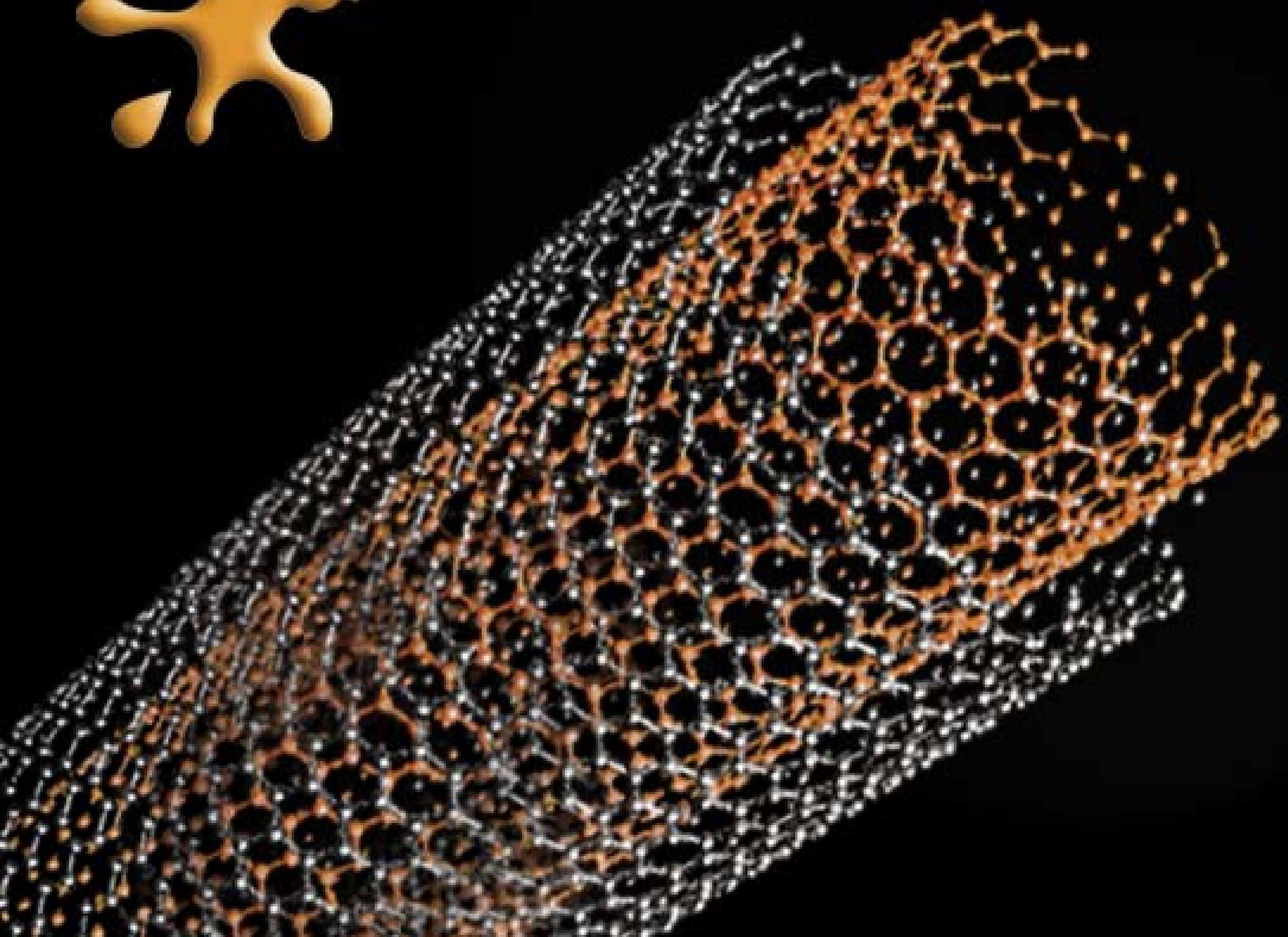
05

NANOTECHNOLOGY

The Industrial Revolution of the 21st Century

FUNDACIÓN DE LA INNOVACIÓN BANKINTER



The Accenture Foundation collaborates with the Bankinter Foundation of Innovation to bring out the report of the Future Trends Forum (FTF) and to help advertise the work of a leader in independent opinion on prospective and innovation. In this sense, the consulting firm endows the FTF with the whole of its intellectual capital and its expertise at making enterprises and institutions to become high-performance organizations.

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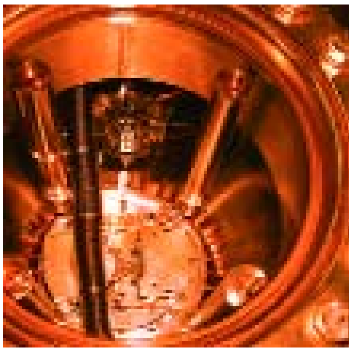
Executive Summary



The Technological Revolution of the 21st Century

In 1959, in a paper entitled "There's Plenty of Room at the Bottom", physicist Richard Feynmann proposed a new field of study for science: technology at an atomic and molecular scale. "The principles of physics, as far as I can see, do not speak against the possibility of manoeuvring things atom by atom", Feynmann told the American Physical Society, opening the way to any interested investors. His talk sparked an interest in developing technology at a minute scale, which has continued to the present day, and which will probably result in a silent revolution which will have an impact on many different areas of our everyday life.

Nanotechnology is a series of multidisciplinary techniques used to manipulate matter at the scale of atoms and molecules. The prefix nano- denotes a billionth part. A nanometre is a billionth of a metre. In order to understand the potential of this technology it is essential to know that the physical and chemical properties of matter change at nano scale: electrical conductivity, colour, resistance, elasticity and reactivity, among other properties, behave differently than at a larger scale.

Nanotechnology can be applied in various fields, including materials, electronics, biomedicine and energy. Materials of much greater hardness and resistance, much faster computers with greater capacity, more effective medical research and diagnoses, capable of responding faster to new diseases and abundant low-cost environmentally-friendly energy are just some examples of how nanotechnology will revolutionise the potential of many common fields today.

Nanotechnology is already here, however; nanoscale materials are used in a range of consumer products: Some of the applications already to be found on the market include much more effective cosmetics offering better protection, more flexible and resistant tennis rackets and non-scratch glasses. Researchers consider it to be just a matter of time before nanotechnological products start entering our everyday lives. Indeed, they estimate that sales of products incorporating nanotechnology will increase from 0.1% of the total manufactured at present to 15% by the year 2014.

The development of new products and processes and entry into new markets requires large-scale investments that will be of key importance in the successful development of nanotechnology. To date, it has been public initiative that has enabled the early take-off of nanotechnology, but the private sector is now beginning to take the reins, 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 we will still have to wait some time before we see the private sector leading investment in nanotechnology.

Conclusions of the Future Trends Forum on the development of the nanotechnology

The FTF experts forecast that developments in nanotechnology will begin to have a major impact over the next five to ten years, though to a different extent from one industry to another. Because nanomaterials can be applied in a range of sectors, it is predicted that they will be the first to enter the market, opening the way for the subsequent penetration of nanotechnology into electronics and energy. The experts consider that nanotechnology will take longest to emerge in medicine, which is heavily conditioned by statutory considerations.

The development of nanotechnology can be studied in three phases:

- The present: nanotechnology is at investigation phase and scientific knowledge is beginning to take shape in solid applications.
- The next five years: during this period many different applications are expected to be developed and to begin to be produced on an industrial scale.
- Ten years and more: nanotechnology will be consolidated as an industry and consumers will enjoy a wide range of products using nanotechnology.

These trends will depend on a series of key factors which the FTF experts have identified from amidst the uncertainty surrounding nanotechnology. These factors will play a determining role in its success. The existence of suitable tools to allow study at a nanometric scale, the search for practical applications to attract private investment, a reduction in the costs of processes and equipment, and a government policy that encourages the development of nanotechnology –these will all help speed up its entry into the market.

Although the experts consider that it is very likely that these conditions will be fulfilled, they have also identified a series of obstacles which might slow nanotechnology down. A lack of investment, for example, would mean a much longer take-off period for nanotechnology, while a lack of coordination between research centres and business could hinder industrialisation of the applications.

Nonetheless, the FTF tends to feel that nanotechnology will gradually emerge in the medium term, with the incorporation of many elements using nanotechnology in our lives. The experts believe that some of the most revolutionary changes in everyday life will come in hygiene and communications. Other lifestyle changes that nanotechnology has in store for us will come in the areas of food and transport: for example, thanks to nanoparticles, we will know when food has gone bad by colour of the wrapping; vehicles powered by hydrogen stored in tanks incorporating nanotechnology will allow us to tap into a source of renewable, non-polluting energy. These are just some of the many advances that nanotechnology will bring to practically all aspects everyday of our everyday lives.

Like all new incipient technologies, there are uncertainties about the potential of nanotechnology. Here it is the scientific community and the government –with specific regulation– that must work to minimise possible risks. The FTF experts think the primary risks that might cause most public unease will be uncontrollable nanoparticles representing an environmental hazard and the use of nanosensors that violate an individual's right to privacy.

In conclusion, nanotechnology is destined to play a lead role in the twenty-first century with applications that will improve our quality of life. It will have a huge impact on the economy, generating new business opportunities and offering new opportunities for developing countries to catch up technologically with the major powers if they train their professional personnel appropriately.

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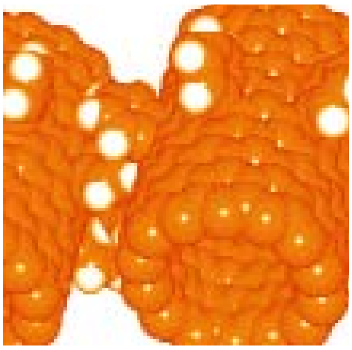
CHAPTER 1

The Promise of Nanotechnology

1 The Promise of Nanotechnology



Nanotechnology is a field of science and engineering that deals with structures having at least one of their three dimensions less than 100 nanometers (nm). (A nanometer is one billionth of a meter.) We have "living proof" of the importance of nanostructures in that living systems are complex assemblies of nanoscale components: macromolecules, protein complexes, organelles, quasi-inorganic systems (e.g., shells, bones), etc. The marvelous functions performed by living systems (logic, memory, motion, chemical synthesis, energy conversion, even our self consciousness) are the direct result of nanoscale structural complexity.

The transistors, numbering in the millions, that constitute the chips that drive our computers and cell phones, are clearly nanostructures. Thus, the field of nanotechnology is extremely broad ranging from molecular biology to electronics and beyond. Although research and development in nanostructures has been going on for decades, and commercial products based on nanostructures have been available for decades, interest in the field has accelerated recently in scientific circles as well as at government agencies and in the investment community.

The growth of interest in nanoscale science and engineering is due to the conjunction of several factors: improved nanofabrication and microscopy techniques; recognition that novel properties become available in synthetic nanostructures; the anticipation that a commercial and societal revolution, similar to that produced by the semiconductor industry, will result from research in nanotechnology and, finally, increased government funding of nanoscale science and engineering.

History tell us that the fruits of research are impossible to predict. However, history also tell us that certain areas of research can be recognized as highly promising, even at an early stage. This was the case for molecular biology, 30 years ago, and we see that the research efforts begun then are bearing fruit today in improved health care and greater understanding of genetic diseases, to name only 2 impacts.

Similarly, in the early days of computer technology it was clear that investment in computer science research would bear valuable fruit. Yet, none of the early pioneers in computer science anticipated the World-Wide Web. In the early days of research in optical fibers no one anticipated the enormous optical communication network we have today. With the invention of the transistor in 1947 the importance of semiconductor research was widely recognized but no one in their wildest dreams would have envisaged billions of transistors in low-cost personal computers operated by schoolchildren.

So, taking this history of research into account, there is every reason to anticipate that research on nanotechnology, if intelligently funded and pursued, will bear fruit that fully justifies today's enthusiasm.

Henry I. Smith
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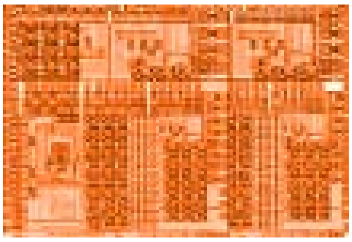
CHAPTER 2

Introduction

2 Introduction



In a context of constant change, people are increasingly looking for true and accurate sources of information that will help them keep abreast of new trends. By developing new study approaches, we can gain a better insight into the future of technology and be better positioned to harness the business opportunities it offers.

Bankinter's Fundación de la Innovación (Foundation of Innovation) was set up with the stated mission of "influencing the present by looking to the future", and of stimulating and consolidating innovative thinking in the Spanish business environment. It is an ambitious and innovative project, whose main aims are to enhance social awareness of technology and to encourage business opportunities, based on the emerging technologies detected. The project, which now has 130 members, seeks to reinforce Bankinter's commitment to society.

The flagship project of the Fundación de la Innovación Bankinter is its "Future Trends Forum" (FTF), a showcase for the Bankinter culture of innovation and commitment to new developments. The forum is backed by a select and exclusive group of experts from different spheres of human knowledge, leading scientists and intellectuals on the international stage. It boasts some of the world's top minds, who work together, trying to predict the immediate future (in a 5 - 10 year timescale), detecting social and economic trends and technological developments, analysing their possible impact on a range of spheres and deciding what conclusions to convey to different strategic areas of society.

The FTF's methodology is based on three essential pillars: multi-disciplinary approach, neutrality and globality. These three aspects are essential in ensuring that any new response to the future will not be affected by private interests or favouritisms of any kind.

The FTF members freely propose, vote and finally decide on a subject, which they then go on to debate in greater depth. The final result of each of these processes is to disseminate the conclusions of this research work among the business community, professionals, senior management and companies and institutions. This part of the forum's work takes the form of a lecture tour of major Spanish cities, and the release of this publication.

In the conclusions of this fifth FTF meeting, for example, you will find meticulous, reliable and credible information on a subject which was debated and considered to be of priority importance for the immediate future: "Nanotechnology: The Industrial Revolution of the Twenty-First Century".

The publication sets out the analyses made by the FTF, in conjunction with its main collaborator, Accenture, on the possible impact nanotechnology may have on sectors such as materials, electronics, medicine and energy –and on society at large. The book includes chapters on the present and context of nanotechnology, which analyses the nanotech presence and research in different industries, and on government support, so vital in getting this new science off the ground. It also gives the "FTF view", with the experts' conclusions on possible scenarios for the future and the most likely economic and social impact on the different regions identified as leaders.

Once again the Fundación de la Innovación Bankinter hopes that this new publication will serve as a source of knowledge, but above all as a stimulus and guide for professionals and business people in different industries who will to some extent be influenced by the emergence of nanotechnology on all the world's markets.

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CHAPTER 3

Current Status and Context of Nanotechnology

3 Current Status and Context of Nanotechnology

While some people are already speaking of a new industrial revolution, others have scarcely heard of nanotechnology. This new science, if we can call it that, is a great unknown. We have been using some nanomaterials for decades and yet most of us are entirely unaware of the fact.

The purpose of this chapter is to lay the foundations for understanding what nanotechnology is, what advances can be called "nanotechnological" and what context we are currently operating in.

To do this, we will first examine the definition and historical background and look at the current status of the four main areas of application in which research is being conducted: materials, electronics, medicine and energy. We will then examine the role of the public authorities in this new technological adventure.

3.1. Definition and Background

Nanosciences and nanotechnologies are new approaches to research and development (R&D) that seek to control the fundamental structure and behaviour of matter at the level of atoms and molecules.

These fields open up the possibility of understanding new phenomena and producing new properties that can be utilised at the micro- and macro-scale. Applications of nanotechnology are becoming increasingly visible and their impact is beginning to be felt and will soon extend to many areas of everyday life.

First things first.

Defining nanotechnology is no easy task. There are many similar definitions, with small differences of nuance, especially when it comes to putting "the science of the small" into practise and we therefore need to take things step by step.

The prefix *nano* comes from the Greek and means 'dwarf': in science and technology it represents 10^{-9}. A nanometre (nm) is a billionth of a metre, i.e., tens of thousands of times smaller than the diameter of a human hair.

Illustration 1 shows some examples of structures generated by nature or man-made developments getting smaller and smaller down to nanometric size.

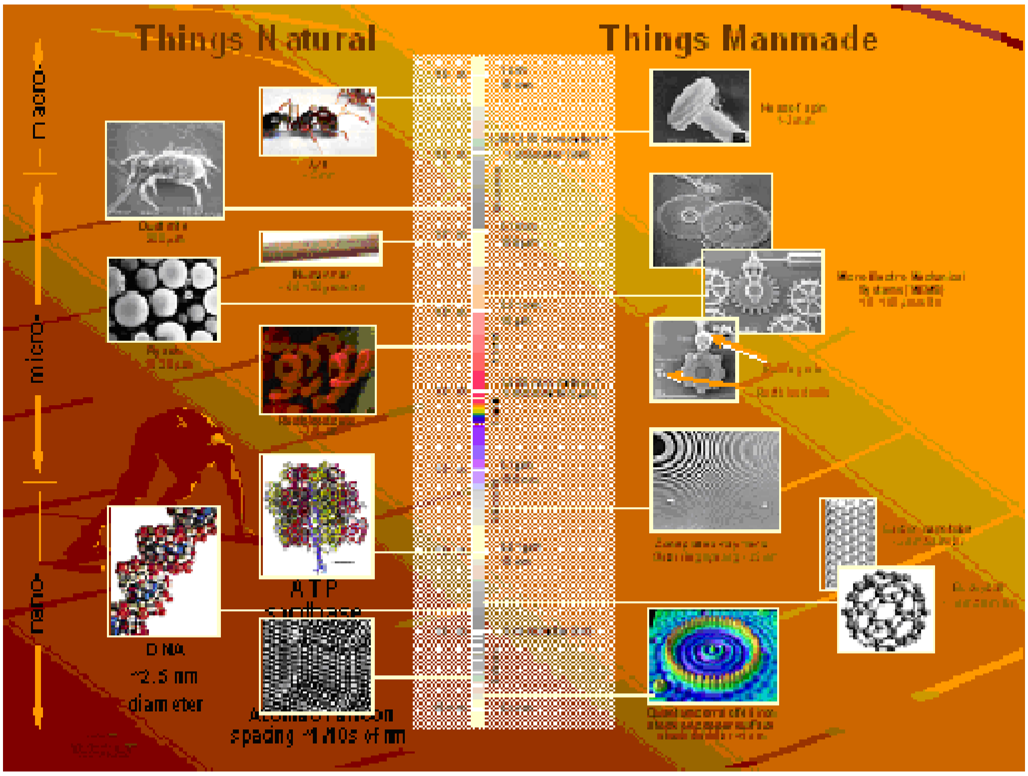

Illustration 1. Natural and artificial structures
Source: presentation at the FTF by Dr. Brent M. Segal.

