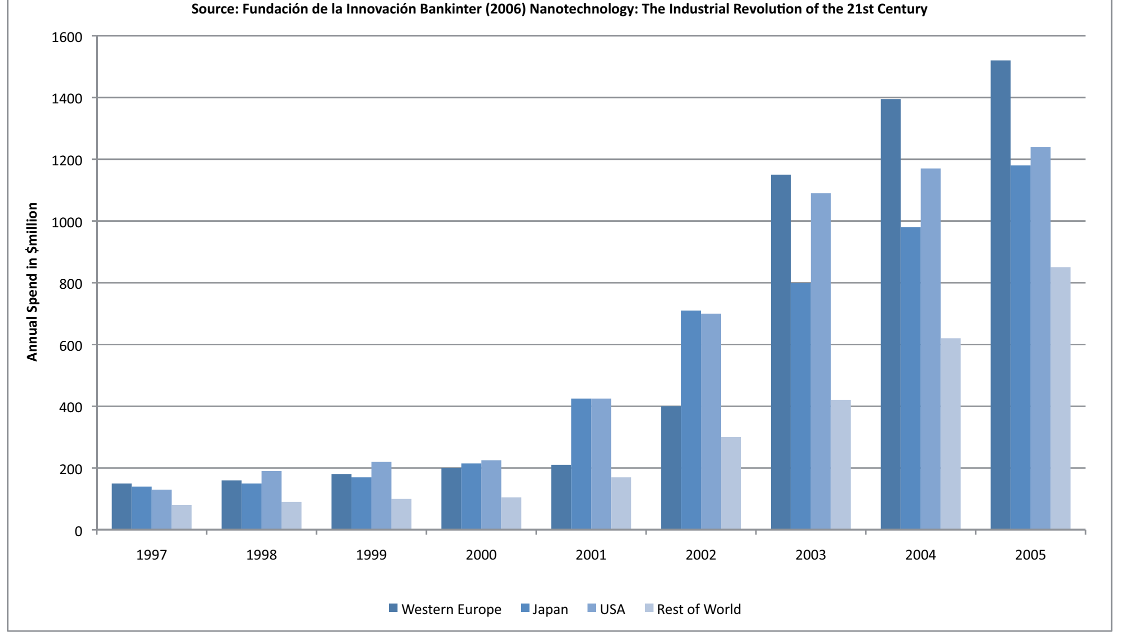
C SE : In Germany in March 2006 an incident relating to an aerosol sealant spray known as “Magic-Nano” led to approximately 100 people being hospitalised with severe respiratory conditions. However, a thorough investigation by the German Federal Institute for Risk Management (BfR) found that, despite the product’s name, the product did not actually contain nanoparticles, a finding confirmed by chemical analyses performed at two separate specialist chemical laboratories. The BfR found that the health problems were caused by inhalation of the aerosol spray.

C SE : Samsung’s Silver Nano washing machine is advertised as using silver nano-particles as an antibacterial agent. The machine produces silver ions – referred to as nanoparticles – by electrolysis which are released into the washing machine during the wash cycle. As the particles are then released into the water system, concerns have been raised over whether the silver ions could have a detrimental effect on the environment and on waste water treatment.

However the UK’s Health and Safety Executive (HSE), and the US’s Environmental Protection Agency (EPA) investigated and found that the silver particles were normal ions, as are found in all silver salts both natural and manmade. Since there are actually no nanotechnologies involved, there are no new risks beyond those ordinarily presented by silver ions.

Source: Nanotechnology in Consumer Products, Nanoforum Report, European Commission, 2006; and Nanosciences and Nanotechnologies: A Review of Government’s Progress on its Policy Commitments, UK Council for Science & Technology, March 2007

Because of this expectation, governments and private industry all over the world are spending billions on R&D in an effort to ensure they remain at the forefront of developments and are able to participate in the expected economic and social benefits.



Government Annual Spending on Nanotechnology 1997-2005
Source: Fundación de la Innovación Bankinter (2006) Nanotechnology: The Industrial Revolution of the 21st Century

W Y S O E O O Y DE E O SO K Y

Nanotechnology has been around a long time, although it wasn't known as such. Nano-particles, nano-structured surfaces, and nano-materials are widely found in nature and mankind has often inadvertently made use of their special properties. One of the earliest known uses of nano-materials dates back to the 4th century AD; the Lycurgus Cup from Rome is made of a special glass that changes colour when held up to the light. Modern investigation has shown that this special property is due to nano-sized particles of gold and silver which are contained within the glass.

NCIEN N N EC N ycurgus Cup

The Lycurgus cup was probably made in Rome in the 4th century AD.

This extraordinary cup is the only complete example of a very special type of glass, known as dichroic, which changes colour when held up to the light. The opaque green cup turns to a glowing translucent red when light is shone through it. The glass contains tiny amounts of nano-sized colloidal gold and silver, which give it these unusual optical properties.

The Lycurgus cup (left, normal view; right, view when held up to the light).

Photographs reprinted y per ission fro the ritish Museu

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It is also now known that the process developed by B.F Goodrich in 1885 of adding carbon black to tyres to make them black, and which incidentally also made them far more resistant to abrasion, was actually the inclusion of carbon nano-particles into the rubber matrix – one of mankind's first mass-produced composite nano-materials.