Firstly, *nanoscience* can be defined as being the study of the behaviour and manipulation of materials at atomic or molecular scale in order to understand and exploit their properties, which are significantly different to those at a larger scale.

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A communication from the European Commission entitled *Towards a European strategy for nanotechnology* gives the following definition:

"Nanotechnology refers to an interdisciplinary science and technology at the nanoscale of atoms and molecules, and to the scientific principles and new properties that can be understood and mastered when operating in this domain".

Let us divide this definition into three separate aspects each deserving special mention:

- *"Nanotechnology refers to an interdisciplinary science and technology..."*

Nanotechnology is often referred to as a "horizontal" science. Nanotechnology is truly multidisciplinary. It involves specialists in materials working with mechanical and electronic engineers, but also medical researchers, biologists, physicists and chemists. There is a common thread running through all nanoscale research: the need to share knowledge on methods and techniques, combining them with knowledge on atomic and molecular interactions in this new terrain of science.

- *"... science and technology at the nano-scale of atoms and molecules..."*

The term *nanotechnology* describes all those technologies that focus on the production and application of different systems at a scale ranging from atomic or molecular level to around 100 nanometres. To give an idea of this scale, the dot on this "i" contains around a million nanoparticles.

- "...and to the scientific principles and new properties that can be understood and mastered when operating in this domain".

The difference between materials at nanoscale and the same materials at macroscopic scale is that the former have a relatively larger surface area in comparison to their mass, which makes them more chemically reactive and thus allows changes to their essential properties. In addition, below a few nanometres, the classic laws of physics give way to quantum physics, which regulates optical, electrical and magnetic behaviour with different laws.

Research trends in nanotechnology

If we relate this definition of nanotechnology and its component aspects to the research being carried out, we can distinguish between three different trends encompassing the field of nanotechnology:

- *Nanotechnology based on dimension:* scientists are seeking to build smaller and smaller structures and devices, down to nanometric scales.

- *Nanotechnology based on principles of operation:* investigating new characteristics of materials by manipulating them at atomic or molecular scale.

- *Nanotechnology based on method of fabrication: bottom-up assembly* or *molecular self-assembly*- in other words the union or conjugation of atoms and molecules to create a new more complex structure.

Research began with nanotechnology by size, i.e., the miniaturisation of products. Here, scientists are currently reaching physical limits, and research is required into the new characteristics of materials so that they can be manipulated at atomic or molecular scale (nanotechnology by operation).

These two areas, therefore, have gone hand in hand in recent years, although it seems likely that the former will make way for greater development of the latter in the near future.

Experts say that there is greater uncertainty vis-à-vis the third area of research (by manufacturing method), given that this technology has yet to really take off. The possibility of creating new structures could mark a major revolution, but we will probably have to wait a few years before we can see this becoming a reality.

Illustration 2 shows in graph form the opinion of the FTF experts on the development of these areas of research over time.

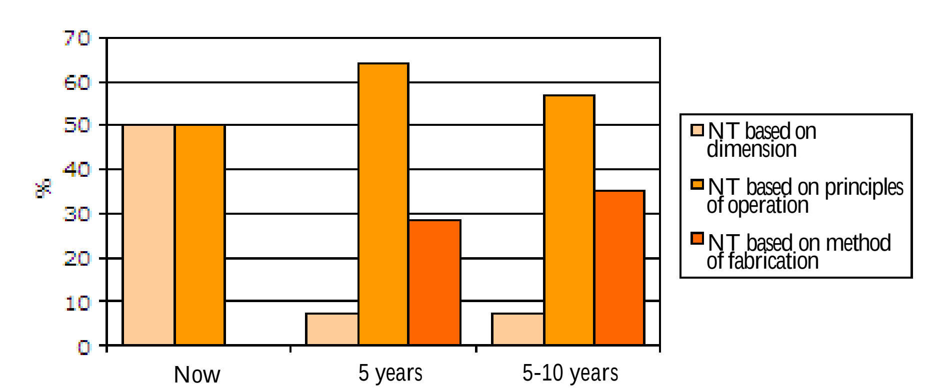


Illustration 2. Development of areas of research
Source: own preparation.

A brief history

The term *nanotechnology* was coined by Norio Taniguchi[1], from the University of Tokyo in 1974, to distinguish between engineering at a micron level (10^{-6}) and engineering at a nano level (10^{-9})... no small difference. Eric Drexler, of the MIT (Massachusetts Institute of Technology) popularised the term in his book *Engines of Creation*, published in 1986.

1. N. Taniguchi: "On the Basic Concept of 'Nano-Technology", Proc. Intl. Conf. Prod. Eng. Tokyo, Part II, Japan Society of Precision Engineering, 1974.

However, the origins of nanotechnology go back to December 1959, when Richard Feynmann, winner of the Nobel Prize for Physics, addressed the American Physical Society in a 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.

However, the smaller the scale used in research, the more complicated it became to see what was going on. 1981 saw a major advance in the "dwarf race", when researchers at IBM managed to create an instrument called a "scanning tunnelling microscope" (STM)[2], which could capture images of the atomic structure of matter.

Out of the Box

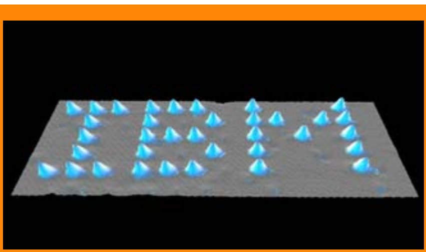
Feynmann offered two prizes of $1,000 each: one for the first person capable of creating an electric motor in a 0.4 mm cube; the other for anyone capable of reducing the information on the page of a book by 25,000 times (i.e. making it 100 nanometres long).

The first of the two prizes was claimed less than one year after he gave his lecture, but it took another 26 years before anyone won the second of the two.

The IBM researchers were also responsible for another major advance: the atomic force microscope, which made it possible to examine and view atoms individually.

Simultaneously, a group of researchers at Rice University came to public attention by discovering a football-shaped carbon molecule (*fullerene* or *buckyball*). This structure, one nanometre in diameter, can conduct electricity and heat; it is harder than steel and lighter than plastic.

In the 1990s, the story developed further thanks to the accidental discovery of carbon nanotubes, consisting of structures similar to *buckyballs*, but in elongated form. Like buckyballs, they are extremely hard and very light.



In 1989 IBM used the scanning tunneling microscope to write the letters IBM with 35 atoms of Xenon.

Over recent years, the pace of research into nanotechnology has accelerated greatly, with discoveries such as quantum corrals, quantum dots and single-electron transistors.

2. There is a glossary at the end of this document with a description of some of the technical terms used in the text.

The enthusiasm for nanotechnology appears to be contagious. In 1999, President Bill Clinton announced a National Nanotechnology Initiative, intended to accelerate the pace of research, development and marketing of applications in this field. The initiative had repercussions in other countries and in 2001 the European Union approved a budget of 1.3 billion euros for nanotechnology research under its Sixth Framework Programme. Japan, Taiwan, Singapore and China have begun developing similar measures to speed up development in this new science.

Is nanotechnology with us already?

As a small foretaste of the rest of the this book, let us say at this stage that nanotechnology is already a reality and is currently being used in products readily available on the market:

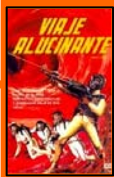
- Sunglasses that use tissues of ultrafine polymers with protective and anti-glare properties.
- Tennis rackets with increased flexibility and resistance thanks to carbon nanotubes.
- High performance ski wax that increases sliding speeds.
- Catalysers for cars that reduce their impact on the environment.

However, the second great industrial revolution is still to come and, depending on the specific industries, the length of time may vary for technological reasons (in the case of nanoenergy, for example) or legal reasons (in nanomedicine).

It all began in the year 400 BC, when the Greeks coined the terms *element* and *atom* to describe the smallest components of matter

1940s
Von Neuman studies the possibility of creating self-reproducing systems to cut costs.

1959: Richard Feynman started the ball rolling with his talk "There's Plenty of Room at the Bottom".".

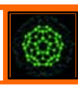


1966
The movie *Fantastic Voyage* tells the story of scientists travelling through the human body. The scientists are reduced to the size of a particle and introduced inside a researcher's body to destroy a deadly tumor. For the first time in history this is seen as a real scientific possibility.

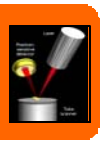
1974
Norio Taniguchi coins the term *nanotechnology,* to differentiate between nanoscale and microscale (nano- is 1000 times smaller than micro-).

1981
- Scanning tunnelling microscope (STM) invented, allowing molecules to be observed at atomic resolution. Its inventors, Heinrich Rohrer and Gerd Karl Binnig of IBM, win the Nobel Prize for Physics 1986.
- The first scientific article on nanotechnology, "Protein Design as a Pathway to Molecular Manufacturing," by Dr. K. Eric Drexler, suggests the possibility of building complex and functional nano-machines.

1985: New milestone: the structure of *fullerenes* or *buckyballs* is discovered.

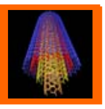


1986: Invention of the Atomic Force Microscope (AFM), a new type of scanned-proximity probe microscope for manipulating atoms one by one, through physical contact between the probe and the atom.



1989: IBM spells out the letters *IBM* using a Scanning Tunnelling microscope, moving just 35 atoms of Xenon.

1991: Sumo Iijima, of NEC in Japan, discovers carbon nanotubes.



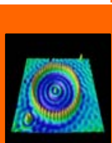
1993
- A team from the Weizmann Institute of Science in Israel creates the first nanostructures, with surprising properties. The resulting creation of "nanotube ropes" attracts international interest in the physical and chemical of carbon nanotubes.
- Warren Robinett (UNC), and R. Stanley Will (UCLA), create a nano-manipulator, a device connected to an STM that allows researchers and "feel" atoms.

1996
- Richard Smalley wins the Nobel Prize for Chemistry for his part in the discovery of *fullerenes* C-60 in 1985.
- George Whitesides designs chip circuits for computers 30 nanometres wide. Each chip has the potential to operate at a speed of over one teraflop, i.e., 4,000 times faster than a PC.

1998: Cees Dekker's team at the Delft University of Technology (Netherlands) builds a transistor with a carbon nanotube. "Nanopencil" made from carbon nanotube is constructed and can be used for writing.

1999
James Tour (Rice) and Mark Reed (Yale) create the molecular switch, proving that nano-scale computational devices can be built from a single molecule.

2000
- President Clinton launches the *National Nanotechnology Initiative,* with a budget of $422 million.
- Don Eigler and his colleagues at IBM create a "quantum corral".



2001
- IBM scientist Phaedon Avouris creates the first single-molecule logic gate.
- Cees Dekker builds a transistor in a carbon nanotube that can be switched on and off with a single electron.
- Charles Lieber of Harvard, uses different formations of nanowires and combines them to create the smallest ever light-emitting diode (LEDs).
- IBM researchers in Zurich develop the "millipede" memory card, with a potential of 1 terabit per square inch.
- The European Union allocates a budget of €1.3 billion between 2002-2006 to research on nanotechnology under the Sixth Framework Programme.

Illustration 3. Main advances in nanotechnology
Source: own preparation.

3.2. Main Areas of Application

This section will centre on the four areas of application on which most research is being concentrated and where the first advances are being seen:

- Probably the most developed field, and the one with the greatest impact, is the design of new *materials*, with properties which were previously unexploited-and sometimes even unknown. Nanotechnology is opening up new opportunities ranging from the development of everyday applications –such as more flexible and resistant materials for tennis rackets– to ideas that still sound like science fiction, such as controlling the individual behaviour of electrons.

- Applying nanotechnology to *electronics* allows a reduction in chip size and an enlargement of memory. Work is being carried out on semiconductors and even on so-called "organic" computers, which will allow data to be stored and processed without intervention from other electronic elements, in the very same way as in the human brain.

- *Medicine* is another area where work with nanotechnology has already begun, but the final results will not be seen for some while, given the necessary time limits on testing new pharmaceuticals, for example. Research is being conducted into pharmaceuticals that will specifically target the sick area of the body and artificial "tissues" which will operate in the same way as organic ones.

- In the fourth field of action, *energy*, new less pollutant and more efficient sources and new means of storing energy are being developed.

The figure below shows the relation between these four areas of application (materials, electronics, medicine and energy) and the three spheres of research set out in the section above (nanotechnology by size, by operation and by method of manufacture).

Notes

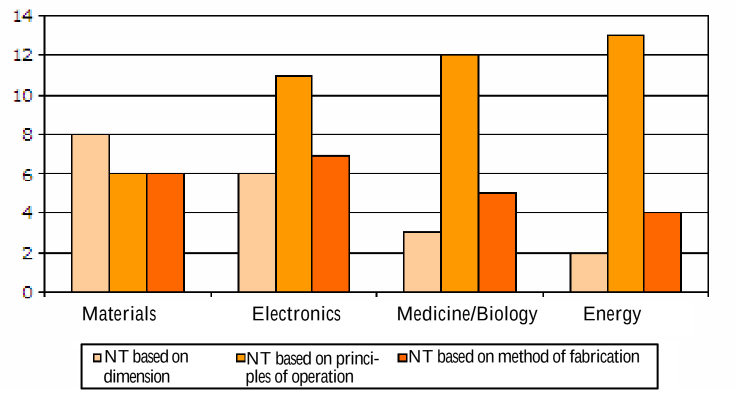


Illustration 4. Trend in nanotechnology in each area of application
Source: own preparation.

The FTF experts believe that the predominant trend in practically all areas of application will involve research into new properties through nanoscale manipulation of elements. Miniaturisation continues to play an important role in nanomaterials and nanoelectronics. The creation of new structures may be particularly influential in the field of electronics and the manufacture of new materials.

3.2.1. Materials

The foundation stone must be laid first

Nanotechnology is a new field of research with a growing influence. However, for several decades now a number of products have been available using nanomaterials, and indeed some are even being mass marketed. Some ski-suits, for example, contain water-repellent nanofibres and tennis balls are now using clay polymer nanocomposites which make them last twice as long as traditional ones.

In addition to these tangible advances, *bottom-up* research continues to produce blocks of materials (or structures), designed and assembled in a controlled fashion to have specific properties, unlike those previously seen. Nanotubes, nanoparticles and quantum dots are some of the key materials now being produced, but certain hurdles still need to be overcome before they can be manufactured on a large scale.

Before examining one of these four areas of application –nanomaterials– in greater detail, there is an important point that should be mentioned. Nanomaterials form the basis for developing all the other areas: research with quantum dots will allow a take-off in nanoelectronics; the development of biosensors may revolutionise nanobiology and the creation of new more resistant ceramics for storing hydrogen, which could mark a turning point in the energy industry.

For all of these reasons we are going to examine this area of application first. Although it is somewhat more abstract, it is the launch-pad for the development of all the others.

Nanomaterials already exist on the market

You don't need to know how a computer is built to make use of its technological advances, and similarly, you don't need to know the composition of all clothes and cosmetics we wear every day to enjoy the improvements nanotechnology has brought.

The following are just some of the products already on the market which incorporate improvements based on nanomaterials:

- *Non-scratch glasses:* tissues made of ultra-fine polymers exist with protective and anti-glare properties. Reasonably priced spectacles for everyday use are now being sold with scratch-proof glass.

- *Self-cleaning windscreen:* Crystals coated in nanoparticles of titanium oxide are being used which can eliminate dirt when they come into contact with sunlight. The principle is that the ultraviolet rays from the sunlight react with the nanoparticles of titanium oxide, generating radicals that oxidise the organic matter and eliminate incrustations of dirt. When water falls on the windscreen, instead of forming into drops, it spreads uniformly across the surface of the glass, carrying the dirt along with it.

- *Crease-proof and stain-proof clothes:* Save on laundry expenses, with ties that repel dirt and shirts that do not need ironing. You can also buy skiing anoraks that use nanofibres to resist water and wind.

- *Sports equipment that makes players more competitive:* Tennis rackets are already readily available that use carbon nanotubes to make them more flexible and more resistant. You can also buy a new type of ski wax that will improve your performance by hardening the surface and giving greater sliding power.

- *More effective and protective cosmetics:* L'Oreal is now marketing a range of lotions granulated to below 50 nm. The result is that the creams let light through, giving a purer, cleaner feel. Anti-wrinkle creams area available using polymer nanocapsules to distribute active agents such as vitamins more efficiently. Some sun creams use nanoparticles of titanium dioxide; they offer the same degree of protection against UV light as traditional creams, but do not turn white when spread on the skin.

Less easily applicable advances

Whenever you read an article or hear an item on the radio or television about nanotechnology, the words *nanotube* and *nanoparticle* are almost sure to come up. While these terms are targeted primarily at the scientific community and may prove difficult for laypeople to understand, they form the basis of many of the advances currently being researched.

Illustration 5 shows that "carbon nanotubes" and "nanoparticles" were the terms most often used in press articles about nanotechnology published during 2004 and 2005.