However the massive growth of interest in nano-scale science and engineering over the past decade is due to the conjunction of several factors:[4]

- *Technical advances such as atomic force microscopy and electron microscopy have enabled scientists to both see and manipulate matter at the nano-scale*
- *Fabrication advances largely driven by the micro-electronics industry and synthesis advances in both organic and inorganic chemistry have enabled commercial manufacturing of nano-scale devices*
- *Scientific advances in physics and chemistry have led to understandings of how and why the properties of matter change so dramatically at the nano-scale*
- *Biological advances driven by the pharmaceutical and biochemical industries have enabled nano-scale biological molecules to be bound to inorganic surfaces such as glass metal and plastic thereby enabling the lin age of biological mechanical and electronic components*
- *Global co-operation in R&D in many sectors has led to a critical mass of facilities and scientists engaged in developing nanotechnologies such that advances are being made at a rapid pace and*
- *Increased government funding in nanotechnology in particular over the last years accompanied by a general belief by science and industry that nanotechnology will create a revolution similar to that created by semiconductor technology.*

The current boom in nanotechnology is therefore the result of a convergence of technological advances that have come together over the past decade.

As new advances are made, for example in equipment to visualise and manipulate matter at the nano-scale, these in turn fuel further advances, leading to the snowball effect of technological and scientific advances and commercial applications that seems to be occurring.

Short istory of Nanotechnology

Source: NANOTECNOLOG A, La revoluci n industrial del siglo I, Fundaci n de la Innovaci n Bankinter 2006; www.fundacioWikipedia: Nanotechnology

The birth of the science of nanotechnology is famously credited to Richard Feynman, winner of the Nobel Prize for Physics, who in 1959 gave a keynote lecture entitled "There's Plenty of Room at the Bottom".

In his lecture, Feynmann examined the possible benefits for society of being able to catch atoms and molecules and put them down in given positions, and to manufacture artefacts with a precision of a few atoms.

Feynmann offered two prizes of 1000 each: one for the first person capable of creating an electric motor in a 0.4 mm cube; the other for anyone capable of reducing the information on the page of a book by 25,000 times. The first prize was claimed the following year, but the second wasn't claimed until 1985.

In honour of Feynman, since 199 the Foresight Nanotech Institute offers the Feynman Prize in Nanotechnology to recognize significant achievements that contribute to the development of nanotechnology.

The term nanotechnology itself was coined by Norio Taniguchi1, from the University of Tokyo in 1974, to distinguish between engineering at a micron level and engineering at a nano level. The term was made famous by Eric Drexler in his book Engines of Creation, published in 1986, which laid the theoretical foundation for much of today's nanotechnology and articulated the amazing possibilities and dangers associated with engineering at the molecular scale.

Experimental nanotechnology began to accelerate in the 1980s with the development of new microscopes, such as the scanning tunnelling electron microscope and the atomic force microscope which could visualise and manipulate matter at the atomic scale.

In the 1990s, the amazing properties of carbon nanotubes, and other nano-particles were discovered, opening up the possibility of a much wider field of nanotechnology applications than had previously been envisaged.

The current wave of investment and acceleration of nanotechnology was kick-started in 1999 by then US President Bill Clinton who announced a National Nanotechnology Initiative. Similar initiatives were launched soon after by Europe and Japan and the growth of nanotechnology has been accelerating ever since.

W W E E O OE OO Y

Opinions differ widely on how fast the nanotechnology revolution may occur and to what extent it will impact on both local and global economies.

Timeline

In general, most analysts foresee three broad phases of development:[6]

- *Early stage (next 5 years): nanotechnology is at investigation phase and scientific nowledge is beginning to ta e shape in solid applications*
- *Commercial development (5-10 years): during this period many different applications are e pected to be developed and to begin to be produced on an industrial scale and*
- *Widespread use (10-15 years): nanotechnology will be consolidated as an industry and consumers will en oy a wide range of products using nanotechnology.*

The above estimates on timeframes vary quite significantly from industry to industry.

Medical applications will take much longer. Because new medical applications have very strict requirements with long clinical trials, medical nanotechnologies are expected to take several decades before they are in common use.

Industrial applications are already commercially available – the use of nano-materials in widespread commercial applications such as paints, adhesives and construction materials is already occurring.

APPLICATION EXAMPLE - Nanotechnology makes textile fibers dirt-repellent

Nano-particles give the surface of these textile fibers a structure with an effect similar to that of the lotus plant's leaves. From the leaves of this plant water and dirt just roll off. This effect makes the fibers water- and dirt-repellent. Tiny particles measuring less than 100 nanometers on the textile fibers produce a similar self-cleaning effect. These surfaces are coated with billions of these nano-particles so close together that a speck of dust wouldn't fit between them. Between a particle of dirt and the surface of the textile fibers, a layer of air is formed on which the impurities "hover" – and can simply be washed off with water. Even stubborn dirt is then easy to remove.

The nano-coating has so far been applied mainly to engineering textiles, such as fabrics for tents, awnings or sunshades. But materials used for work clothing and home textiles will also be benefiting from this new technology in future.

Press Photo S

actors affecting the de elop ent of nanotechnology

Asides from factors specific to particular applications, such as licensing of medical products, there are a number of general factors that will affect the development and spread of nanotechnology.

Capability factors:

The existence and availability of suitable tools to allow study at the nano-scale. Suitable public and private infrastructure.

Coordination between research centres and business in technology transfer and commercialisation and educated and trained interdisciplinary workforces.

Financial factors:

Una bona identificaci de les aplicacions pràctiques per a atreure inversions privades.
A reduction in the costs of processes and equipment.
Investment centred on specific projects rather than dispersed among different industries.
Availability of venture and other forms of start-up capital.

Government factors:

Government policy that encourages innovation and the development of nanotechnology.
Specific regulation for nanotechnology and its applications.
Coordination between countries/regions.

Social factors:

Public acceptance of nanotechnology, in particular as regards safety and privacy issues.
Confidence in regulators and regulatory processes.

Serendipity:

Many new discoveries are anticipated for the near future, but as with all research, it is impossible to know beforehand what will, or will not be, discovered.

Si e of the mar et

In recent years there have been numerous studies estimating the future sizes of different segments of the nanotechnology markets. These range from[8] 150 billion by 2010 (Mitsubishi Institute) to 2.6 trillion by 2014 (Lux Research). One of the most well-known figures is that published by the US National Science Foundation of 1 trillion by 2015.

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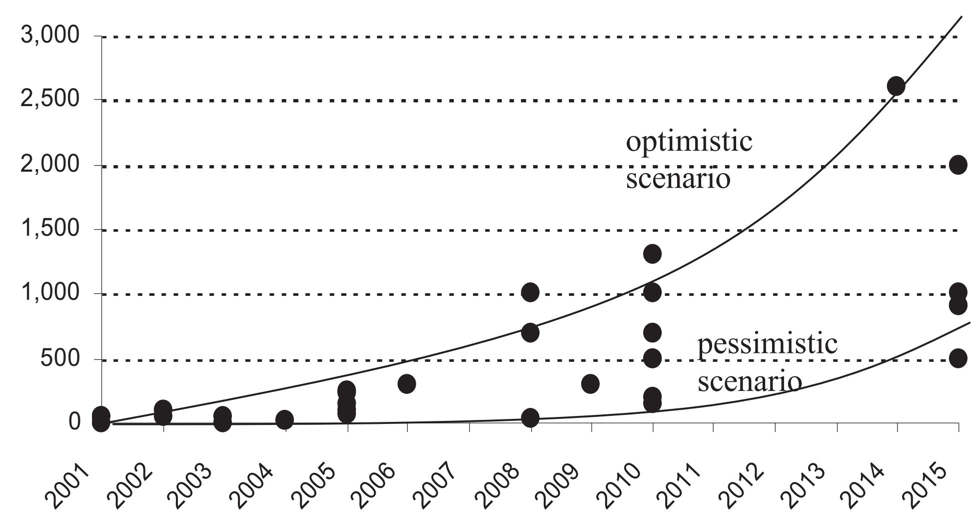


Impact on industry

Nanotechnologies are expected to:

- *Improve existing technologies: glues that stic better construction materials that are stronger and lighter surfaces that clean easier or don t scratch*
- *Enable entirely new applications: clothes made of materials that ill bacteria sensors that detect contaminants and germs drugs that release only in the tissues where they need to act paints that can act as solar cells and*
- *Improve efficiencies: new catalysts to reduce wastage in chemical processes improved storage and efficiency of fuel cells more powerful computing and communications technologies coatings that last longer and need less cleaning.*

PP IC I N E MP E – Nanocu es act as a storage ediu for hydrogen

The desire to be mobile and yet not to be without communication and entertainment had led to ever smaller and lighter electronic devices. Whether it's laptops, cell phones or CD players, a key issue is how to power these portable devices. What batteries do today could in the future be done by mini fuel cells. Hydrogen could act as a source of energy provided that the problem of storage for its use in mobile devices can be solved. A possible storage medium for hydrogen would be nanocubes made of metal organic frameworks (MOFs), whose properties are currently being tested by BASF researchers. Press Photo S

Impact on the environment

The environmental impact of nanotechnology is still largely unknown. It is expected that nanotechnologies will have both positive and negative effects.

Positive effects may derive from improved efficiencies in industrial processes, more efficient energy systems, better performing materials which need less repair and maintenance and enhanced protection of the environment through better sensors and filters for monitoring and controlling pollution and disease.

Negative effects may derive from the potential toxicity of nano-particles and nano-tubes, unintended side effects of manufacturing processes and materials, the misuse of nanotechnology for bioterrorism, and badly controlled nano-machines resulting in unintended damage.

En iron ental enefits

Sources: eo ear ook Nanocap - pplications of Nanotechnology: En iron ent No e er

Nanotechnologies are likely to have important positive environmental benefits in a number of ways:

Savings in raw materials: nano-materials that are stronger, more durable or otherwise more effective mean that less raw materials will be required in products ranging from buildings to machinery. Less raw materials in turn requires less mining, processing and transport leading to reduced environmental impacts throughout the production chain.

ore efficient processes: nano-technologies are already providing improved catalysts for chemical reactions and energy transformations. Improved efficiencies imply reduced energy and raw materials requirements.

Improved monitoring: nanotechnology enabled detection devices can be significantly less expensive and more sensitive than conventional ones. These can be used to monitor air, water and soil, detecting both contaminants and naturally occurring substances. Improved monitoring not only tracks pollution, but also enables farmers to improve crop management and better utilise fertilisers and pesticides.

Functional surfaces: nanotechnology surfaces with functional properties are already commercially available. These might be surfaces that are self cleaning (waters and oils don't stick) used for roofing, cars and walls, or clear glass and plastics that transmit less heat thereby reducing airconditioning needs of buildings, surfaces that don't scratch, etc. Cleaning, restoring and repairing surfaces consume huge amounts of resources, so any technology that leads to large savings in this area will have huge benefits to the environment.

emediation of pollution: some nano-structures show excellent promise for use in filtration and catalyst systems, to remove contaminants from air, soil and water. These can be employed at source, for example outlets of factories or vehicles, or to help clean up polluted environments such as oil spills and contaminated land.

Energy storage and production: nanotechnologies are expected to significantly improve solar cells, fuel cells, batteries and other energy technologies. All these combined are likely to result in significant improvements in energy production, storage and efficient utilisation, in turn reducing greenhouse gas emissions and environmental damage.