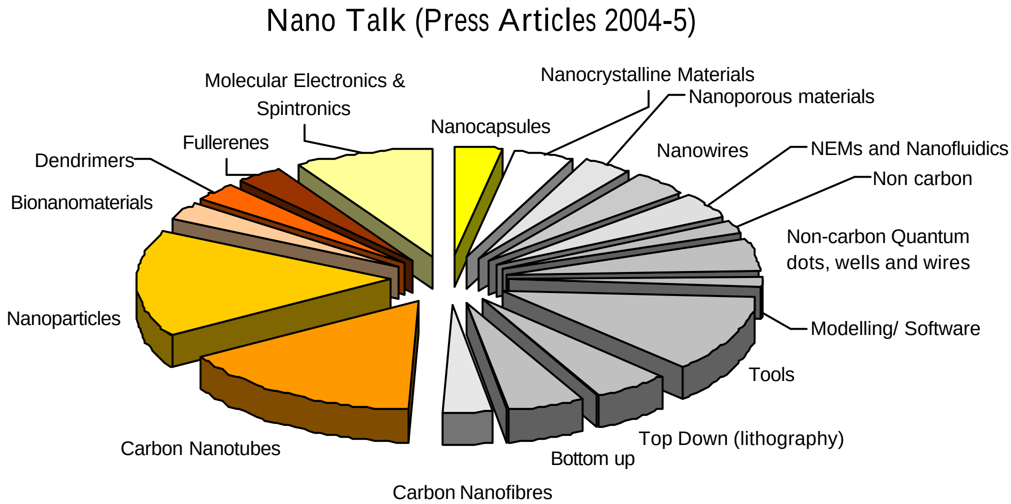


Illustration 5. Terms published in the press on nanotechnology
Source: Científica.

We are now going to look at the nanomaterials currently being developed and see what their most likely applications are. This will take us directly to a discussion of nanoelectronics, nanomedicine and nanoenergy.

Carbon Nanotubes

Nanotubes are often mentioned as if they were a single perfectly defined structure. However, there are many types of nanotubes, of different sizes, shapes and thus properties.

Initially, nanotubes can be said to be cylindrical structures of sheets of graphite, with one hundred times the tensile strength[3] of steel and six times lighter. They also have other important properties: they are as efficient at conducting heat as diamonds, can be just as effective as copper at conducting electricity or take on the properties of semiconductors.

The most common means of classifying these structures is by the number of layers they contain: single-walled nanotubes (SWNTs), which consist of a single cylinder, and multi-walled nanotubes (MWNTs) which are made up of concentric cylinders.

The properties described above refer to single-walled nanotubes (SWNTs), which are much more difficult to create than multi-walled nanotubes. Indeed, this is the first difficulty that needs to be overcome before economies of scale can be achieved in production. Existing equipment cannot be scaled up, meaning that the only way of producing more is to build more nanotube-manufacturing machines... which does not exactly help lower the price.

3. Tensile strenth measured as resistance to stress; i.e., the capacity to resist a yield force without breaking.

The second problem faced in manufacturing nanotubes is that generally speaking a metal catalyst is needed to produce them, and this contaminates the original properties of the nanomaterial.

There are other materials, nanofibres, which although they are also often known as nanotubes, do not have the same structure, and their properties are therefore not as spectacular. On the other hand, they appear to be easier to produce, and as a result they are now attracting great interest in ceramics, metallurgy, electronics, optical devices and power storage, among other industries.

Some more information

Nanotubes are, basically, molecular structures comprised of curved hexagonal sheets. They are normally closed at the ends in semi-spheres, although these ends can be removed.

These cap-shaped terminations are made out of combinations of pentagons and hexagons. As a result, nanotubes are viewed as the first cousins of *buckyballs* or *fullerenes* – spherical molecules made up of 60 atoms of carbon, which look like footballs.

The following are some of the applications of nanotubes currently under investigation:

- *Bone replacement:* thanks to their strength, flexibility and lightness, nanotubes could act as scaffolding, capable of supporting bones and helping people suffering from osteoporosis.

- *Field emission devices:* screens are being developed for televisions and computers that use nanotubes because of their special properties, such as their excellent field emission. They may also be useful as sources of X-rays for medical applications.

- *Supercapacitors:* these are perfectly ordered structures of nanotubes, which allow more efficient energy storage.

- *Nanosensors:* the electrical resistance of semiconducting nanotubes change when they are exposed to alkalines, halogens and other gases at ambient temperature. This is a promising sign for the possible production of much more powerful chemical sensors than at present.

- *Storage of hydrogen and ions:* hydrogen could be stored in nanotubes and gradually released in small fuel cells. Equally, they could be used to contain lithium ions, giving much longer battery life.

- *More powerful windmills:* Scientists are exploring the possibility of encrusting nanotubes in the resin used to manufacture the blades of the turbines in wind farms, to reduce the weight of the blades and increase their length. This would mean that it would be possible to manufacture larger and more powerful windmills.

- *Superhard materials:* nanotubes encrusted in other compounds could strengthen materials, enhancing personal safety in a range of applications. For example, they could be used in cars, to absorb the impact of a collision, or in construction to make roof beams that would be more flexible in the event of an earthquake.

Nanoparticles

As with nanotubes, nanoparticles encompass a wide variety of concepts, which can sometimes be described using other terms, as is the case of the quantum dots we will look at below.

Chinese ceramics workers have used nanoparticles since ancient times. Over a period of many decades, 1.5 million tonnes of carbon black (one of the most abundant nanoparticles) has been produced. It is true, however, that these natural materials were used unwittingly and their properties as nanomaterials were not properly understood.

Out of the Box

In 1885, the tyre manufacturer B.F. Goodrich decided to manufacture black wheels to hide the dirt (previously, tyres had been white because of the natural colour of the rubber). To change the colour, they added carbon black, a coal material which stained the rubber black. To the company's surprise, however, they found that the new wheels were up to five times more resistant than the uncoloured ones.

Today's tyres are more sophisticated, with dozens of layers and steel reinforcements, but carbon black is still one of the main components.

The two main factors impacting the move from microparticles to nanoparticles (and therefore marking the special properties of the latter) are:

- *The reduction in the size of the particles means that they tend to be governed by quantum principles.* This transition from classic physics to quantum physics is not a gradual one; once the particles are reduced to a certain size, they begin to act in accordance with the laws of quantum mechanics (see the section on quantum dots below).

- *Increase in the surface-to-volume ratio.* A very large surface and a small volume is a critical factor in the operation of catalysts and other structures, such as electrodes, allowing improvements in the efficiency of batteries and fuel cells. Some nanocomposites generated with interactions between nanoparticles and other materials have special properties that increase the resistance of these composites and their resistance to heat.

However, some properties of nanoparticles cannot be predicted only by taking these two factors into account. For example, there are perfectly formed silicon nanospheres which are not just harder than normal silicon, but rank amongst the hardest materials known, alongside sapphire and diamond.

Huge advances are being made in nanoparticles, with new discoveries almost every day on many fronts. One example are biosensors or iron-based particles used against cancerous tissues. Bio-medicine is one of the most promising fields for potential applications.

Great hopes have also been placed in the environmental sector, where work is already being carried out with nanoparticles capable of cleaning polluted areas and eliminating toxic pollutants.

Half way between preventative medicine and the textile industry, a fabric is on the point of being marketed in which a host of nanoparticles have been stuck together to form a barrier between pollen and gaps in the cloth, thus helping to prevent pollen from sticking to it.

In addition, because nanoparticles are smaller than the wavelength of light they are transparent and therefore have a range of applications in the field of *cosmetics*.

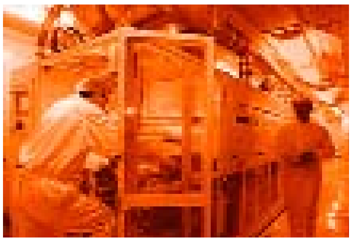
Quantum dots

The quantum dot could be defined as a particle of matter so small that the addition of a single electron would alter its properties. The quantum attribute is a reminder that the way the electron functions in such structures has to be described in terms of quantum theory.

Notes

Quantum dots are so called because their nanometric size causes a quantum confinement of the electrons in its structure. Manufactured from semi-conducting material and with only a few hundred atoms, when excited, quantum dots emit light at different wavelengths depending on their size, which makes them extremely useful as biological markers of cell activity.

The structuring of matter into quantum dots produces a number of properties which can be controlled at will. Some of these properties and their possible applications are described below:



- *Light emitters:* when lit, quantum dots emit light at a very specific wavelength which depends on the size of the quantum dot. Some molecules are currently "photographed" using fluorescent molecules with organic dye: however, no more than three dyes can be used at the same time because they overlap. The use of quantum dots would be a great advance, allowing full-colour images (by positioning quantum dots of different sizes) from a light source with a single wavelength.

- *Optoelectronics is another immediate application:* with quantum dots of semiconductor materials, such as indium arsenide and indium phosphide, LED lasers can be manufactured which are more efficient than current CD or barcode readers.

- *Quantum cryptography:* It is possible to embed quantum dots in banknotes and documents. These are invisible to the naked eye but reveal some visible mark when exposed to ultraviolet light. This is one of several applications in the security industry.

- *Quantum computing:* This is the concept that is most closely associated with quantum dots and where most attention is being focused on research and a search for applications. If a way is discovered of preventing the destruction of data stored in quantum bits when they interact with them, quantum computers will mark a major leap forward with regard to processing speed, with an exponential increase in computing capacity.

Other nanomaterials

Some other nanomaterials now being applied in advances that are close to marketing stage include:

- *Nanostructured materials* are metals or ceramics bulk materials made up of crystals sized at nano-scale. Reducing crystals to create new structures gives these materials different structural properties to those of metals or ceramics made at normal scale. One possible application is hydrogen storage.

- *Nanocapsules* could be described as hollow nanoparticles, to which different types of substances can be added. One of their main applications is for delivering pharmaceuticals, where they have the advantage of getting straight to the target and avoiding undesirable side-effects of the pharmaceuticals in healthy cells.

- The main characteristics of *nanoporous materials* are that they are catalysts, absorbents and adsorbents. Filters with incorporated nanoporous are now being used in vehicles, because they can reduce pollution and fuel consumption.

- Fullerenes (or *buckyballs*) have antioxidant properties and a high tolerance to biological systems and act as superconductors at very low temperatures. They are currently being used, among other applications, as lubricants and as solar cells.

- *Nanocables* are solid cylinders (unlike nanotubes, which are hollow) with a diameter of between 10 and 100 nanometres. Due to their electrical, optical and magnetic properties, they are primarily being applied to build nanoscale electronic and optical instruments.

- *Dendrimers* are synthetic molecules made from a nanoscale manufacturing process, whose highly ramified three-dimensional structure provides a high degree of surface functionality and versatility. The first experiments with dendrimers focused on the area of electronics, because they appear to be able to alter the behaviour of semiconductors. An application is being researched in the area of environmental protection, because they can act as "attractors" of metal ions, which are pollutants, thus cleaning the air or water. Studies are also underway into the use of dendrimers as vehicles for dosing pharmaceuticals.

In general terms, all the nanomaterials we have examined in this chapter have great potential for developing applications that could revolutionise a range of markets. However, production scalability needs to be addressed if companies are to be able to meet manufacturing costs and take the next step in the value chain towards industrialisation.

Main government support to nanomaterials

Progress in research into nanomaterials will to a large extent depend on government involvement, and support in the form of government-created platforms will offer an unquestionable impetus to the technology.

United States

Research into nanomaterials in the United States is integrated into the National Nanotechnology Initiative[4], which has the following aims:

- To maintain a research and development programme that will make it possible to expand knowledge and understanding of the behaviour of materials.

- To investigate the development of instruments and methods that will help measure, characterise and test nanomaterials, and monitor their consequences.

- To provide suitable training and infrastructures for the study of nanomaterials.

4. Website: www.nano.gov.

Europa

Europe provides support to research into nanomaterials through EuMat (the European Technology Platform for Advanced Engineering Materials and Technologies)[5]. The main aims of the EuMat are:

- To ensure the involvement of industry and other players in establishing European research and development priorities in the area of advanced materials and technologies.
- To improve consistency between existing and future European projects, introducing "radical changes" and ensuring "sustainable development" in the industry of materials and related technologies.
- Interdisciplinary education and innovation in technology.

Spain

In Spain EuMat-Spain[6] was created to be a EuMat "national platform". Its aim is to convey to the European Commission the interests and priorities in research, development and innovation of Spanish science, technology and society.

3.2.2. Electronics

Miniaturisation requires another approach

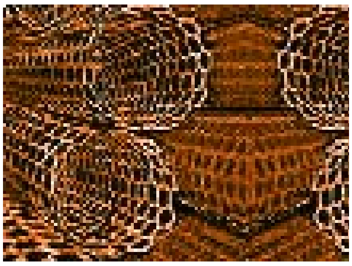
The electronics industry has long been immersed in a process of miniaturisation. Moore's Law, formulated in 1965, states that the number of transistors in the average computer will increase approximately twofold every 18 months. The law still holds today, but the limits of silicon-based technologies appear to be getting increasingly close.

In this miniature world, the laws of quantum physics become more and more relevant. Quantum physics says that the way electrons operate is based on probabilities. This is a concept that engineers find very difficult to work with; they don't like running into a 0 when there should be a 1... not to mention the trouble involved in handling atoms.

So, while nanotechnology is still at an early stage, nanoelectronics is still piggy-backing on its immediate predecessor: microelectronics.

Microelectronics, which we could define as the development of electronic components of microscopic size, reached a major level of technological sophistication and industrial development in the 1990s. Given the extreme miniaturisation now achieved in components, we can safely say that we are moving into the world of nanoelectronics.

5. Website: www.eumat.org
6. Website: www.eumatspain.org.



Nanoelectronics, however, goes further. It is defined as the research, manufacture, characterisation and application of functioning electron devices of less than 100 nanometres in size. This would make it possible to use quantum properties, which, once controlled, could offer benefits such an increase in processing speed and storage capacity and a considerable reduction in the size of any technological component or equipment.

The European Commission[7] says "the world market for nanoelectronics is worth hundreds of billions of euros and this industry is the driving force behind the current development of nanotechnology". It is generally believed that any development involving multiple applications could spark a new industrial revolution. Processing time and the size of devices will be considerably reduced, and there will be an increase in the power of computers and transistors for use in microprocessor-controlled telephones, cars, domestic appliances and industrial machinery.

Nanoelectronics is now beginning to show results in a variety of applications at advanced stages of industrialisation or already being marketed.

Nanoelectronics in our everyday lives

Nanoelectronics is currently in the process of entering our society, even if we are not always aware of the everyday devices in which we are using it. The following are a number of developed technologies which illustrate the current status of nanoelectronics.

- *Brighter, lighter, more energy-saving screens:* OLED (Organic Light-Emitting Diode) technology, is already available on the market, allowing brighter images, in lighter devices, with lower energy consumption and wider angles of vision. It is used in screens for laptop computers, cinemas, mobile phones, automobile dashboards, GPS systems and digital cameras. This technology is expected to take over from glass and liquid (LCD) screens because of its higher image quality.

- *Farewell to batteries?:* In September 2005 Toshiba presented two revolutionary models of MP3 player, capable of operating without batteries, thanks to the use of nanoscale fuel cells. Using a combination of hydrogen and oxygen, fuel cells can produce enough power, with water as the only waste product. This is their great appeal, since they produce clean energy that does not harm the environment. This new technology, called DMFC *(Direct Methanol Fuel Cell) is also used in mobile phones and laptop computers.*

- *Dyes that change colour to order:* "electronic ink" is a development that uses a series of capsules containing white and black particles charged with different polarities. By applying an electromagnetic current, these particles are placed in one position or another, to show one or other of the two colours. The invention has all sorts of applications, from billboards and traffic signals to wallpaper

7. Publication by the European Commission's Directorate General of Research as part of its "European Research in Action" initiative.

whose pattern could be changed at the owner's whim. It could even be used for camouflage wear, with the design of the garment changing to match the background. It has great advantages over existing technologies in terms of sharpness for reading, low energy consumption and the versatility of the materials it can be applied in.

- *Much faster computer chips:* In May 2002, IBM announced the creation of carbon nanotube transistors that outperform even the best prototype transistors available. Transistors are the elements from which computer chips are built. The new technology offers great advantages in that it eliminates the problem of the excessive heat today's chips generate when they operate above a certain speed; It also gives higher speeds because the distance the data has to travel is shorter.

- *Memory cards the size of a postage stamp with the capacity of 25 DVDs:* the Millipede project by scientists at IBM managed to create a system with a storage density of one terabit (a trillion bits) per square inch. This astounding storage density, equivalent to accumulating twenty-five million pages of text in a surface the size of a postage stamp, uses less energy than traditional storage systems and allows for rewriting.

Which areas are being researched?

The constantly changing milieu of the electronics industry requires constant progress, anticipating possible barriers that may arise in the short and medium term.

There follows a list of some of the main research projects being carried out, which the electronics industry hopes to be able to apply in coming years.

In the field of communications devices research is focusing on improving the existing media:

- Nanoscale mobile phones are now being developed. A far cry from Alexander Graham Bell, these *nanophones* consist of radio transmitters less than the diameter of a human hair in size. Because the radio frequency amplifiers now being used in mobile phones are hot tungsten filaments with an efficiency of only 10%, researchers are looking to replace them with high efficiency carbon nanotubes, which would consume less energy.

- Research is also being conducted into the manufacture of *nanocompasses*, which, once connected to GPS systems, would allow the telephone to be used to detect the user's exact location. *Nanomicrophones* are also being developed to improve the way interference is filtered out and the right sounds are received.

In the field of communication networks, important steps have also been taken:

- It is a fact that data through the internet can be processed incredibly faster by means of a silicon chip that efficiently controls the beam of light carrying the information. The light, through the optic fibres, has proved to be the best alternative to transmit huge amounts of information at a great speed. However, the processing and the information management is still done by changing the optic signals into electric ones, which reduces the speed and increases the number and cost of the components[8].

It is also benefiting from the numerous potential applications of nanoelectronics, such as in *quantum computing*, for example:

- With the ever-increasing capacity of chips now approaching the limits of today's technology, many researchers believe that the future lies in *spintronics*, a nanoscale technology in which data is transmitted using not only the *charge* of the electron –as is the case at present– but also its rotation.

  Today's electronics codes computer data using a binary system of ones and zeros, depending on whether an electron is present or not. In principle, however, the rotation of an electron (in one direction or another) could also be used as information. This means that spintronics could enable computers to store and transfer twice the amount of data per electron.

  If a reliable way of controlling and manoeuvring these rotations can be found, spintronic devices (such as Spin-FET transistors) might offer higher speeds of data processing, lower energy consumption and many other advantages over conventional chips, including the capacity to make really innovative quantum computations.

Out of the Box

Don't try looking for Silicon Valley on a map. It doesn't exist. Silicon Valley was a nickname given to the area of Santa Clara valley (from Palo Alto to San José, by way of Mountain View, Sunnyvale and Cupertino). The nickname comes from the fact that silicon is the material used to make computer chips, which are manufactured in Silicon Valley.

- This technology is closely related to quantum computing; scientists are researching the possibility of using the electron spin for future *quantum computers*, in which this rotation would act as a *qubit* or *quantum bit.*

  If we are to ensure that computing is not held back by the inability of conventional technology to operate at an atomic scale, one alternative is to create devices that make use of quantum properties - in short, what are known as "quantum computers".

8. In 2004, scientists from the Cornell University (USA) and the Photonics Technology Center of the Polytechnic University of Valence (Spain) proved for the very first time that the optic control of a photonic commuter was feasible in a silicon micro-nanochip, which is the equivalent to a photonics silicon transistor (Nature, vol. 431, pp. 1081-1083, 2004).

Specific programmes have been developed for these computers that make it possible, for example, to run a search for information in a database. What makes them different is that instead of checking each of the elements in the database one by one, as a conventional computer does, quantum computers check them all at the same time, thus reducing the search time. To achieve functions like this, these quantum computers store the information in the form of *qubits*, which are quantum states (a combination of location and speed of the particles which is impossible to measure with absolute precision) representing ones and zeros. Today's computers, like electronics in general, process the data in the form of zeros and ones, depending on whether electricity is emitted by the transistors or not. The extraordinary thing about quantum computers is that the atom can be found in a superimposition of the two states, in other words, in both the 0 and 1 position at the same time. A single *qubit* could store an unlimited quantity of data by playing with the quantum superimposition ratios of the 0 and 1 states. This would make it possible to put the *qubits* to work like an enormous set of parallel computers, increasing data storage and processing capacity to extraordinary levels.

Quantum computers also represent a new way of calculating. A quantum computer could decipher military information hidden behind a 1024 bit key (the current standard in this field) in a question of hours, whereas at present, it would take around eight thousand computers over 800 million years to crack the code.

The great barrier to quantum computing is the interaction between the quantum state and its setting: any alteration to this interaction transforms the quantum system. Experts around the world are now researching the viability of quantum computing.

Research into quantum computing and spintronics have led to the development of new *forms of storage* allowing more efficient usage:

Notes

- *MRAM memory (Magnetic Random Access Memory)*, now stands at quite an advanced phase of research. This new type of memory uses principles of magnetism related to spintronics (and not electric charge, as at present) to store and recover data at high speeds. It marks a major advance over current RAM memory: in the latter system, the existing contents of each memory cell needs to be rewritten at regular intervals, whereas MRAM memory keeps the information in bits inside miniscule magnetic fields. Because it needs no type of power supply, MRAM is an energy saver. Moreover, data cannot be lost when the terminal is turned off and it is faster and more resistant. All this makes the application very appealing in a range of applications, from computers to digital cameras.

- Work is also ongoing on a new type of *storage technology* that would allow up to 150 gigabytes of data to be stored in a format similar to today's DVD.

Another area now under research focuses on *biomolecular nanoelectronics* and specifically on the application of the DNA computer in the treatment of diseases or the search for selected atoms or molecules:

- The *DNA computer* can be defined as a nanocomputer which uses DNA (deoxyribonucleic acid) for storing data and making complex calculations[9]. The main advantage of using it for complex problem solving is its capacity to check all the possible solutions at once, unlike the procedure used by most existing computers, which solve problems one by one. This vast capacity for parallel calculation is heightened by the great density of data in the DNA molecule, because more than ten quintillions of these molecules could be contained in a cubic centimetre. In this way, a DNA computer could contain ten terabytes of data and have the capacity to make ten quintillion calculation processes at the same time. The main problems of using DNA in computing are the transformation of the problem to be solved into molecules; the synthesis of possible solutions and the manipulation of the possible molecules/solutions in aqueous media. The means that for the time being it has only been possible to solve relatively simple problems, in contrast to the vast potential calculation capacity of DNA.

Another field of research is *image recording* to improve the manufacture of chip circuits:

- *Lithography* is a technology used to define and print circuits in computer chips. To allow more transistors to be included on a single chip, semiconductor manufacturers have to print smaller and smaller figures. Nanolithography or extreme ultra-violet (EUV) lithography will be the alternative to the current chip-printing technology, which is expected to reach its limits sometime in the next decade. Like a painter who needs a tiny brush to paint fine lines, the semiconductor industry has to use shorter and shorter wavelengths of light to print smaller circuits on a chip.

Among *other research projects* into nanoelectronics being carried out with a fairly long-term estimated success one of the most important is neuromorphic engineering:

- *Neuromorphic engineering* is one of the areas of research being carried out in parallel with nanoelectronics, since it uses the latter to develop artificial and sensory applications at a nanometric scale.

  Biological systems perform many complex processing tasks with an efficiency that is still not within the reach of artificial systems. As a result, biology is a good benchmark for implementing systems that perform tasks that living beings develop naturally, such as sight, movement-learning, motor coordination, etc. Neuromorphic engineering projects are trying to overcome numerous challenges that are inherent to natural systems in artificial systems. For example, research is being conducted into the development of devices incorporated

9. In 1994, a computer scientist at the University of Southern California, Leonard Adelman, suggested that DNA could be used to solve complex mathematical problems.

into the neuronal space as if they were an extension of the muscles or senses, which could be used to give an unprecedented increase in human sensations and motor, cognitive and communicative performance.

Out of the Box

The development of nanotechnology could be compared to the rise of the Internet. Potentially, the nano- prefix could spark the same sort of investment frenzy as the dotcom. There are, however, some major differences:

- Whereas the Internet mainly derives from IT and electronic engineering, nanotechnology requires an understanding of and *cooperation across many different sciences*, including biology, physics, chemistry, IT and engineering.
- Unlike dotcoms, nanotech companies will have *tangible processes* and products and will not only be trading in information.
- A combination of *high equipment costs*, the many areas of knowledge required and copyright platforms will represent a hurdle to possible competitors which was not the case during the dotcom boom. In general, a high level of expertise in the business sector is required to make intelligent investments with sufficient information.

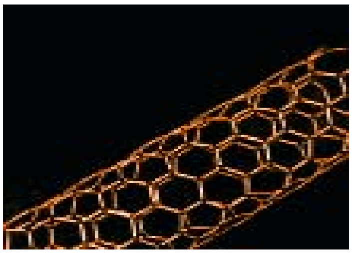
Primary governmental support to nanoelectronics

There follows a summary of the main initiatives targeted at encouraging nanoelectronics in the United States, Europe and Spain in particular.

United States

The government of the United States launched its National Nanotechnology Initiative in 2000, and it has already brought valuable results in the area of nanoelectronics. Its goals are to:

- 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 benefit.
- Develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.
- Support responsible development of nanotechnology.



Europe

A specific nanoelectronics platform has been created in Europe, called the ENIAC (European Nanoelectronics Initiative Advisory Council), whose principal mission is to:

- Provide a strategic research agenda for the nanoelectronics sector, with respect to R&D.
- Stimulate increased and more effective and coherent public and private investment in R&D in the nanoelectronics sector.
- Contribute to improving convergence between EC, national, regional and private R&D actions on nanoelectronics.
- Promote European commitment to R&D thus ensuring Europe as an attractive location for researchers.
- Interact with other policies and actors at all levels that influence the competitiveness of the sector such as education and training, competition, finance and investment, etc.

Spain

Spain recently laid the foundations for a new National Platform of Nanoelectronics and Integration of Intelligent Systems[10]. The initiative has backing from the Ministry of Industry, Tourism and Commerce, the Ministry of Science and Education, and the Centre for Industrial Technological Development (CDTI).

The primary goals and functions of the platform are to:

- Prepare a work programme that will revive the area of action and generate strategic proposals in the medium and long term with the aim of encouraging competition and research and development in industry.
- Promote Spanish participation in the preparatory activities and launch of the Seventh Framework Programme through its involvement in the European Technological Platform, the European Centres of Excellence and the projects of coordination of national policies (ERA).
- To prepare proposals on the common public-private research infrastructures needed to incorporate the platforms in European networks of excellence and technology platforms.
- To generate strategic, high-priority science and technology projects, through the interaction of the agents that form the platform.

10. The Plataforma Nacional de Nanoelectrónica e Integración de Sistemas Inteligentes has been developed and backed by the Basque Association of IT and Electronics Industries (GAIA), the National Microelectronics Centre (CNM), the Higher Council of Scientific Research (CSIC) the Technological Electrochemistry Research Centre (CIDETEC).

- To cooperate with public authorities on the actions of technological prospecting and monitoring laid out in the national plan, as part of the Committee for Monitoring and Assessment of the Area of Information Technologies and the Information Society.

3.2.3. Medicine/Biology

In 1900, average life expectancy was 33.85 years for men and 35.70 years for women[11]. Infant mortality stood at around 30‰; by 1994, this figure had shrunk to 6.2‰[12].

Improvements in diet and the development of new treatments managed to extend our stay on this earth. And doctors, researchers, scientists and scholars kept on working. A long list of experts, including the persistent Fleming, the revolutionary Pasteur and the brilliant Ramón y Cajal smoothed the path, facilitating our understanding and studying the body at an ever smaller scale.

The next milestone will come with nanotechnology. As always, a few glorious laurel-strewn names will pass into history, but more than ever before, the credit will be due to everyone working in the field.

A quiet revolution

In nanobiomedicine, the revolution has awoken silently. Despite its size, it will give plenty to talk about. Medicine and biology are two very closely related fields. *The Dictionary of The Spanish language*, published by the *Real Academia Española*, defines them as:

- *Medicine:* "Science and art of guarding against and curing the diseases of the human body".

- *Biology:* "Science that deals with living beings".

It is reasonable to presume that two such inter-related fields will continue to work together as they develop down towards the atomic scale. The European Union states that “nanotechnology in health and medical systems is part of the so called 'nanobiotechnology”[13].

Within the area of nanotechnology, the medical industry offers particular added value. The possibility of a future without serious diseases, with treatments that require neither needles nor scalpels, is a very attractive one. This is its main appeal, and the spur that will be used to encourage development.

Unlike other areas, the great obstacle facing nanomedicine may not be financing, but regulation. Laws, directives, standards and regulations can hasten or delay its take-off and, consequently its profitability.

11. Figures taken from the Instituto Nacional de Estadística: www.ine.es (24 January 2006).
12. Figures taken from http://www.emsf.es/rev9/ad9p12.htm (16 February 2006).
13. NanoRoadMap Project, Sectoral Report, Health and Medical Systems, p. 5. Author: VDI/VDE Innovation + Technik GmbH, October 2004.

Step by step

Nanomedicine involves many applications and the advances that have been achieved to date have had many very different impacts on our everyday life. Many sectors are involved, including the pharmaceutical, medical, environmental and food industries, but they are all pursuing a common target: to achieve better quality of life for all, while at the same time offering benefits for the company and society at large.

The area in which nanomedicine currently has the greatest potential is *drug delivery*. Its fast development and market introduction is due to two factors: firstly, these applications do not pose any serious legal problems; the second is its great demand. Who could say no strawberry-flavoured medicine or a syringe that doesn't hurt?

Some of the applications now beginning to be marketed are:

- *The invisible syringe:* Using a diagnosis sensor or nanocontainer for the medicine, it is possible to reach the fluids to deliver a drug or take a sample. And it doesn't hurt!

- *The intangible pill:* this is an idea which has been with us since 1956, when the introduction of the metered-dose inhaler (MDI) marked a major advance for asthmatics. Sixty years later an inhaler has been marketed which can supply everything from corticoids and steroids to glucose, for example. It is an old method, but an improved and painless one.

Very significant advances are also taking place in the field of *tissue regeneration*:

- *Muscle regeneration:* the purpose is to replace non-working tissues with other artificial ones that perform the same function. Thanks to nanotechnology the technique has been enormously improved, so that "By adding small blood vessels to artificially grown muscle tissue, the chances of successful tissue 'repair' rise"[14].

A bit more information

The various phases in the regeneration of tissue are as follows:

- *Artificial regeneration:* creation of replacement biomaterials, made up of cells and artificial material. These are "grown" in a mould before being introduced into the body.
- *Live generation:* the new tissue can be introduced into the body, provided the immune system does not reject it.

In other specialities, although still at an early stage, applications are also being developed using this technique to regenerate bone structures, cartilage and the pancreas. For example, it is hoped to use carbon nanotubes to strengthen bones in people with osteoporosis.

14. Website: http://www.bmti.utwente.nl/library/other/bmti_in_the_news_2005/engineered_tissue_is_more_viab.doc/.

Another field of research in which progress is already being made on the market is the diagnosis and improvement of techniques for curing diseases. The following are some examples:

- *Fluorescent marker for sick cells:* this is a fluorescent material which is activated when it interacts with sick cells, because it is linked to a biomarker capable of selectively recognising proteins associated with certain diseases, such as cancer. By attaching a nanomaterial to this protein, it may be possible to give a short-term "diagnosis" of its extent.

- *Chiral drugs:* the *Instituto de Ciencia de Materiales de Aragón* explains this concept as follows: "If you look in a mirror, you will see that the two halves of your body appear to be divided by a plane of symmetry, with two eyes, two arms, two legs, a well-placed nose in the middle, and so on. This symmetry gives rise to a property which you can clearly see if you look at your hands. Although the two are symmetrical -one is the mirror image of the other- they are not identical, as you will soon see if you place one on top of the other or try putting on the wrong glove. This property is known as chirality".

  Chirality reduces the effectiveness of pharmaceuticals, because, although the molecules are chemically equal, they are not biologically identical. The fact that they are asymmetric means that the effect is different. The right tends to be the positive one and the left the negative.

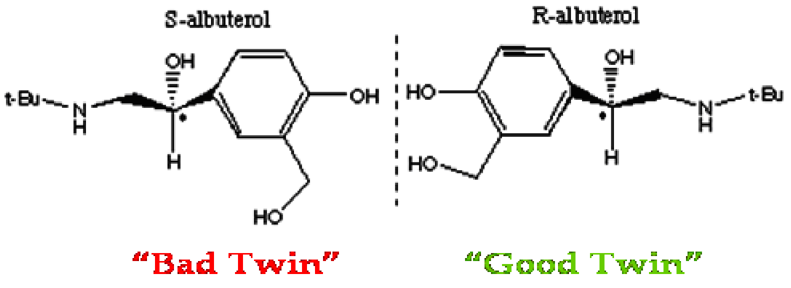


Illustration 6. Chiral drugs. *Source: presentation given at the FTF by Brent Segal.*

Nanotechnology has done away with this barrier. Polymers cause a stereo-selective reaction in the drugs, so that the human body only receives the "positive" components.

The chiral drugs industry produces billions every year, so although the term is unfamiliar to the wider public, laboratories devote a considerable amount of work to improving the processes. Among others, some of these improvements focus on reducing the inefficient processes caused by chiral ingredients, which lower the effectiveness of the drug.

The most revolutionary applications are still to come

We are currently at an initial phase in which, for the time being, nothing can be ruled out... or in. Experts speak of far-reaching medical and technological advances still to come.

The basis of these studies is the working of the human body itself. Several companies are now trying to manufacture nanocomponents that share the same properties as natural nanostructures. In this way it is hoped to develop artificial nanostructures that capture and repair the "wounds" in the human organism, in much the same way as lymphocites act as the body's defences.

There is one premise which-although it holds true for all areas of nanotechnology-is particularly apt in the case of nanomedicine: technology is never important. It is, quite simply, a way of doing things. Patients will never need a pill in itself, but the remedy for a dysfunction.

For example, the use of a nanopill to give a diagnosis instead of endoscopy (as at present) will not involve any radical change from the perspective of the doctor, who will continue to get the same result using different methods. From the patient's point of view, though, there is a vast difference; would anyone really prefer to have a tube stuck down them to swallowing a simple pill?

However, these are not the only aspects that need to be taken into account; from a legal angle, this possible technological development is very complicated. And without a suitable awareness campaign, patients may be reluctant to swallow a pill if they are not sure it is harmless.

Notes

Having made these preliminary remarks, which help situate the developments in nanomedicine into their time and place, the following is a list of some areas of research currently being conducted:

- *Intelligent medicine:* corticoids, pain-killers, antibiotics...; in the future, all drugs which currently have to be taken orally will be ingested by means of nanotransport. The goal is to cross the barrier between the blood and brain and the cell membranes to convey the drug to its destination as accurately as possible.

- *More accurate imaging:* an improvement in the quality of radiography, ultrasounds, tomography and resonance imaging will make it possible to film molecules. With more detailed information, the diagnosis will also be much more precise. From a futuristic point of view, the summit of such developments would be to provide diagnosis and therapy even *before* the actual symptoms appear. For example, using an X-ray to scale of a single molecule, it will be possible to detect which cells are sick and which are not. Combined with individualised drug delivery for each cell, this will bring about a revolution in medicine.

- *Invisible plaster:* Breaking a bone will no longer mean having to go around with a big white plaster cast on. Instead, invisible plasters will be available. Collagen nanofibres, which will strengthen the bone cells during the healing process (and will of course be biocompatible) will make the recovery process after a fracture faster and easier.