The main immediate environmental concern is focussed on nano-particles[28] which are not embedded in a fixed matrix, as these are an early application that in some cases are already in mass production, and they have the theoretical potential to cause a lot of harm to both human health and the environment generally.

Impact on society

Because nanotechnologies are expected to be very widespread, affecting many industrial sectors and consumer products, it is anticipated that significant social, economic, workforce, educational, ethical and legal issues will arise.[29]

Research has shown [0] that the primary concern of society with nanotechnology in general is the impact on human health and the environment. Beyond these broad concerns, issues tend to be specific to particular applications. Often these issues exist already and are not unique to nanotechnology, but may become more important as nanotechnology makes the application more accessible and widespread.

For example, initial medical applications of nanotechnology are likely to be very expensive, leading to a health divide based on wealth, between those who can afford a nanotech cure for their cancer and those who cannot. Whilst this is an important social issue, it is not unique to nanotechnology; the same is true of most new forms of medical treatment. (See Appendix "Ethical Legal and Social Aspects").

Concerns have also been raised at futuristic scenarios, where runaway hordes of nano-robots chew up the earth and turn it into grey-goo', or malicious nano-bugs are used to infect people turning them into hostages of those who control the bugs. While these and other vivid scenarios are hypothetically possible, current technology is very far from having these capabilities and concern by mainstream science is focussed on the more immediate threats.

As discussed earlier, currently the key perceived threat is the unknown (and at the moment unmeasurable) toxicity of nano-particles and nano-tubes. Because nano-particles are relatively easy to produce (compared to more complex nanotechnologies) and have widespread applications, they are already being used in commercial applications and are expected to be used in many more. Many of these applications involve the nano-particles and nano-tubes being embedded in a fixed matrix (such as glass, plastics or construction materials) and so are not of particular concern – the main risk stems from free nano-particles and nano-tubes.

Examples of current nano-particle use include zinc oxide or titanium dioxide nano-particles in sunscreens and cosmetics to provide UV protection whilst allowing the cream to be transparent, carbon black particles in tyres to improve resistance to wear (used since the 1920s), silicon dioxide (glass) nano-particles in scratch resistant surfaces to improve durability, and even gold nano-particles that change colour for use in sensing devices such as home pregnancy tests.

PP IC I N E MP E – inc o ide nano-particles in sunscreen

Z-COTE is a special zinc oxide which, used in suncreams, offers protection against sunburn by filtering against harmful UVA and UVB radiation.

The fine particles of zinc oxide function as physical UV filters - UV radiation is not only reflected, but also dispersed and absorbed by them. Since these particles are white, they can cause an undesired whitening effect on the skin at high concentrations.

This is prevented by reducing the size of the pigment particles to about 200 nanometers – which makes them transparent on the skin. Physical UV filters are used mainly in sunscreens with higher sun protection factors above 25. They are also suitable for the sensitive skin of children and people with allergies.

In some of these cases, such as tyres or construction materials, where the nano-particles are contained within a solid there is less concern of direct impacts on human health and more concern of the long term environmental impact, as the encasing solid decays and releases the nano-particles into the environment.

In others, such as cosmetics, there is concern at the unknown direct health impact of nano-particles, both because they penetrate further into the skin than traditional, larger sized ingredients, and because their unique chemical properties may react with the body in unforeseen ways. Of especially high concern are those nano-particles that are likely to become airborne and thus inhaled into the lungs. There is some preliminary evidence [1] showing that carbon nano-tubes above a certain length can act as irritating fibres, showing some similarities to asbestos.

However not all nano-particle production is deliberate; car exhausts have been pumping significant quantities of nano-particles into the air for a century. To date, asides from the general negative impacts of pollution, no specific ill effects have been directly attributed to the nano-scale nature of these particles.

Nanotechnology may have a positive role to play in this regard, as better understanding of the nature of nano-particles and development of other nano-materials is expected to lead to new technologies that could significantly reduce air pollution.

In much the same way that asbestos, GM-foods and other new technologies or products have sometimes been rapidly introduced only to be followed by disastrous consequences or social backlash and rejection, there are fears that allowing nanotechnologies to be introduced without due care and regulation could lead to a similar reaction.

One of the difficulties faced by those wanting to implement more stringent regulation and testing is that nanotechnologies are so varied, with such differing risk/benefit profiles, is that it is neither feasible nor desirable to enact widespread, general regulations. For example, requiring that no device emit man-made nano-particles into the atmosphere would make all combustion engines (such as cars and planes) illegal. On the other hand, there are so many nanotechnology applications either on the market or under development, that it is also not feasible to examine each on a case by case basis.

Thus the current challenge faced by society, governments and industry in attempting to minimise potential risks while not stifling technological development. A recent EU [7] dhighlights that “mechanisms to address these concerns and to sort out what is real from what is imaginary are needed. Promising strategies that have been implemented in the EC are scientific cafes and consensus conferences. In these venues, scientists meet with citizen groups to discuss implications of new scientific discoveries. Such meetings have the potential to build communication and trust between the public, policymakers, the media, and the technical community.”

Press Photo S

Job creation, education & training

In terms of employment, it is claimed [2] that nanotechnology development is likely to require an additional two to ten million workers across the world by 2014. If Europe maintains a leading edge in nanotechnology it can expect that many of these jobs will be created in Europe, especially in start-up companies and SMEs.

Asides from direct employment, the expected diversity of nanotechnology applications is likely to result in their incorporation into many facets of life, thereby improving and enabling many other industries.