- *Longer-lasting implants:* Dental implants, cochlear implants, breast implants, hair implants, extramedullar implants, hip implants... The list is so long that if you look around you, you can be sure that a large percentage of the people you see probably have at least one implant. These people will see an improvement in their standard of living thanks to the biocompatible coatings of the implants whose adhesive properties and durability have been improved through nanotechnology. The material used in the implants will also improve: nanocomposite foams, rebuilt from the natural ingredients of the bone, are very similar in structure and chemical composition to natural bone, with a high level of bioactivity.

- *Miniature video cameras attached to spectacles for blind people:* the apparatus works by capturing visual signals which are then processed by a microcomputer on the person's belt and sent back to electrodes in the eye.

- *Glucose biosensors:* 6% of the population of the western world is diabetic. In the near future, diabetics will be able to use a glucometer in a molecular biosensor implanted in their bodies. Goodbye to lancets!

- *Medical devices that aid diagnosis and treatment:* a microfluid device is currently being investigated to study cell migration and deformation, which is of fundamental importance in cancer research. Endovascular micro-tools are also being developed to perform minimally invasive surgery.

- *Intelligent food:* using nanosensors that adhere to the pathogens in foodstuffs, it will be possible to detect whether the mayonnaise is off, the meat is bad or the fruit is over-ripe.

- *The nanonutritionist:* Are you getting enough iron? Are you not eating as much protein as you should? In ten years or so, it will be possible to remedy inadequate diets using a new nutritional system, which will more accurately deliver the active agents to the parts of the human body that need them.

- *Laboratory on a Chip:* one very long term goal is to introduce a subcutaneous chip which will continuously monitor the key parametres of the human body. It will even be possible to predict molecular changes and prevent pre-carcinogenic cells from turning into malignant tumours.

All that glitters is not gold

All of the applications above were developed from very simple nanomedical or nano-biological developments. In the future, very complex technology will be available to the public at large.

Illustration 7 summarises the present marketing status of drug delivery using nano-medicine.

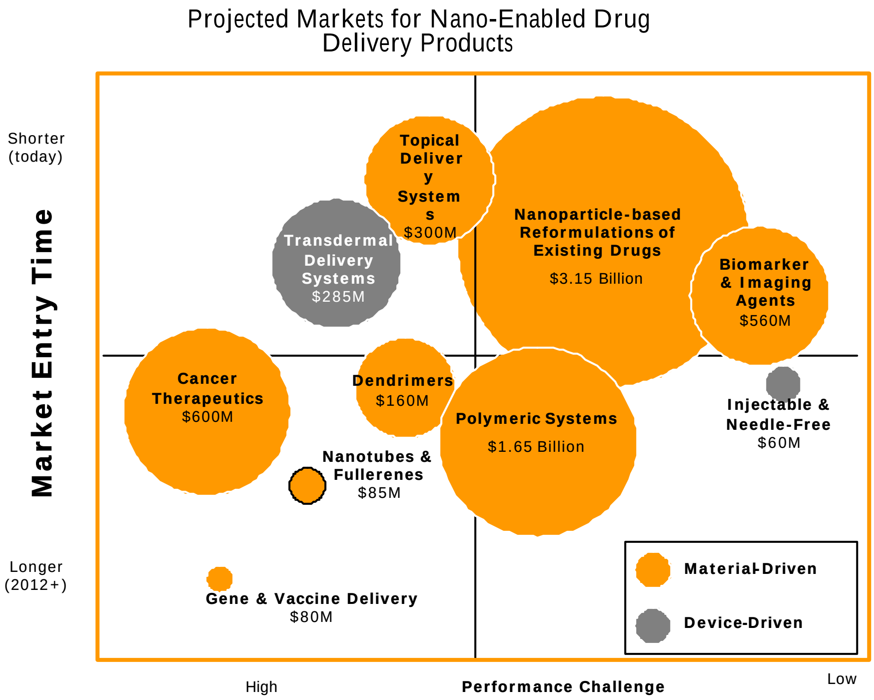
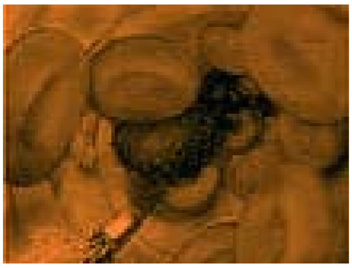


Illustration 7. Projected markets for nano-enabled drug delivery products
Source: presentation given at the FTF by Michael Moradi.

It is reasonable to expect that developments in nanobiomedicine will enjoy public and private support. However, other factors will also be decisively influential.

On the one hand, social pressure exerts a great influence and nanotechnology promises individualised treatments, even at a cellular level. If the doctor has sub-cellular information on proteins, he will know what drug will work and what won't work in a given patient.

At the same time, the use of nanobiomedicine may create complicated ethical dilemmas. For example, the possibility of controlling the food we eat and the particles we breathe is very promising, but the debate must also decide who will be given the power to allow such moves and whether we will have all the information needed to control possible side-effects.



Main governmental support to nanomedicine

Nanomedicine needs support from the public sector to continue offering developments that will lead to improvements in health. As a result, governments are now creating specific platforms to help achieve this.

United States

The US government channels its research on nanomedicine through the NIH (National Institute of Health)[15], which forms part of the National Nanotechnology Initiative and has the following goals:

- To introduce novel research strategies whose applications will form the basis for developing the nation's capacity to protect and improve health.
- To develop, maintain and retain scientists capable of ensuring the nation's research into preventing diseases.
- To expand our understanding in health sciences in order to increase the nation's economic wellbeing and ensure public investment in research.
- To promote the highest level of scientific integrity and social responsibility in the use of science.

Europe

In the face of the rapid growth, great fragmentation and lack of coordination in nanomedicine, the EU has created the European Technology Platform on Nanomedicine, which has been operating since September 2005[16]. Its main aims are:

- To establish a clear strategic vision in the area resulting in a strategic research agenda.
- To identify priority areas of research.
- To mobilise additional public and private investment.
- To decrease fragmentation in nanomedical research and boost innovation in nanobiotechnologies for medical use.

Spain

In Spain, nanomedicine is supported through the *Plataforma Tecnológica Española de Nanomedicinas* (Spanish Technological Nanomedicine Platform[17]). The platform has over 75 members, including major participation from business, technology centres and public research bodies. It is one of the most active platforms of its kind in Spain

15. Website: http://www.nih.gov.
16. Website: www.cordis.lu/nanotechnology/nanomedicine.htm.
17. Website: www.nanomedspain.net.

and is backed and funded by the Ministry of Industry, Tourism and Commerce, the Ministry of Education and Science, the Ministry for Health and Consumer Affairs, and the CDTI (Centre for Industrial Technological Development). The Spanish Nanomedicine Platform is organising the first meeting of the European Nanomedicine Platform, to be held in September 2006.

The main aims of NanomedSpain are:

- To represent Spanish interests with a single voice on the new European Nanomedicine Platform.

- To encourage dialogue on scientific, technological, organisational and industrial aspects in the area of nanomedicine amongst all interested parties from industry, research and government.

- To give recommendations on the best approach to strategic lines of action in the field of nanomedicine at a national and regional level.

- To publicise aspects related to nanomedicine.

3.2.4. Energy

We are increasingly more dependent on energy

Access to cheap, safe and renewable energy sources is of key importance for sustainable development throughout the world. Nanoenergy will try to contribute to this development by applying technologies that offer improved levels of performance, durability, efficiency, saving and safety and developing technologies that increase competitiveness in energy and make it more environmentally-friendly.

Industrialised societies now demand and use vast quantities of energy, to run machines, transport goods and people and produce light, heat and refrigeration. Our whole way of life is built on the provision of abundant low-cost energy. Energy consumption has grown continuously in parallel with changes in living habits and the structures of social organisation.

To cope with this growth, strategic actions need to be developed, and here nanoenergy will be of vital importance. Otherwise, an increase in population and greater industrialisation will lead to a scenario of high risk and conflict in the twenty-first century, and it will be impossible to maintain levels of economic growth with the energy sources currently available to us.

A future without widely-available energy would affect many essential aspects that allow society not only its economic growth, but also its progress and productivity. New energy sources are therefore essential for a safe, productive, modern and global civilization that demands renewable, sustainable, clean and abundant alternatives.

Nanotechnology will play an important role in this move towards a new type of energy, representing as it does a technical and strategic platform that allows manufacturing materials and processes to be developed that were not previously available. Nanotechnology can help exploit previously unconsidered sources of energy, to give a new paradigm of *sustainable energy*.

Nanoenergy can increase the efficiency of solar, geothermal and hydrogen power, by speeding up access to these renewable energy sources. It also enables energy to be produced at lower prices, possibly through new hybrid energy sources. Nanoenergy will also speed up the transition to a source of clean, sustainable and renewable energy that will enable us to reduce our dependence on oil-based energy.

The goal of nanoenergy, therefore, is to develop nanoscale applications for supplying energy.

The first step towards the market

Nanoenergy is already beginning to show its potential and commercial prototypes of applications and technologies are now being developed:

- *Solar cell = abundant power:* In theory, there is enough solar photovoltaic energy to supply all the world's electricity needs, and nanotechnology is now beginning to enter this field in an attempt to improve power conversion. Existing solar cells have only a limited efficiency and are very costly because they use silicon. Thanks to nanotechnology, however, solar cells are being developed made of nanostructured surfaces of quantum dots which are more efficient in capturing solar energy. Nanotechnology allows solar cells to be manufactured from cheap materials that do not harm the environment. Example include the first ultrafine solar cells made entirely from nanocrystals[18]. Cheap and easy to manufacture and a thousand times thinner than a human hair, these cells have the added advantage of being stable in air. By coating the roofs of homes and commercial buildings with these cells it may one day be possible to convert enough sunlight into power to meet practically all our electricity needs.

- *Clean, high-performance fuel cells:* In a fuel cell hydrogen and oxygen are combined in a controlled reaction, producing water and electricity. This means that they are pollution-free, since the only waste product is water. In the medium to long term, fuel cells are expected to replace most existing combustion-powered systems.

18. Developed by researchers at the Lawrence Berkeley National Laboratory (http://www.lbl.gov/).

> **Out of the Box**
>
> Fuel cells have been used on space-ships for many years to supply on-board power, but this is not their only function. They are so clean that astronauts on the space shuttle now use the pure waste water for drinking

Before this can happen, though the price of the materials used in fuel cell technology will have to be cut. High costs currently prevent fuel cells from competing with conventional power equipment. Nanotechnology needs to develop less costly materials, because otherwise it will not be possible to apply it in the use of hydrogen as an energy source for vehicles. It is also predicted that fuel cells will shortly be used in portable applications such as laptop computers, mobile phones, PDAs, etc.

- *Long-life batteries:* Although it seems likely that fuel cells will be the energy source par excellence of the future, research continues on conventional batteries. One example are the new materials used for lithium batteries[19]. This development will allow a new generation of rechargeable batteries. The new nanomaterials allow rechargeable batteries to be made which are three times more powerful than existing lithium ones for the same price and with a much shorter charging time than in a traditional battery.

- *Hydrogen for houses and cars:* The third Experimental Home Energy Station has now been launched[20]. It operates using either natural gas or propane and water, which are used to make hydrogen, which powers a fuel cell that generates heat and electricity for the home. It is designed to operate in a home environment and is also able to supply a sufficient amount of hydrogen to power a fuel cell vehicle. Overall performance increases with more energy-efficient operation, increased hydrogen storage and production capacities, and a faster start-up time of about one minute.

- *Hydrogen storage, allowing hydrogen to be used as an energy source:* experiments are ongoing with a new class of nanomaterials that act like sponges, absorbing the hydrogen and retaining it until it is used[21]. Previously, no material had been found with the necessary capacity to store hydrogen at the required pressure and temperature, and this new development may therefore hold out the possibility of using hydrogen as a clean alternative

- *Improvement in hydrogen production:* a new system has already been researched for producing hydrogen by breaking down water using sunlight[22]. The device, known as Tandem Cell, would allow hydrogen to be used as an alternative energy thanks to nanocrystalline materials which allow segregation of water.

- *The first hydrogen-driven transport:* In July 2005, the first test flights were successfully completed with an aeroplane powered by liquid hydrogen[23]. With just a tankful of hydrogen powering a line of eight propellers on the front edge

19. Development made by Altair Nanotechnologies (February 2005): http://www.altairnano.com/.
20. Presented by Honda and Plug Power (November 2005): http://world.honda.com/news/2005/c051114.html.
21. Published in Technology Review (February 2005): http://www.technologyreview.com/.
22. Announced by Hydrogen Solar (February 2005): http://www.hydrogensolar.com/.
23. Created by AeroVironment (July of 2005): http://www.aerovironment.com/.

Notes

of its wing, the unmanned Global Observer can stay up for 24 hours. Because it carries liquid hydrogen on board, it is essential that the fuel tank is isolated with nanomaterials.

- *Longer-lasting fuels for cars:* A technology has been developed that would modify car engines driven by metal nanoparticles making them last three times longer than existing petrol combustion engines[24]. Metal fuels also have great potential for unmanned vehicles and as battlefield power sources for military use.

- *"Eternal" lights:* Light-emitting diodes (LEDs) already exist which are powered by mechanical effects, meaning that they do not generate heat. This extends the life of the mechanism, and they could therefore conceptually be catalogued as "eternal". They are efficient in terms of both energy consumption (low consumption; they can be powered by batteries) and ergonomics (no wires).

A long way still to go

Nanoenergy is currently developing a wide range of applications to tackle the challenges facing the quest for new energy sources:

- Large scale methods for desegregating water using sunlight to produce hydrogen.

- Transformation of sunlight energy 20% more efficiently and ten times more economically.

- Reversible hydrogen storage materials operating at ambient temperature.

- Low-cost and reduced-consumption fuel cells, batteries and supercapacitors.

- Power lines capable of transmitting up to one gigawatt.

- Lighting with 50% of present power consumption.

- Production and consumption of clean, environmentally-friendly energy.

- Synthesis of materials and energy-gathering based on the efficient selective mechanisms found in biology.

However, we do not yet have a sufficient understanding of nanoenergy: particularly areas such as durability, reliability and other issues involved in support technologies for hydrogen storage and production (such as biotechnology).

Nonetheless, this barrier has not held back researchers and work continues apace to come up with commercial applications[25]:

24. Developed by ORNL Laboratories: http://www.ornl.gov.
25. The first three points are taken from the NanoRoadMap Project. Sectoral Report: Energy. Author: Mika Naumanen. VTT Technology studies. October 2004.

■ *Human heat transformed into electricity = Thermoelectricity:* thermoelectric devices are solid-state systems that can provide cooling/heating precise temperature control, and can convert heat into electricity using properties of thermal conductivity. Their main advantages are their minute size, the absence of mechanical parts and their simplicity.

This technology would have wide applications in IT, with quantum dots of thermoelectric materials used in computer chips, to help cool them and thus allow faster processing speeds without ventilation. Quantum dots could act as small refrigerators or energy generators.

Another of the most interesting applications of thermoelectricity is the possibility of converting the heat of the human body into electricity, making it possible, for example, to install a GPS (powered by human heat) in children's jackets so that they can be located at all times.

■ *Energy insulation:* Insulating materials are used to keep the temperature constant in enclosed spaces. A vast amount of energy is currently being wasted through poor insulation in homes and industries. Developments in insulation will allow a reduction in energy demand and costs. Nanotechnology's contribution to this goal comes in the form of aerogels, which are thermal, acoustic and electrical insulators. The pores and particles in aerogels are smaller than the wavelength of light.

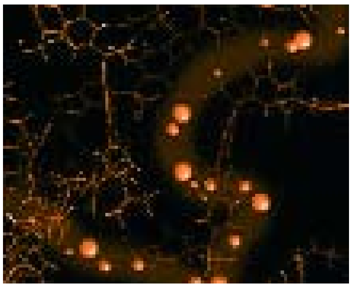
■ *Cheaper and more efficient supercapacitors:* supercapacitors are devices that take one a certain electrical charge. Unlike conventional condensers and batteries, they are more reliable, faster and more efficient at low temperatures.

The use of multiplex wall nanotubes in condensers allows a reduction in size, greater speed and greater energy capacity. Low-voltage supercapacitors may be of great use in devices such as CD-players, cameras, computers, watches, alarms, etc.

■ *New more efficient electric conductors:* various groups of researchers are trying to find a way of transmitting electricity over power cables, superconductors or quantum conductors developed using new nanomaterials. The aim is to replace high voltage lines and allow long distance or continental power transmission grids, reducing or eliminating voltage falls resulting from thermal faults or current losses, and replacing copper and aluminium cables.

■ *Extraction of geothermal heat as alternative energy:* teams of scientists are working on the development of nanomaterials and coatings that will allow deep wells to be drilled at a low cost to tap geothermal heat energy in deep strata.

■ *Artificial photosynthesis for producing hydrogen:* Thanks to nanotechno-



logy, British scientists have identified the exact location in plants where photosynthetic reactions take place. This scientific discovery may also allow the manufacture of small artificial photosynthesis plants, capable of obtaining hydrogen from water and absorbing CO_2 from the atmosphere. If this can be done, the hydrogen thus obtained could be used to power fuel cells. Another possibility this discovery holds out is of absorbing carbon dioxide in a new procedure.

- *Nanofilters that separate water from oil:* There are a number of possible applications for nanofilters, such as separating water from oil. Chemical industries spend $200 billion every year on this process, which accounts for between 80% and 90% of all refining costs. The development of high quality nanofilters would bring a major reduction in costs.

- *Nanorobots in search of oil:* Research is currently being conducted into the application of minute nanorobots to be used to explore oil deposits. The idea is that the nanorobots will be capable of patrolling oil reserves, checking on the way the hydrocarbons flow and making it possible to decide on the best way of maximising extraction.

Main government support to nanoenergy

The governments of the world's leading regions are laying the foundations of support on which the future development of nanoenergy can be built. We will now briefly look at the way in which new energy sources based on nanoenergy are being encouraged in the United States, Europe and Spain.

United States

The United States supports research into nanoenergy through its National Nanotechnology Initiative. One of the platform's priorities is nanoenergy, where its goals are as follows:

- To develop an R&D programme that will enhance understanding of nanoenergy at all levels.

- To help find applications for all research being carried out in the field of nanoenergy.

- To give adequate support to human resources so that they can continue to take new steps in the area of nanoenergy.

- To monitor nanoenergy's impact on the environment.

Europe

In Europe there are two platforms indirectly associated with nanoenergy, in that they involve research which builds on the advances in this field:

- Technology Platform for Zero Emission Fossil Fuel Power Plants: in line with the priorities set out in the Seventh Framework Programme "Power generation with near-zero emissions", the platform strives to identify and remove obstacles to the creation of efficient power plants, with near-zero emissions. This will dramatically reduce the environmental impact of the use of fossil fuels, especially coal.

- European Hydrogen and Fuel Cell Technology Platform: the platform and its activities are contributing to an integrated strategy to speed up the creation of a sustainable hydrogen economy in Europe. Its main aims are to:

    - Facilitate and accelerate the development and deployment of cost-competitive, world class European hydrogen and fuel cell based energy systems and component technologies for applications in transport, stationary and portable power.

    - Facilitate effective coordination of European, national, regional and local research and development programmes and initiatives.

    - Ensure balanced and active participation of the leading players, and help enhance awareness of the opportunities of the energy market and scenarios for fuel cells and hydrogen.

Spain

In Spain, nanoenergy receives support from the *Plataforma Tecnológica Española del Hidrógeno y Células de Combustible* [Spanish Hydrogen and Fuel Cells Technology Platform], whose purpose is to:

- Prepare a national technological strategy for the European Platform.

- Prepare a short, medium and long term plan for research, development and innovation.

- Promote strategic R&D projects.

3.3. Government Support

Nanotechnology has been called the latest great revolution. Indeed, most countries see it as an opportunity for development they cannot afford to ignore.

How, then, does each country go about promoting nanotechnology? The options range from offering subsidies and grants, building research centres or providing tools to existing ones, to offering indirect support, by giving subsidies or tax incentives to business.

Right from the outset, governments around the world have shown an interest in ensuring that the impact of the nanotech revolution brings positive results for everyone (this movement, which also extends to the private sphere, is known as *green-nano*). In the area of nanoparticles, for example, where the first nanotech applications will be seen, scientists have identified a risk of emissions that might harm the environment or human health. As a result, all processes, research and applications launched in this area will be regulated, and possible harmful elements will be duly inspected and supervised.

A large number of countries are now jumping on the nanotechnology bandwagon, with governments as the first players. The advisory firm Lux Research[26] has created a world ranking of "nanotech penetration" based on two criteria:

- *Nanotech activity* in the country itself: public investment, government or university research centres, spending on nanotech R&D by business, etc.

- The current strength of *technological development* in the country itself: human resources working on nanoscience and nanotechnology, R&D spending as a percentage of GDP and production of latest-generation technology, also as a percentage of GDP.

After the data was weighed up and analysed, the countries were classified into four groups.

1. Today's *dominant* nanotechnology leaders: the U.S., Japan, South Korea and Germany.

2. The *niche players*, defined as "technology powerhouses with relatively small populations that need to convert that activity into jobs and GDP": Taiwan, Israel and Singapore.

3. Two countries come out as "Ivory Tower" nations, high on nanotechnology activity but low on technology development strength in relative terms: The U.K. and France.

4. The minor league: countries with a high *potential* for development in the medium term: China, Canada, Australia, Russia and India.

If we compare Lux Research's list with figures for the amount of public spending the different countries devote to nanotechnology we can see a clear relationship, although the number of countries analysed is different in each case.

26 Website: http://www.luxresearchinc.com/.

Govermment annual Spending on Nanotechnologies 1997-2005

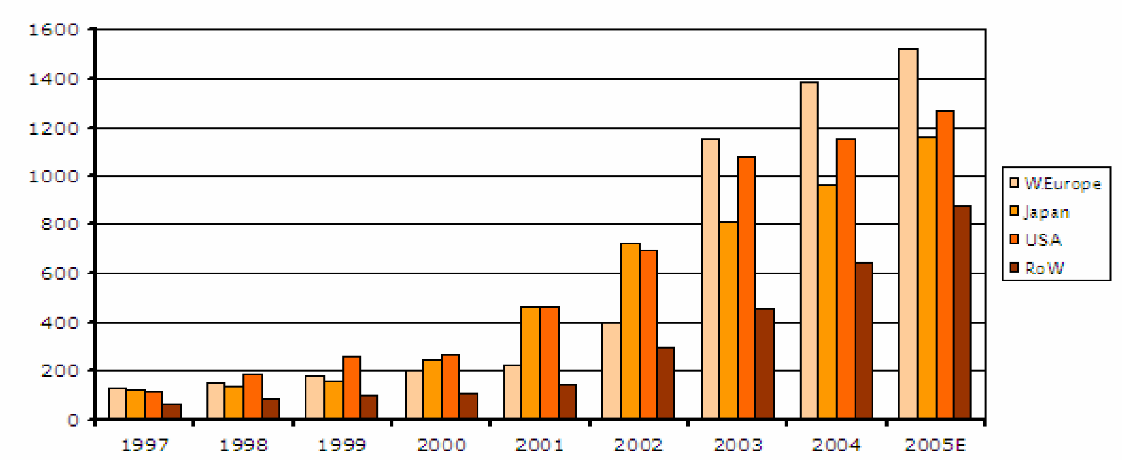


Illustration 8. Government annual spending on nanotechnologies (1997-2005) *Source: Cientifica.*

The first most striking aspect is the practically exponential rise in the growth curve, especially over the last three years. In Western Europe, for example, public spending in 2003 was three times higher than in 2002.

The predominance of Western Europe can be explained by the fact that it includes several countries ranked in some of the categories of Lux Research's classification.

This chapter looks at the most important government development-support initiatives in the leading nanotech countries. It will centre mainly on support in the European area and, in particular, on promotion in Spain.

3.3.1. Government Support on a Global Scale

Notes

The following countries are included in this section because they are leaders, because of their great potential or because they show a series of strengths and best practices that could serve as a role model for Spain.

United States

As in so many other technological sectors, the United States has initiated, channelled and spearheaded successive developments in nanotechnology.

In terms of government support, it is also a model for other countries, which are now trying to reproduce its initiatives and follow in its footsteps. One example is the domain name used in official URLs: in the United States the tag is nano.org. As a result official nanotechnology-related websites from other countries are forced to add their own eponym to the domain name: nanoisrael.org, nanospain.org.

To look at government support in the U.S. we are going to focus on three initiatives responsible for promoting the development of nanotechnology.

National Nanotechnology Initiative (NNI)[27]

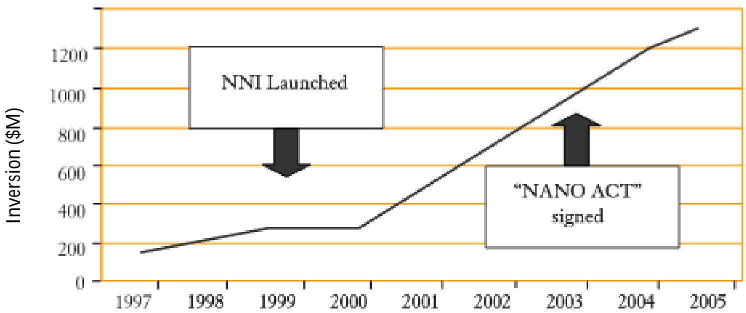
The first draft of a plan for an initiative in nanoscale science and technology was completed in 1999. Subsequently, in its 2001 budget submission to Congress, the Clinton administration raised nanoscale science and technology to the level of a federal initiative, officially referring to it as the National Nanotechnology Initiative (NNI).

The NNI is now the organisation that coordinates work in the field of nanotechnology throughout the country. The aims it pursues, as set out in its strategy plan in December 2004, are to:

- Realise the potential of nanotechnology through internationally significant research and development programmes.
- Facilitate the move from the research in the laboratory to the marketing of products, which will in turn lead to economic growth, job creation and other public benefits.
- Develop the educational resources, workforce, infrastructures and tools needed to develop nanotechnology.
- Responsibly use technology in medicine, manufacturing, materials, information technology, energy, etc.

This is all made possible by the generous funding the plan receives from government. The presidential budget for 2007 allocates $1.2 billion dollars to the National Nanotechnology Initiative. Since it was set up, it has received total government financing of over 6.5 billion dollars.

The launch of this initiative in 2001 led to a substantial increase in investment in nanotechnology in the U.S., as Illustration 9 shows.



27. Website: http://www.nano.gov.

Illustration 9. U.S. Nanotech R&D spending
Source: presentation by Dr. Brend M. Segal at the FTF.

Approximately 65% of NNI funds go to research in the academic arena, although a considerable proportion also goes to supporting joint initiatives between researchers and private companies intended to add leverage to public investment. To date, the NNI has financed over one hundred nanoscience and technology centres, as well as networks of excellence for individuals and institutions.

Nano Act 2003

This act gives official backing to development in nanotechnology; in other words, it is a further step in formalising government support to this new industry. The act's stated purpose is "to authorize appropriations for nanoscience, nanoengineering, and nanotechnology research, and for other purposes"[28].

Its aims are to:

- Establish the goals, priorities, and metrics for evaluation for Federal nanotechnology research, development, and other activities.

- Invest in Federal research and development programs in nanotechnology and related sciences to achieve those goals.

- Provide for interagency coordination of Federal nanotechnology research, development, and other activities undertaken pursuant to the Program.

As a first measure, to authorise the relevant items, the act creates the (*National Nanotechnology Programme*), whose mission is coordinated with the NNI.

Investment focuses on providing grants to individuals and teams to carry out research projects, establishing a network of facilities and centres, increasing productivity and industry competitiveness through investment, and support for the private sector, including start-up companies.

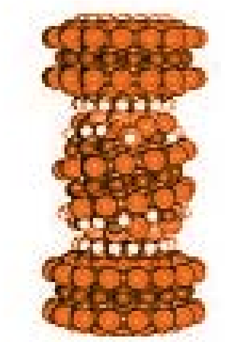
Responsibility for implementing the national nanotechnology programme lies with the National Nanotechnology Coordination Office with a Director and full-time staff. The guidelines and investigation to be pursued are established by the Advisory Panel.

Japan

Japan is orienting its nanotech development towards the existing market. With a very commercial focus, Japanese public-sponsored initiatives are aimed at improving the materials used to manufacture conventional devices and apparatuses, such as reinforcement for car bumpers using nanotubes, and nanohorns (a horn-shaped variant of the nanotube) for powering laptops.

In 2002, the Japanese Ministry for Education, Culture, Sports, Science and Technology launched a common website[29] for nanotechnology researchers intended

28. http://www.smalltimes.com/smallstage/images/nanobills189.pdf.
29. See http://www.nanonet.go.jp/english/



to disseminate developments by research centres and offer a platform of communication for business, academic and public areas that are in contact with nanotechnology.

Japan's economic input in this area can be seen in Illustration 10, with per capita public spending on research and development in nanotechnology higher than any of the other countries featured.

Government Spend per capita ($ / citizen)

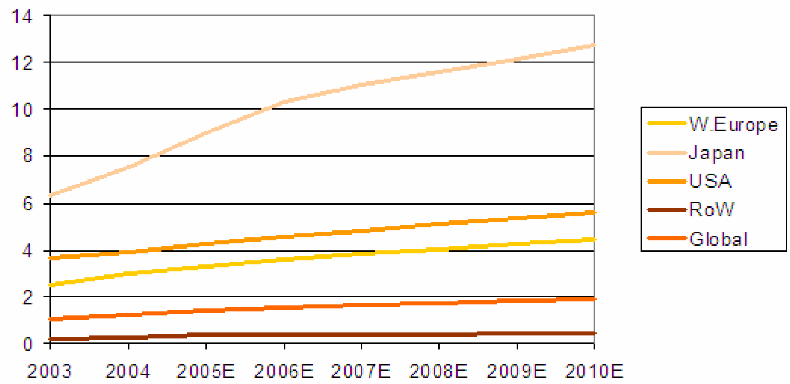


Illustration 10. Government spend per capita.
Source: Científica.

Between 2001 and 2003, the two years prior to the graph, financing for nanotechnology by the Japanese government rose from 400 to 800 million dollars.

The main institution created for these purposes is the Nanotechnology Research Institute[30]. This nanotechnology research centre channels all its nanotech activities in the Advanced Industrial Institute of Science and Technology[31].

The long-term aim of the NRI is to launch technological applications using the expertise acquired in nanoscale physics, chemistry and biology.

Bilateral Agreements

The United States and Japan have signed a collaboration agreement on nanotechnology and materials. Symposia and inter-nation exchanges for young researchers are organised through the National Science Foundation and the Ministry for Education, Culture, Sports, Science and Technology.

The AsiaNANO project focuses collaboration among countries in South East Asia. Its aim is to favour interdisciplinary research in the fields of chemistry, physics, biology, materials science, semiconductors, optics and photonics.

Finally, the Japanese government has signed specific agreements with countries in

30. See http://unit.aist.go.jp/nanotech/.
31. See http://www.aist.go.jp/index_en.html.

Europe, including the UK, Sweden and Italy, though none with the European Union as an institution.

Israel

The Israeli government's aims are set out in a more ambitious plan than the Japanese one: it centres on marketing innovative and successful products in the short term and competitive ones in the long term.

With this target in mind, the framework of the Israel National Nanotech Initiative[32], is intended to facilitate communication between companies interested in investing in research projects, with an efficient team of experts in logistics and industry from a university background.

With such clear targets, it comes as no surprise to see such positive results:

- Of the six universities in Israel, the Technion Institute and the Bar-Ilan university are leaders in training and research. Since 2002, the number of scientists working in nanotechnology has almost doubled. As well as the usual fields (nanomaterials, nanobiotechnologies and nanoelectronics), their central R&D themes also include nano-water.

- The industrial fabric in Israel centres on offering products with a technological added value. Twelve established companies have a joint turnover of around $76 million. There are also another thirty start-up companies with great potential.

This boost to business, academic institutions, risk capital investors and government agencies who look after the country's nanotech interests form the links in the value chain.

Bilateral Agreements

The United States-Israel Science and Technology Foundation is a non-government organization charged with managing and carrying-out strategic programs developed by the United States-Israel Science and Technology Commission for the benefit of the two countries. Since 1995 it has sponsored projects in various areas, including nanotechnology. Although it now focuses on research centres, in the past it has subsidised risk-capital companies. Israel enjoys very close exchange of ideas and mutual support with the United States.

It has also signed a collaboration agreement with the European Union. As well as specific collaboration agreements, such as that established between the European consortium Charpan and the Israeli technology institute Technion[33], Israel is the only country outside the European Union to form part of its Sixth Framework Programme[34]. In the first two years of this programme, Israel has worked on projects to a value of €1.5 billion.

32. See www.nanoisrael.org.
33. See http://www.menewsline.com/stories/2005/november/11_11_4.html.
34. See http://www.iserd.org.il/.

Other leading countries

China

China is now taking its first steps in nanotechnology, as it is in many other fields.

The trend for the next 5-10 years will not be very different to that in the rest of the world: China's nanotech market is now worth $5.4 billion. In five years, this will rise to $31.4 bn and by 2015 to $144.9 bn.

With a view to promoting communication between research centres, business and government, in February 2006 a platform[35] was launched to disseminate and provide information about nanotechnology. It also offers employers, foreign investors, the public sector and other agents a platform to communicate.

According to the consulting firm Helmut Kaiser, 800 Chinese companies are now trying their luck on the nanomarket.

Taiwan

The rebel island is ahead of mainland China in the technology race. The Center for Applied Nanotechnology Institutes, which opened in 2002 with initial investment of $290m from Taiwan's Industrial Technology Research Institute, is devoted to research into industrial technology.

The island will also spend $700 million of public finances on a five-year nanotechnology fund[36]. 62% of this capital will go to industrialisation and the remaining 38% to R&D (including infrastructure and human resources).

The Industrial Technology Research Institute (ITRI) has allied with Berkeley University to promote nanotechnology and identify markets for its products. This alliance has been created for a period of five years and is renewable.

South Korea

In keeping with its growing commitment to technological development, in 2006, South Korea opened the country's first nanotech R&D centre. The national 10-year programme will devote two billion dollars to nanotechnology.

Once again, the aim is to industrialise and market nanomaterials. It is hoped to unite businesses, laboratories and other schools working in nanotechnology around the nanotech centre of the Pohang University of Science and Technology.

It is an ambitious project: by 2015 it is planned to commercially launch over thirty applicable technologies and create more than five hundred nanostart-ups.

35. See http://www.nanochina.cn/english/.
36. See http://investintaiwan.nat.gov.tw/en/opp/nanotech.html.

3.3.2. Support from the European Union

The EU sees nanotechnology as an opportunity to position itself at the forefront of the technological world.

Around a third of European public spending on nanoscience and nanotechnology comes from the Sixth Framework Programme. The remaining two thirds comes from national and regional programmes. This investment, totalling over €1 billion, is intended to create applications that will improve existing products. In the medium to long term, the goal is to achieve major improvements centring on the construction of entirely new applications, which will mark the beginning of a new technological cycle.

There is good reason for centring on industry and applications: whereas 24% of scientific articles on nanotechnology between 1997 and 1999 were published in the US, 32% came from EU member states. In contrast, over the same period 42% of applications in this area were patented in the US as compared to 36% in the EU.

The Sixth Framework Programme

Framework programmes are established every three or four years to delimit the scientific fields in which EU investment is going to centre. In addition, calls for projects are made every year for grants and other forms of financing awarded by the programme.

The aim of the EU's Sixth Framework Programme[37], running from 2002 to 2006, has been to create a financial instrument that will allow for the creation of a proper European Research Area. The third thematic priority of the Framework Programme, after "life sciences, genomics and biotechnology for health" and "technologies for the information society", is precisely the area this publication centres on: "Nanotechnologies and nanoscience, knowledge-based multifunctional materials and new production processes and devices".

The specific goal of this initiative is "to help Europe to build the necessary capacities for the development and use of nanotechnologies and nanoscience in order to create new materials, devices and systems for manipulating matter at an atomic scale".