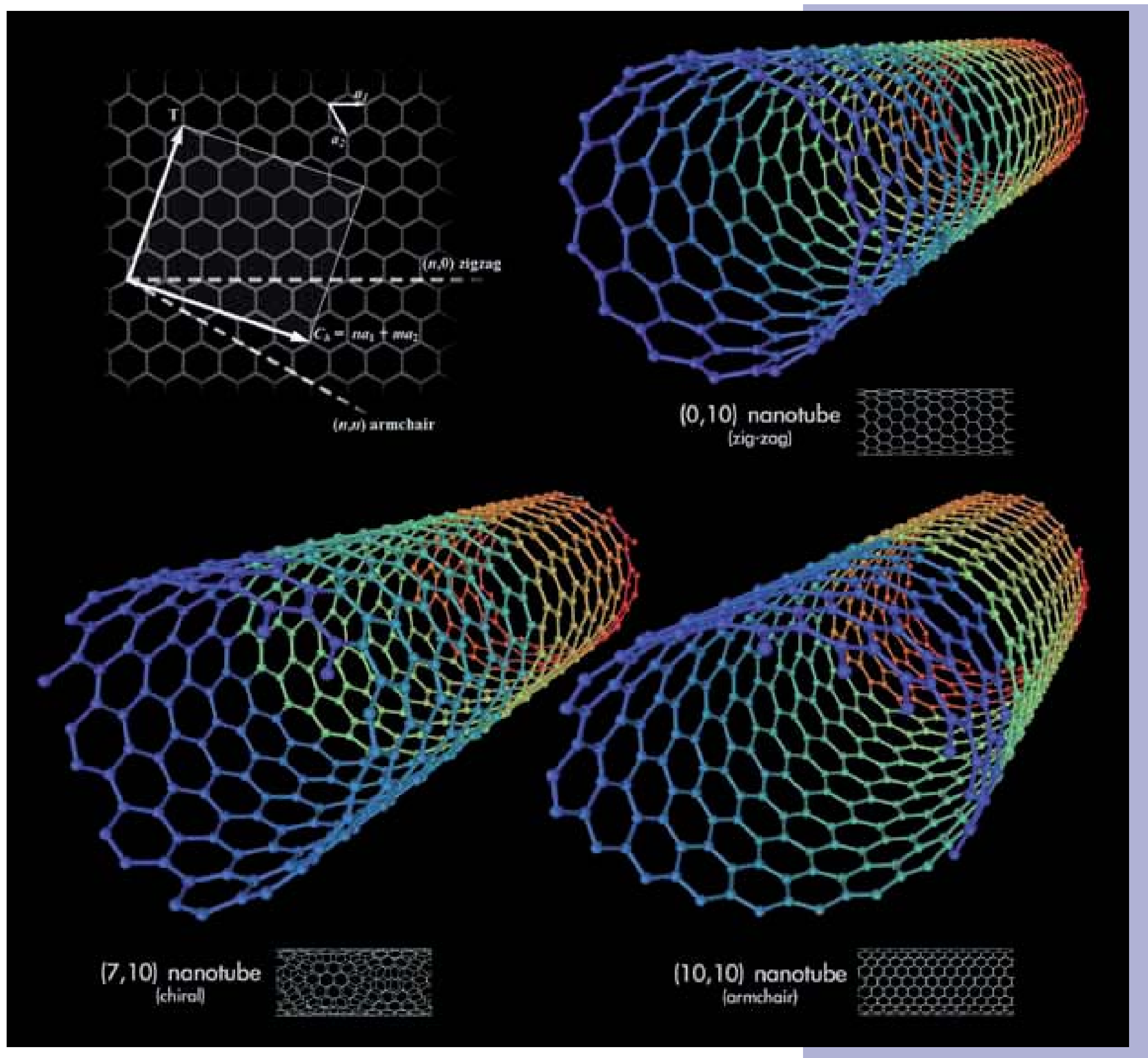
An analogy can be made with electricity. Although only a relatively small number of people are directly employed in the generation and distribution of electricity, the impact of electricity on the wider workforce is immense. Virtually no-one in the western world would perform their work without at some point utilising electricity in some way, even if it is just to turn on a light.

In much the same manner as electricity enables other processes, it is expected that nanotechnologies will also improve existing, and enable many new, processes and activities.

The extent to which this will occur will depend very much on the speed with which nanotechnology applications are brought to market and the extent to which individual countries have adequately trained and educated workforces that can adapt and incorporate the new technologies.

Education and training has been identified as a key requirement by virtually all major nanotechnology initiatives.

The US National Nanotechnology Strategic Plan[16] has as the rd of 4 major goals: “to develop and sustain educational resources, a skilled workforce, and the supporting tools and infrastructure to advance nanotechnology educational programs and resources are required to produce the next generation of nanotechnologists, that l, the researchers, inventors, engineers and technicians who drive discovery, innovation, industry and manufacturing”.



Car on nanotu es

Carbon nanotubes are rolled up sheets of carbon atoms. The tubes come in many forms, different lengths, widths and configurations. The can have closed or open ends, curves and even multiple concentric walls (tubes within tubes), known as multi-walled nanotubes.

Photograph by Michael Str ck and free available at http://commonswikimedia.org/wiki/File:Types of Carbon Nanotubes.png, under GNU license.

Carbon nanotubes are of particular interest to both scientists and industry for a number of reasons.

Carbon nanotubes are the strongest and stiffest materials on earth, and have already been used to produce stronger and lighter composite materials for aircraft and sporting equipment.

Multi-walled nanotubes exhibit a striking telescoping property whereby an inner nanotube core may slide, almost without friction, within its outer nanotube shell thus creating an atomically perfect linear or rotational bearing. Already this property has been utilized to create the world’s smallest rotational motor.

The structure of a nanotube strongly affects its electrical properties which can range from semiconductor to metallic. Theoretically, some carbon nanotubes could carry currents 1000 times denser than those carried by traditional wires such as a copper.

Are carbon nanotubes safe?

The answer to this is still unknown. Studies are very difficult as each type of carbon nanotube is unique and behaves like a different substance. Parameters such as structure, size distribution, surface area, surface chemistry, surface charge, and agglomeration state as well as purity of the samples, have considerable impact on the reactivity of carbon nanotubes.

However, available data clearly show that, under some conditions, nanotubes can enter cells and suggests that if raw materials reach the organs they can induce harmful effects as inflammatory and fibrotic reactions. There are some fears that carbon nanotubes could behave like asbestos fibres.

The EU's Strategic Plan for Nanotechnology[1] includes a section on human resources: "The Commission calls upon Member States to contribute to:

a identifying the educational needs of nanotechnology and provide e amples of best practice and or results from pilot studies

b encouraging the definition and implementation of new courses and curricula teacher training and educational material for promoting interdisciplinary approaches to nanotechnology both at school and graduate level

c integrate complementary s ills into post-graduate and life-long training e.g. entrepreneurship health and safety issues at wor patenting spin-off mechanisms communication etc.

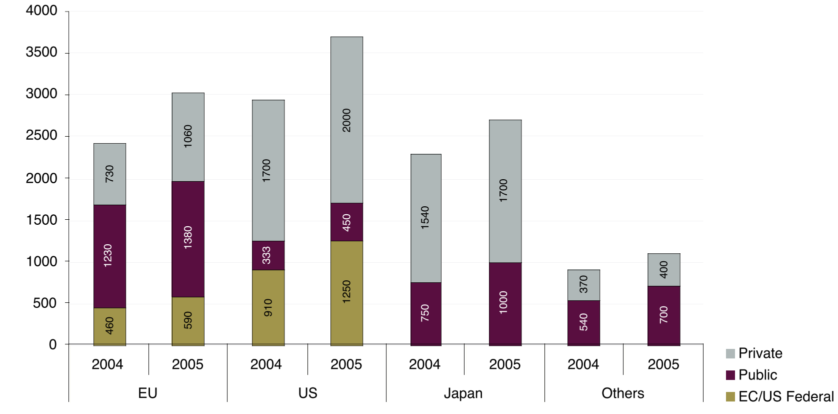
The German Innovation Initiative for Nanotechnology [4] has as one of its key goals "Promoting the young and developing qualifications One of the most important factors that goes into shaping a region's economic development and thus the creation of a nanotechnology-driven industry in Germany is not only the presence of a capable scientific and economic community but also the availability of qualified workers on all levels. If the increase sought in the number of self-employed people and the quick diffusion of technologies wanted are to be achieved, then a correspondingly qualified workforce is needed. Education is thus the key to the future nanotechnology job market".

RRE ES E O E O O Y

The technological development of the applications described in this document and the changes to existing industrial infrastructure necessary to bring these applications into widespread use will require large-scale investments. Those countries that fail to make appropriate investments risk having their industrial capabilities being made redundant and losing significant economic productivity.

To date[21] it has been public funding that has enabled the early take-off of nanotechnology but the private sector is now beginning to invest heavily too, playing an increasingly important role. The current position varies from region to region , however: in America and Asia, the business sector already contributes more than government, but in Europe private sector investment lags behind. In Europe, only of the total funding comes from private sources while in the United States, private sources provide 54 and in Japan they account for over 60 . In other countries (mainly emerging Asian countries) the share is around 6 .

This is of particular concern to European policy makers, as the technology transfer from the scientific sector to the industrial sector will largely depend on how quickly existing firms, especially SMEs, invest in both equipment and training to commercialise new nanotechnologies. Therefore although the European scientific sector is performing well, early signs are that private industry is not responding as fast as in other parts of the world.



Sources: European Commission (2005) and Lux Research (2006).

Source: eo ear ook : E erging Challenges Nanotechnology the En iron ent

The European Union in its Framework Program 7 budget has allocated .5 billion euros into nanotechnology research between 2007 and 201 (ie about 0.5 billion euros per annum), in addition to the private sector investment and national research budgets of European member states. In comparison, the US federal government alone currently spends over US 1 billion (0.7 billion euros) per annum on nanotechnology research.

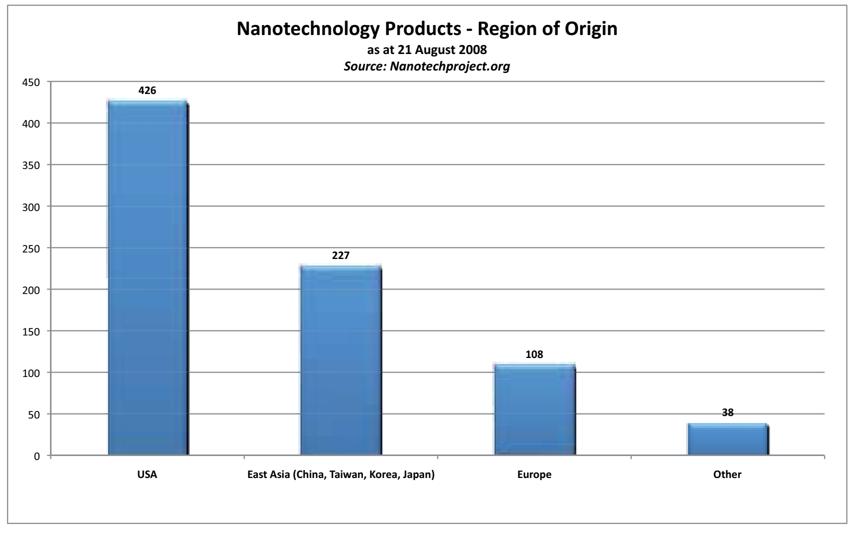
Within Europe, research in nanotechnology is concentrated mainly in Germany (almost half of all EU research institutes active in nanotechnology are located there) with the other major players being France and the UK (each representing about 8 of active institutes) followed then by western central and northern member states.