Like the US and Israel, the EU is aware of the importance of business, universities and research organisations all pulling together, and it lends particular support to projects presented by various institutions working in collaboration with the EU.

Five dynamics to stimulate progress

In 2004, the European Commission brought out a specific communication on the development of nanotechnology, entitled "Towards a European Strategy for Nanotechnology"[38]. The five essential synergic pillars on which initiatives need to be adopted are:

37. See http://europa.eu.int/scadplus/leg/es/lvb/i23012.htm.
38. Communication from the European Commission Towards a European Strategy for Nanotechnology, May 2004, Brussels.

■ *Research and Development:* the EU is aware that excellence in R&D is essential to ensure that Europe can remain competitive in the long term. It therefore encourages increased investment by member states in these areas. It also promotes competition and coordination among national and regional policies and programmes.

■ *Infrastructures:* without a first-class infrastructure ("poles of excellence") European countries will find it difficult to lead the way in the nanoscale. The Commission therefore highlights three key requirements:

- To map existing infrastructure to identify the most urgent needs to maximise performance;
- To build, if needed, new dedicated nanotechnology infrastructure;
- To explore the possibility of financial synergy with the European Investment Bank, European Investment Fund and Structural Funds.

■ *Investing in human resources:* to realise the potential of nanotechnology, the EU needs a population of interdisciplinary experts who can generate knowledge and transfer it to industry.

Nanotechnology presents a golden opportunity to attract a greater number of young scientists and other skilled personnel to careers in research. New forms of training are needed, moving beyond the traditional disciplinary boundaries at university and postgraduate level.

For example, the EU has given its backing to the creation of a masters course[39] in nanoscience and technology. A number of European universities are collaborating on this course, which is an initiative of the Erasmus Mundus programme and reflects the multidisciplinary nature of the nanoworld.

■ *Industrial innovation:* The aim is to develop better coordination between the various marketing phases involved in nano-applications. The governments of the member states are invited to conduct actions of support, establishing conditions that will promote investment by business in R&D and increasing cooperation between patents offices.

■ *Societal dimension:* To culminate the process of nanotechnology, this new technology must be taken out of the laboratory and industry, and reach out to the general public. The European Commission is aware that, although nanotechnology can potentially improve living conditions, there are also associated risks. Ethical principles must be respected and, where appropriate, enforced through regulation.

39. See http://www.emm-nano.org/indexnano.htm.

In this respect, the complex and invisible nature of nanotechnology presents a challenge for communicators. The public trust and acceptance of nanotechnology will be crucial for its long-term development and allow us to profit from its potential benefits.

Out of the Box

The "NanoTruck": In January 2004 an unusual project was launched, consisting of a bus which travelled around Europe providing information on the current status of research into nanotechnology and its development. Its aim is to encourage dialogue between the scientific community and the general public.

These five dynamics proposed by the European Commission to stimulate progress required the launching of specific activities in all fields in order to generate synergy. However, given the current situation of the nanotechnology market and its need for development, the FTF experts feel that each of these five dynamics should be prioritised as shown in Illustration 11.

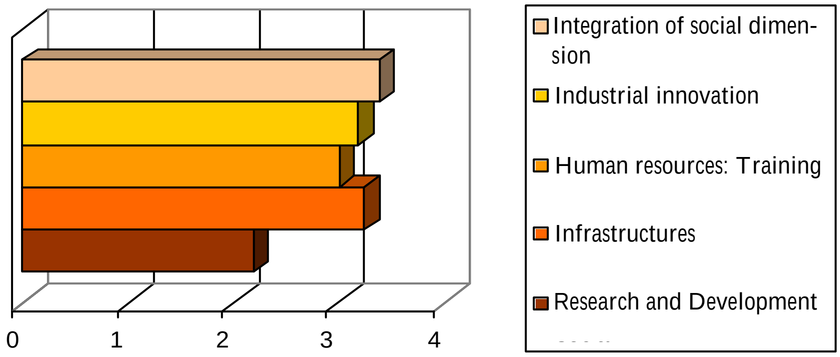
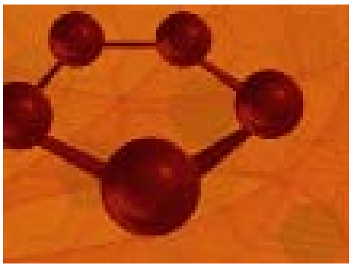


Illustration 11. FTF experts' assessment of the priority of European initiatives

Source: own preparation.



Other initiatives

Among the many initiatives related to nanotechnology financed by the European Union[40], the following are particularly important:

- *Specific support action (SSA):* WomenInNano, aimed at encouraging young women to study and pursue careers in nanotechnologies and nanosciences.

- *Nanologue:* to facilitate a dialogue on the benefits and potential impacts of nanotechnology.

- *Nanodialogue:* intended to facilitate contact and encourage joint activities among nano experts. With a view to achieving the same goal, a survey has been launched entitled *Towards a European Strategy for Nanotechnology* to gather the opinions and ideas of specialists in order to help design this strategy.

- *Nanoregulation:* platform promoted by the industry, EU governments, the academic world and NGOs, intended to create a forum of debate on issues related to legislation for nanotechnology.

- *Nanoroad SME (the nanomap for SMEs):* the innovating potential of SMEs was recognised in the Lisbon agenda, and now the EU is seeking to provide support to SMEs that have good ideas but few resources through a range of projects. Between 2002 and 2006, €1.7bn-worth of projects have been subsidised under the Sixth Framework Programme. These include a number of applications in the field of nanotechnology.

Bilateral agreements

The European Union works with several countries on many different areas. It has cooperation agreements with EU candidate countries (Bulgaria, Rumania and Turkey) and with members of the EFTA (Iceland, Liechtenstein, Switzerland and Norway). At the same time, within the framework of the Sixth Framework Programme, the European Union has signed collaboration agreements with various third countries[41]. The countries involved in these science and technology cooperation agreements are:

- *The Americas:* Canada, United States, Brazil, Chile and Argentina.

- *Africa:* Egypt, South Africa, Morocco and Tunisia.

- *Europe:* Ukraine and Russia.

- *Asia:* China, India and Japan.

- *Oceania:* Australia

40. See http://www.nanoforum.org.
41. See http://europa.eu.int/comm/research/iscp/index_en.cfm.

European Nanobusiness Association[42]

The European Nanobusiness Association is another EU initiative. It consists of a non profit organization whose purpose is to help position the European Union in the nanotechnology market. Its main aims are to:

- Identify and address continent-wide issues holding back the adoption of nanotechnologies;
- Identify and promote nanotechnologies which have an impact on European competitiveness;
- Facilitate the transferral from laboratory to business. Research is one of Europe's strong points and the expertise gained at this phase must be transferred to industry.

The European Nanobusiness Association has two essential tasks: to provide a forum for companies, from start-ups to multi-nationals and to hold regular meetings with the European Commission and Parliament.

The Seventh Framework Programme

In 2007, the European Union will launch its Seventh Framework Programme, which is intended to serve as the main instrument for R&D in EU member states. For the first time, FP7 will cover a period of seven years instead of just five. Based on the notion of the "triangle of knowledge", its purpose is to transmit the three pillars of the programme: research, training and innovation.

Community financing for this programme will be generous, with a budget of €72,726,000,000 for the period from 2007 to 2013; of which, 4,832 million will go directly to nanoscience and nanotechnology. The general budget for the next Framework Programme does not include a further €3.092 bn earmarked for the area of nuclear energy between 2007 and 2011.

The final purpose, already announced in the Sixth Framework Programme, is to build a European Research Area. In keeping with the principle of transparency that characterises all EU institutions, the CORDIS (Community Research and Development Information Service) gateway has a section[43] listing all the developments made in the European Research Area.

To achieve this ambitious target, the Seventh Framework Programme is broken down into four more specific sub-programmes:

- *Cooperation:* intended to promote collaboration between universities, industry, research centres and public authorities to lead the scientific-technological industry.

42. See http://www.nanoeurope.org.
43. See http://www.cordis.lu/era/home.html.

- *Ideas:* It is planned to create an independent European Research Council, to stimulate creativity and excellence.

- *People:* intended to promote training, mobility and the professional career of European researchers, through "Marie Curie" actions.

- *Capacities:* targeted at financing activities for improving the capacity for research and innovation throughout Europe, from regional research through work by SMEs to international co-operation[44]

3.3.3. Government Support in Spain

The position of nanotechnology in Spain is contradictory. Despite the low level of national investment in research, development and innovation[45], over 450 Spanish research groups have been involved in some nanotech activity or other, and many of them are excellently placed on the international scene.

In general, initiatives to encourage nanotechnology are few and far between and arise at the initiative of the scientists themselves or are forced upon the Spanish authorities by the European Union. An effort is needed from the government in Spain to facilitate the acquisition of the costly equipment required to develop this field and the creation of joint centres for promoting the work of different research groups.

Existing initiatives to encourage nanotechnology

All nanotech initiatives in Spain are very recent. Indeed, in the government area, neither the previous National R&D+I Plan (2000-2003) nor the regional plans contain programmes drawing together the work of the highly qualified people operating in this new area of science.

National Plan of Scientific Research, Development and Innovation (2004-2007)

The aims of the National Plan of Research, Development and Innovation (2004-2007)[46] are to unite constructively the work of all qualified personnel and to act as a reference point for the industry which requires knowledge on this subject. For the first time the plan covers the areas of nanoscience and nanotechnology. There are many research groups, especially young teams, with excellent capacities and training directly related to nanoscience.

The text of the plan stresses that "the present level of development of nanoscience makes support essential, fundamentally to basic research in the subject; this must be prioritised in the National R&D&I Plan through the various national programmes covering these areas: physics, matter, design and industrial production, electronic and communications technology"[47]

44. See http://cordis.europa.eu.int/press-service/es/20050330.htm.
45. With investment in research, development and innovation (R&D+I) totalling just 1.07% of GDP, Spain has one of the lowest rates of investment in this area of any member state in the old 15-state European Union, according to data published by the Instituto de Estudios Económicos (IEE).
46. See http://www.mec.es/ciencia/jsp/plantilla.jsp?area=plan_idi&id=2.
47. Op cit.

All programmes must be oriented towards achieving general coordination, to generate a *material, human and social infrastructure* capable of promoting the greater advancement of nanotechnology. To achieve this, the plan has two primary aims:

- *Instrumental infrastructures:* People working in nanoscience R&D need specialised techniques and equipment. The current plan considers that a Virtual Centre of Nanoscience Applied Technologies needs to be created, in which different work groups coordinate to acquire and upgrade the technologies they consider to be of greatest interest and make them available to the wider scientific and technical community.

- *Scientific-technical demonstrators:* The great scientific potential contrasts with a relative lack of industrial interest, and actions therefore need to be encouraged that will involve all the players in the system in achieving results of interest to industry. These must be promoted by multidisciplinary organisms, with well-defined and achievable aims, although it should not be an essential condition that the final results be marketable. The basic purpose is to create a network of relations between R&D+I industries, as well as highlighting the innovation-generating capacity of this new area of knowledge.

Others initiatives

Various initiatives have contributed to promoting nanotechnology in Spain in recent years. Among the most significant are:

- The former *Nanoscience Network* which operated for four years, was a pioneer in Spain, concentrating on training and common upgrading of methodologies. It had a membership of nearly two hundred researchers. It was partly-financed by the Ministry of Science and Technology, and had a basic science approach.

- The *NanoSpain Network*[48] seeks to unite the work of business and public research bodies in order to construct a nanotech programme. It was created during the winter of 2000-2001 and has a membership figure of 181 research groups. Its aims are to identify priorities and define the strategies that need to be developed, as well as studying, characterising, manufacturing and testing new nanodevices for semiconductors and IT industries.

- The *Phantoms foundation*[49] promotes the NanoSpain initiative, partly-financed by the Ministry of Science and Technology. This non profit organisation was created in November 2002 to provide a high quality management service for European and national projects in the nanotech field.

- The Strategic Action in Nanoscience and Nanotechnology, called by the Ministry of Education and Science, and awarded in October 2005 proved a great success in terms of participation (with nearly 200 projects covering 600 sub-projects). Altogether thirty projects received funding of around €12 million.

48. Website: http://www.nanospain.org/nanospain.htm. tech field.
49. Website: http://www.phantomsnet.net/.

■ *Trends in Nanotechnology* (TNT) is the world's most important nanotechnology forum and has witnessed the rapid development of the area. A series of lectures was held in Spain from 2000 to 2005. In 2006 it will move to Grenoble (France) to mark the opening of MINATEC (France's large nanotech centre).

■ Another important event is the *Pilot Action in Nanotechnology* [*Acción Piloto en Nanotecnologías]* organised by the Spanish Foundation of Science and Technology (Fundación Española de Ciencia y Tecnología, FECyT). It has included important scientific meetings, including a Nanotech Think-Tank[50] (held in 2004 in El Escorial, Madrid and in 2005 in Barcelona)[51].

■ The CSIC coordinates *IP Nanoker*, a European project for the development of new materials. It has a special application in bio-medicine, optics and aeronautics. It is planned to develop new ceramic materials for implants, cardiac valves and teeth, among other applications. The CSIC participated as the coordinator of IP Nanoker[52], through two of its research centres: the Instituto Nacional del Carbón (National Coal Institute), in Oviedo, and the Instituto de Ciencia de Materiales (Materials Science Institute) in Madrid.

■ The creation of a national platform of nanoelectronics and intelligent systems integration (*Plataforma Nacional de Nanoelectrónica e Integración de Sistemas Inteligentes*) has recently been announced. It has been developed and backed by the Basque Association of IT and Electronics Industries (GAIA)[53], the National Microelectronics Centre (CNM)[54], the Higher Council of Scientific Research (CSIC) and the Technological Electrochemistry Research Centre (CIDETEC)[55]. The initiative is also backed by the Ministry of Industry, Tourism and Commerce, the Ministry of Science and Education, and the Centre for Industrial Technological Development (CDTI)[56].

Resources by region

Madrid and Barcelona, the two cities with the largest presence of public institutions (including the headquarters of the Higher Council of Scientific Research), are also, generally speaking, the ones with the largest number of nanotech companies with an interest in nanotechnology. This is proof of the good communication between the public and private sectors, which is not generally the case in other areas of research. One of the key factors in this communication lies in the fact that many of the companies engaged in nanotech activities have developed as spin-offs[57] from research centres and universities to provide a market outlet for new developments in the industry.

It should be noted that research projects are distributed unevenly across Spain although activities related to nanotechnology are found in nearly all autonomous communities (regions). Some regions have seen a process of specialisation. For example, in Catalonia –and particularly in Barcelona– there is a large number of institutions that are especially interested in the nanotech applications of biotechnology, medicine and pharmacology. In Madrid, on the other hand, work tends to concentrate more on the field of materials physics and applied magnetism. In the north of Spain,

50. Several multidisciplinary theoreticians and intellectuals are involved in the think-tank and issue analyses and recommendations.
51. EOI Escuela de Negocios. Convergencia NBIC 2005: El desafío de la Convergencia de las Nuevas Tecnologías, [s.l.], Colección EOI 2006, 126 pp.
52. Website: http://www.nanoker-society.org/publicarea/p.asp.
53. Website: http://www.gaia.es/.
54. Website: http://www.cnm.es/.
55. Website: http://www.cidetec.es/.
56. Website: http://www.cdti.es/webCDTI/esp/index.html. More information on its aims can be found in the chapter on electronics.
57. Companies created to capitalise on academic research and translate it into business value. They are generally born out of universities or public institutions and are the product of a clear intention to disseminate and exploit knowledge linked to their environment.

the Basque Country and Navarre are home to numerous institutions more closely involved in production engineering.

The list below shows projects and initiatives promoted by the CSIC and/or the various universities. It is not intended to be a complete list, but to illustrate the trends in certain regions:

- In *Madrid*: The Madrid Science Park (Parque Científico de Madrid) offers support to a large number of projects and initiatives. The capital is also home to the Institute of Optoelectronic Systems and Microtechnology (ISOM), in the Polytechnic University of Madrid, and the Small Systems and Nanotech Physics Laboratory of the Higher Council of Scientific Research (CSIC), among others.

Out of the Box

Madrid's particular interest in nanotechnology may have something to do with the fact that the Autonomous University of Madrid was the second place in the world to get a scanning tunnelling microscope (STM), around twenty years ago.

- In *Catalonia*: Important developments include the creation of the Institutes of Nanotechnology and Nanobiotechnology as well as the Institute of Molecular Biology of Barcelona and the regional Nanobiocat network.

- In the *Basque Country*: There is a Basque Nanotech Programme to encourage scientific activity in universities and research centres wishing to seek an involvement in nanotechnology. In addition, the Saretek Network (Basque Network of Science, Technology and Innovation), was created in 1997 on the initiative of the Basque Government.

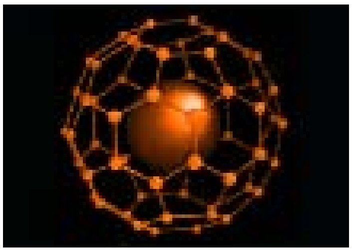
- In *Galicia*: NanoGalicia is an initiative of the Galician government.

- In *Asturias*: The Nanotechnology Platform of the University of Oviedo and the National Coal Institute (CSIC).

- In *Aragon*: The University Institute of Nanoscience Research of Aragon (INA).

Some results of government support

Work in the nanotech field has now begun to yield patents and practical applications in a range of areas. These are very varied, encompassing many different industries, from nanoobjects to the development of sensors with biomedical applications and catalytic nanostructures for energy saving.



According to figures from the European Patent Office (Espacenet) and the US Patents and Trademarks Office (USTPO), patents are often filed by foreign centres and companies in which, thanks to collaboration agreements between Spanish and foreign institutions, at least one of the inventors works in Spain. The opposite situation, however, is less common.

Universities and private companies patent their inventions in nanotechnology to a similar extent, each accounting for around 19% of the patents filed. This would be unusual in other areas, where research centres file much fewer patents than the private sector.