A sometimes useful measure of technology transfer is patenting activity. Patents reflect the intent of scientists to transfer scientific results into technologically based commercial applications and therefore the number of patents filed is an indicator of both the success of research and extent to which the inventions are being transferred to the industrial sector. The European Patent Office (EPO) has developed a methodology in order to identify and classify nanotechnology patents and this has enabled some analysis of worldwide and European trends in patenting activity.

The largest rate of commercialisation of nanotechnologies is occurring in the nano-electronics and nano-materials sectors, for reasons described earlier (see "Timeline" section at page 1) these areas are expected to drive the first wave of commercial applications.

If one looks at the regional breakdown of patenting activity, it is clear that Europe is lagging far behind the US and Asia.

And it seems that the lower level of patenting correlates with a lower level of commercial activity, with very few of the currently available nanotechnology products being manufactured in Europe.



In entory of nanotechnology- ased consu er products y region of origin Source: www nanotechpro ect org .

Yet this is not due to a lack of suitable quality research in Europe; on the contrary, Europe accounts for around 40 of total published scientific output in nanotechnology. The lack of commercial exploitation of these research results is of high concern and the EC is placing increasing focus on developing mechanisms to encourage private industry, in particular SMEs, to collaborate with research institutes and invest in industrial-level

R&D.

S E Y RE O O O E O O Y

Safety in regards to nanotechnology has many aspects; safety in the laboratory, safety in the workplace, safety for consumers and safety for the environment.

The broad scope and variety of nanotechnologies, combined with their rapid rate of advancement and commercialisation, is creating concern in many segments of society that safety issues are being ignored at the expense of commercial gain.

EU legislation

The EC and various other public bodies within Europe, as well as equivalent bodies in the US and other countries, have issued various statements of policy and intent in regards to safe development of nanotechnologies. [5] Most of these are fairly similar in their approach, [7] therefore although the discussion below is limited to EU policies it should be taken as generally representative.

The EC has issued two key communications in recent years that define its policy in regards to health and safety: *Towards a European Strategy for Nanotechnology (May 2004)*[2] *and Regulatory Aspects of Nanomaterials (June 2008).*[38]

The 2004 communication outlined the key principles by which the EU's scientific and commercial communities should develop nanotechnologies:

Nanotechnology must be developed in a safe and responsible manner. Ethical principles must be adhered to and potential health safety or environmental ris s scientifically studied also in order to prepare for possible regulation. Societal impacts need to be e amined and ta en into account. Dialogue with the public is essential to focus attention on issues of real concern rather than science fiction scenarios.

The communication gave some further detail (see Appendix "Extracts on Health and Safety from EC 2004 Communication"), however did little to give specific details on how these objectives should be achieved. This lack was identified early on and led the Commission to undertake a regulatory review, the results of which have just been published in June 2008.

The review concluded that *current legislation covers to a large e tent ris s in relation to nanomaterials and that ris s can be dealt with under the current legislative framewor .*

However current legislation may have to be modified in the light of new information becoming available for e ample as regards thresholds used in some legislation.

The need for improved information is highlighted repeatedly: *nowledge on essential uestions such as characterisation of nanomaterials their ha ards e posure ris assessment and ris management should be improved nowledge becomes the critical factor for implementation and eventually legislation* and therefore *Authorities and Agencies in charge of implementing legislation should continue to carefully monitor the mar et and use Community mar et intervention mechanisms in case ris s are identified for products already on the mar et.*

In order to assist this process of monitoring new products, the review identified that the relevant legislation can be grouped under four categories: che icals worker protection products and en iron ental protection and that when all are applied simultaneously the result is an acceptable level of protection of public health and safety. (See Appendix "EU safety legislation applied to nanotechnology").

Public concern

Despite the fairly positive view of existing legislation by the EC, there is significant concern by worker and consumer groups that the existing legislation and the manner in which is implemented does not provide adequate safety regulation.

NanoCap (Nanotechnology Capacity Building NGOs) is a European project that was established to deepen the understanding of environmental, occupational health and safety risks and ethical aspects of nanotechnology. It established a consortium of 5 environmental NGOs, 5 trade unions and 5 universities that are holding a series of focused working conferences to prepare a portfolio on ethical issues and a position concerning "responsible nanotechnology". The project is funded by the European Commission, from the FP6 Science and Society programme and runs from September 2006 until September 2009.

As an interim result of this process, the European Trade Union Confederation (ETUC) recently adopted a *Resolution on Nanotechnologies and Nanomaterials* [2] in June 2008.

In the resolution the ETUC is generally supportive of nanotechnology *the ETUC is convinced that nanotechnologies and manufactured nanomaterials might have considerable development and application potential. These technological advances and the new obs they might bring may address peoples needs help ma e European industry more competitive and contribute to the achievement of the sustainable development goals set out in the Lisbon Strategy.*

However they note that significant uncertainties exist and that "*preventive action must be ta en where uncertainty prevails. This means the precautionary principle must be applied. This is the essential prere uisite for the responsible development of nanotechnologies and for helping ensure society s acceptance of nanomaterials.*"

Precautinary principle

The precautionary principle has been defined in various ways. Two often quoted definitions are:

. *When an activity raises threats of harm to human health or the environment precautionary measures should be ta en even if some cause and effect relationships are not fully established scientifically.*

In this conte t the proponent of an activity rather than the public should bear the burden of proof. The process of applying the precautionary principle must be open informed and democratic and must include potentially affected parties. It must also involve an e amination of the full range of alternatives including no action.

Consensus statement by the Wingspread conference of treaty negotiators, activists, scholars and scientists from the United States, Canada and Europe, January 1998.

. *Where following an assessment of available scientific information there are reasonable grounds for concern for the possibility of adverse effects but scientific uncertainty persists provisional ris management measures based on a broad cost benefit analysis whereby priority will be given to human health and the environment necessary to ensure the chosen high level of protection in the Community and proportionate to this level of protection may be adopted pending further scientific information for a more comprehensive ris assessment without having to wait until the reality and seriousness of those adverse effects become fully apparent evidents.*

Fisher, Elizabeth, Judith Jones i Rene von Schomberg (ed.). *Implementing the recautionary rinciple: erspectives and rospects* Cheltenham, United Kingdom, and Northampton, USA: Edward Elgar (2006)

On 2 February 2000, the European Commission issued a Communication on the precautionary principle (COM(2000) 1) in which it adopted a procedure for its application. Since then the principle has come to inform much EU policy, including environmental policy, food law, consumer protection, trade and research, and technological development.

The ETUC resolution welcomes the EC's acceptance of the precautionary principle in its 2004 and subsequent communications, but notes some significant deficiencies which it believes require immediate attention:

Funding for R&D on safety: where investment in D is concerned we see and note a gross imbalance between budgets for the development of commercial applications of nanotechnology *and those for research into their potential impacts on human health and the environment. The ETUC calls for at least of national and European public research budgets for nanotechnology and the nanosciences to be earmar ed for health and environmental aspects and to re uire all research pro ects to include health and safety aspects as a compulsory part of their reportings.*

Standardisation of terminology: a standardised terminology for nanomaterials is urgently needed to prepare meaningful regulatory programmes. In particular ETUC calls on the Commission to adopt a definition of nanomaterials which is not restricted to ob ects below nanometers in one or more dimensions. This is important to avoid many nanomaterials already on the mar et to be left out of the scope of future legislations.

No proof, no market: the ETUC finds it unacceptable that products should now be manufactured without their potential effects on human health and the environment being nown unless a precautionary approach has been applied and made transparent to the wor ers. In particular ETUC considers that manufacturers of nano-based products should be obliged to determine whether insoluble or biopersistent nanomaterials can be released from them at all stages of their life cycle. In the absence of sufficient data to prove that those released nanomaterials are harmless to human health and the environment mar eting should not be permitted.

Amend REACH chemical regulations: nanomaterials may indeed evade the EACH registration re uirements the ETUC demands that different thresholds and or units e.g. surface area per volume are used for registration of nanomaterials under EACH.

Improve training and safety in the workplace: there is a great need for training education and research in order to allow health and safety specialists e.g. labour inspectors preventive services occupational hygienists company physicians preventing nown and potential e posures to nanomaterials The ETUC calls on the Commission to amend Chemical Agents Directive EC which it believes does not afford ade uate protection to wor ers employers must be re uired to implement appropriate ris reduction measures not only when nown dangerous substances are present in the wor place but also when the dangers of substances used are still un nown.

Labelling: the ETUC believes that consumers also have the right to now what is in a product the ETUC wants all consumer products containing manufactured nanoparticles which could be released under reasonable and foreseeable conditions of use or disposal to be labelled. In addition as part of the precautionary approach ETUC calls on ember state authorities to set up a national register on the production import and use of nanomaterials and nano-based products.

In response to these and other similar calls for precautionary action, the EU has initiated a public consultation [9] with Member States and other stakeholders in order to increase knowledge and awareness about the potential of nanotechnologies and to continue to ensure an adequate protection of nature, environment and health.

Safety in the workplace

In June 2008 the European Trade Union Conference issued a *Resolution on Nanomaterials and Nanotechnologies* supporting the development of nanotechnologies but calling for preventive action to be taken where uncertainty prevails in regards to safety issues.

They call for the precautionary principle to be applied, such that workplaces treat nanotechnologies as hazardous until proved safe, rather than assuming they are safe until proved hazardous as is often done with new technologies.

The concern is that neither workers nor consumers should be exposed to unknown risks, as unfortunately happened with asbestos, which continued to be used for decades even after there was strong evidence of its toxicity.

Currently there are no requirements for workplaces to apply such principles, however some companies heavily involved in nanotechnology have voluntarily implemented a precautionary philosophy.

For example BASF, the chemical company that employs over 95,000 people worldwide, has implemented a *Nanotechnology Code of Conduct* and a *Guide to Safe Manufacture and for Activities Involving Nanoparticles in the Workplace*. BASF's Code of Conduct states:

The protection of human life and the environment is a fundamental principle for our company.

We identify sources of ris for our employees in our laboratories production plants pac ing facilities and storage facilities and eliminate these using the appropriate measures. In the event of any health and environmental ha ards arising as a result of our operations we ta e immediate action.

We are actively involved in the ongoing development of a scientifically based database for the assessment of potential ris s as well as in improving and refining product-based testing and assessment methods. In addition we actively debate the opportunities and ris s of nanotechnology with partners from all areas of society.

Wherever e isting legislation and guidelines have not yet ta en developments in nanotechnology into account ASF contributes constructively to drawing up legislation. Our goal is to establish ris -appropriate solid standards and to support relevant legislation.

ASF only mar ets products if their safety and environmental impact can be guaranteed on the basis of all available scientific information and technology. We provide our customers and logistics partners with information about the safe transportation storage safe use processing and disposal of our products. Economic considerations do not ta e priority over safety and health issues and environmental protection.