Applications in the medical and pharmaceutical industry are particularly important. Work is being carried out to increase our understanding of a wide range of nanoelements and nanostructures; however, nearly 70% of the inventions involve only nanoparticles and nanoaggregates. The extensive research work being conducted into other kinds of nanoelements, such as fullerenes and carbon nanotubes has yet to yield any patents. This suggests that more research work is still needed into these materials in Spain before a sufficient level of development is reached to enable industrial application[58].

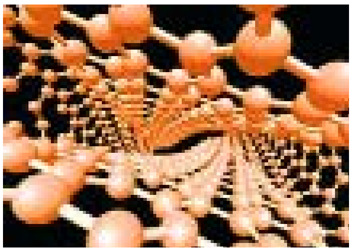
58. Figures taken from Informe Nano, nanotecnología en España, a report published by the Universities and Research office of the regional ministry of education of Madrid in collaboration with the NanoMat project.

4

CHAPTER 4

Value Chain

4 The value chain



The value chain gives an overview of the process leading from the inception of a scientific concept to delivery of the product to the end consumer. It not only involves production and distribution of the product, but also takes in the consumer's needs. The aim of the value chain is to ensure that the user's needs are met by the characteristics of the new product, i.e. to create value for the customer. This value is generated throughout the various phases making up the chain.

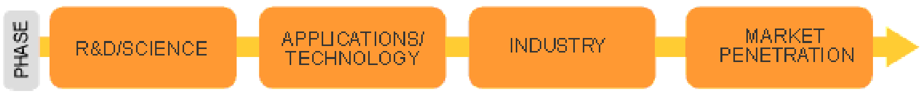
As we saw the previous section, some nanotech advances are already available on the market; however, the main development of the industry is still to come. This chapter will try to explain how the value chain for the nanotechnology industry could be created, taking into account its various phases and the agents and human resources involved.

4.1. Stages in the value chain

It normally takes around twenty years from the time when the scientific concept sparking the R&D process is born and the point where the consumer can pick the product off the shelf in his local shop. During this long period of time, the scientific idea has to be given expression in a practical application, which in turn has to be accepted both by legislation and industry. Suitable mechanisms also need to be found for manufacturing the new application in order to ensure that a reasonable balance is struck between production costs and the benefit passed on to the buyer, and that the final product is worth marketing.

The added difficulty of this process therefore lies in the gap that exists between the base science and the marketed application.

The frame below shows the four essential phases in the value chain.



Increasing nanotech research is vital to allow applications to reach the market. The link between R&D and applications is a key one in the value chain, given that on its success depends the conversion of nanotechnology into a viable industry; otherwise, it will never get beyond the realm of science fiction. The move from nanoscience to nanotechnology will therefore mark the entire development of the value chain.

The practical applications eventually created currently face high industrialisation costs. These high costs prevent many applications from achieving commercial viability, thus creating a bottle neck. One example can be seen in single wall nanotubes, which cannot be produced in economies of scale using existing equipment; their high cost makes them unviable. In order to overcome this barrier, the priority objective must be to find new materials and processes that will reduce costs.

In these early days of nanotechnology, consumers still play a secondary role, given that nanotech products are only beginning to be marketed now. The R&D phase currently takes up the greatest time and effort.

There is still considerable uncertainty as to when the industrialisation and marketing of nanotechnology-based products and services will really be able to take off. The FTF experts consider that the turning point may come in 10 or 15 years time when R&D work and the search for applications will be overtaken by large-scale production and the introduction of nanotech advances onto the market.

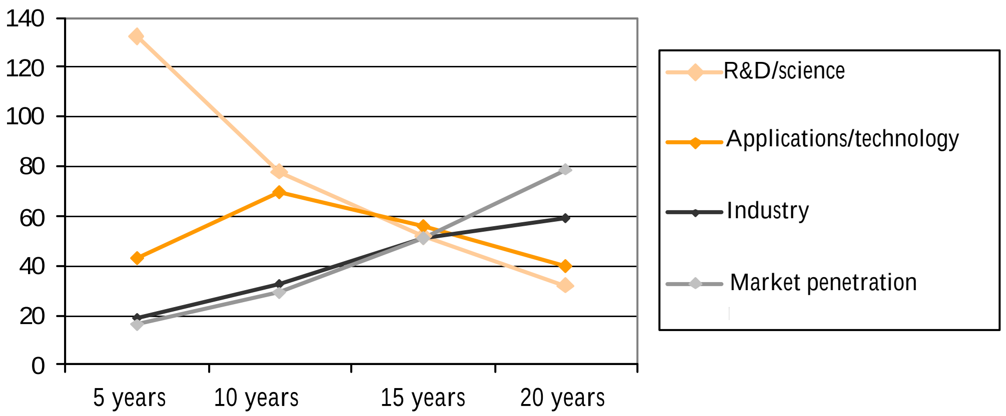


Illustration 12. Stages in the value chain over the next twenty years
Source: own preparation.

4.2. Agents who can promote the nanotechnology industry

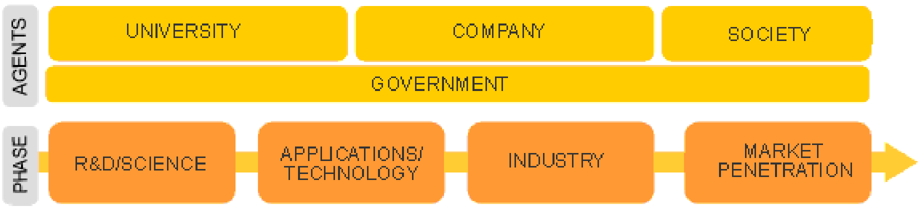
This section will analyse the agents responsible for promoting nanotechnology so that nanotech industrialisation and market penetration can continue.

On many occasions, the first innovative ideas come in academic circles, where work is not initially conditioned by the cost effectiveness of the inventions. Naturally enough, at a second stage, in order to achieve financing, the *universities and other research institutes* need to demonstrate the practical applications these innovative ideas could have for the market. Nanotechnology has followed this pattern and it is amongst the academic community that the sector's first steps are now being taken.

In parallel, the *business community* is of key importance in developing any market. Normally, companies may play a twin role in this scene. On the one hand, they can invest in R&D and foster the development of new applications. This is the role most generally played by large corporations with significant investment capacity. Business also generates demand and pressure to keep the phases of the value chain moving, demanding that the theoretical applications be turned into hard reality by incorporating the advances into production cycles.

On the part of *society* there might also be a certain degree of pressure, since consumers are always looking for ways to improve their quality of life. However nanotechnology is still a great unknown for most people and it therefore seems unlikely that final consumers will act as an agent of change promoting the emergence of this new industry.

Government support throughout the nanotechnology development process may play a decisive role. In the US, for example, the national nanotechnology initiative (NNI) has given a great boost to research, leading to an increase in both public and private investment. Indeed, this initiative has been replicated by several other countries.



We could divide the agents involved in the process into two categories: the ones who generate the supply forces (the pushers), who include universities, industry and government, and those that generate the demand forces (the pullers), including multinationals, SMEs and consumers.

The FTF experts consider that nanotechnology will be turned into a viable industry as a result of a push from university and government, i.e. from the supply-side forces. Companies and consumers (the pullers) are still a long way from playing a leading role in nanotechnology.

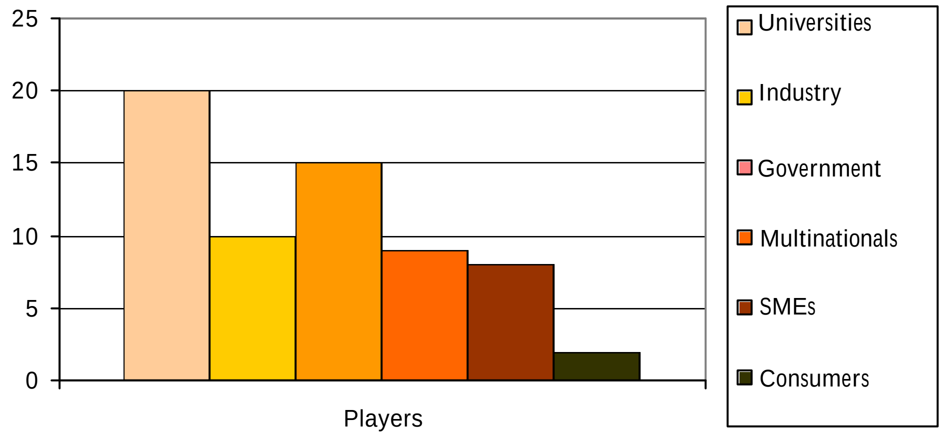
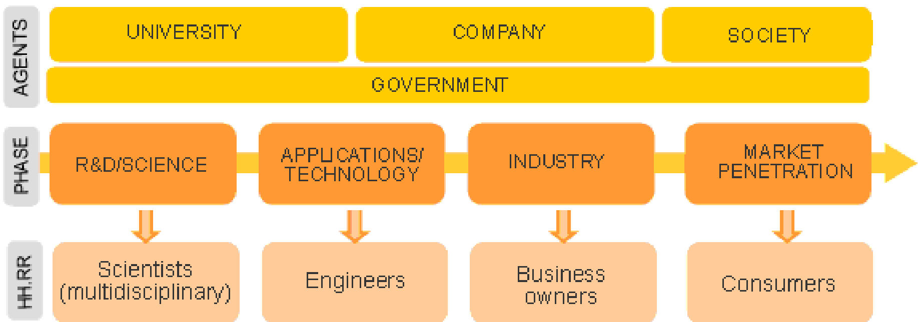


Illustration 13. Influence in the development of nanotechnology at the present time
Source: own preparation.

4.3. People with an influential role in nanotechnology

The current emergence of nanoscience and nanotechnology requires well-trained individuals who can contribute expertise in the various phases of the value chain. They will play an essential role in developing the industry.

Whereas *scientists* have to make further progress on research into the different areas of application of nanotechnology, well-trained personnel who are capable of finding real applications that can be brought to market are also needed. In turn, the industrialisation and marketing phases must have backing from the *business community* who will commit to innovation, and companies that are willing to assume certain risks in exchange for the possible rich pickings of being the first in a very promising market.



According to figures from the European NanoBusiness Association's 2005 survey[59], finding people with the right profile to work in the nanotechnology industry is a complicated task-or at least, just as difficult as finding specialised personnel for other industries.

59. Website: http://www.nanoeurope.org/.

The fact that this branch of science is still at an infant stage and the need for multidisciplinary training that has yet to be developed with formal programmes are two of the main obstacles explaining the shortage of human resources in this market.

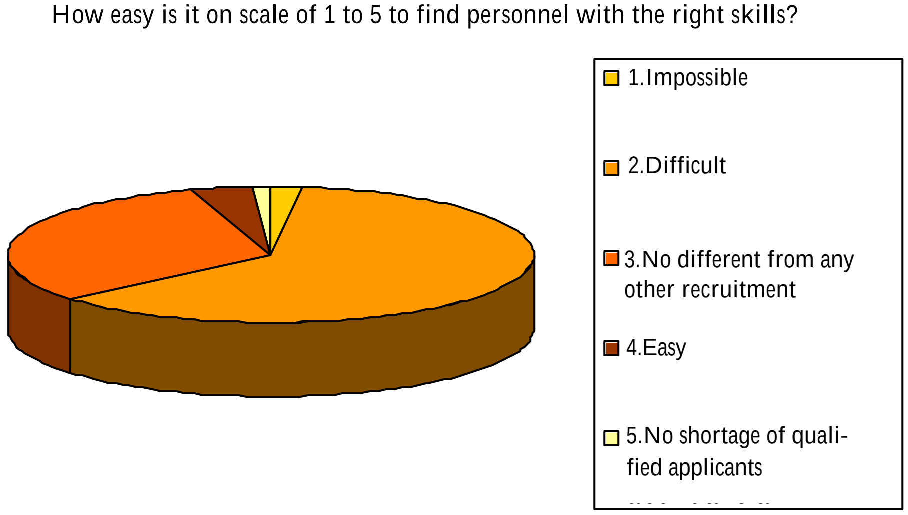


Illustration 14. How easy is it on scale of 1 to 5 to find personnel with the right skills?
Source: The 2005 European NanoBusiness Survey (ENA).

With regard to the perceived quality of the people currently involved in nanotechnology, the FTF experts make a number of differentiations. According to the results obtained, two groups can be distinguished: on the one hand are the business community, which still has to get more involved and more educated about these nanotech developments before this new branch of science can become a strong, profitable industry; and on the other hand are the scientists working in R&D who are looking for practical applications, with a very high level of training, capable of contributing great value to the phases of the production chain in which they are involved.

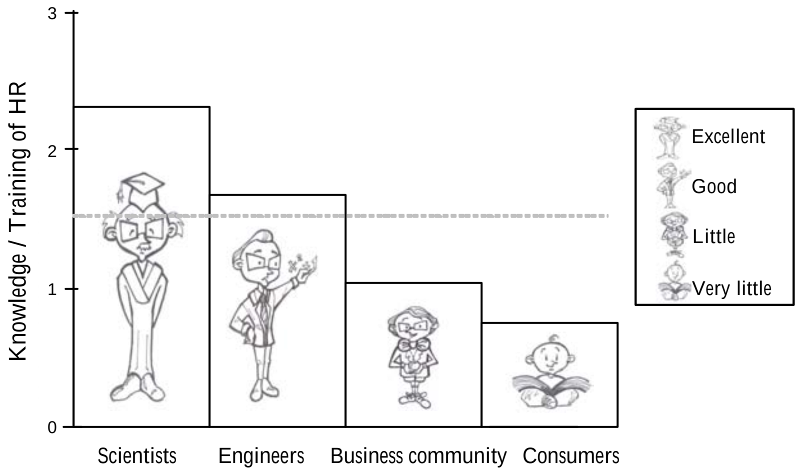


Illustration 15. Training level of human resources *Source: own preparation.*

As a final note, it is worth noting that consumers will take some time to become aware of the potential of nanotechnology. Indeed, many may never be fully aware of the developments, noticing only the improvements in products they were already using without knowing anything about the technology that has made it possible.

4.4. Economic support in the value chain

Financial support plays a key role in allowing a transfer of technological knowledge from research centres to industry and the market. In order to initiate the development of new products and processes and penetrate new markets, investments are required, especially at this point in time. Close cooperation between the financial community and nanotech companies can help achieve these goals.

Investments, for example, can cover different aspects of the value chain, from R&D projects to projects designed to publicise nanotechnology's potential. Two aspects will be vital to the success of these investments: selection of the target and the moment.

The frame below shows the complete value chain with all the necessary components that will allow a scientific concept to be turned into an everyday product.

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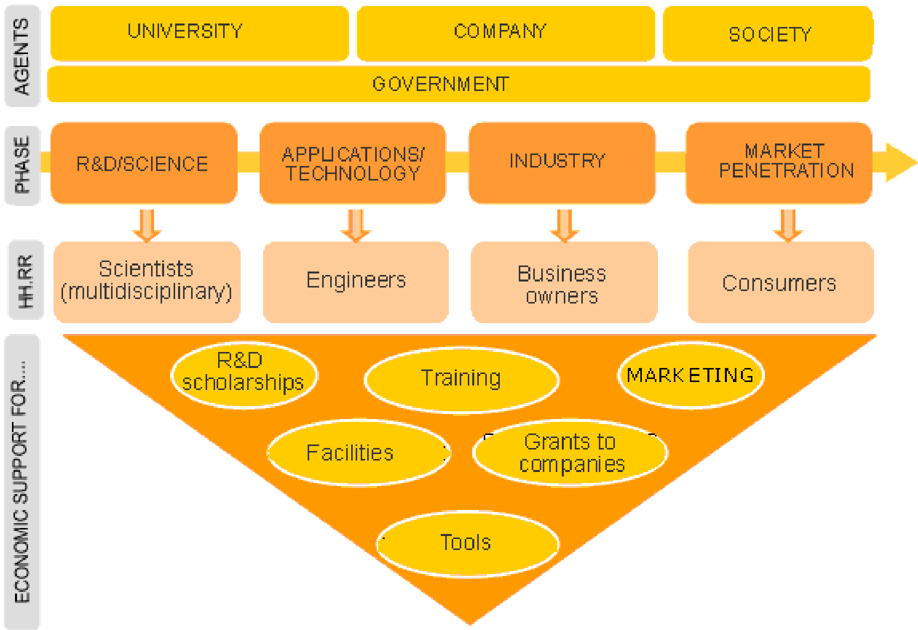


The areas on which economic support focuses could be classified as follows:

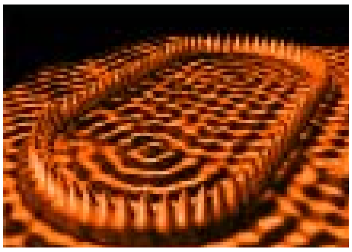
- *Scholarships and other grants to R&D:* the first phases in the value chain must be supported by investment if they can convert science into technology.

- *Facilities and infrastructures:* the creation of facilities in which nanotechnology can be developed, applied and generated is a key factor for its future. Many of the people involved in nanotechnology will converge in the same infrastructures.

- *Tools:* Providing researchers with the right tools at a competitive cost is essential to continued innovation in nanotechnology.

- *Grants to business:* the awarding of grants and other kinds of benefits (including tax incentives) will give businesspeople an impetus to create new nanotech companies.

- *Marketing:* society needs to be made aware of the potential nanotechnology holds out for their everyday lives in order to generate an increased market demand.



■ *Training:* the main agents in the development of nanotechnology throughout the entire value chain need to receive the right training, giving them the skills they need in their work.

As Illustration 16 shows, the FTF experts believe that economic backing, regardless of the source, must be distributed amongst all the links in the value chain. There are only small differences: for example, the awarding of scholarships and other types of grant for research and development and the creation of infrastructures must receive more public funding. However, private investment should play a somewhat more predominant role in disseminating nanotechnology among society and in encouraging multidisciplinary studies.

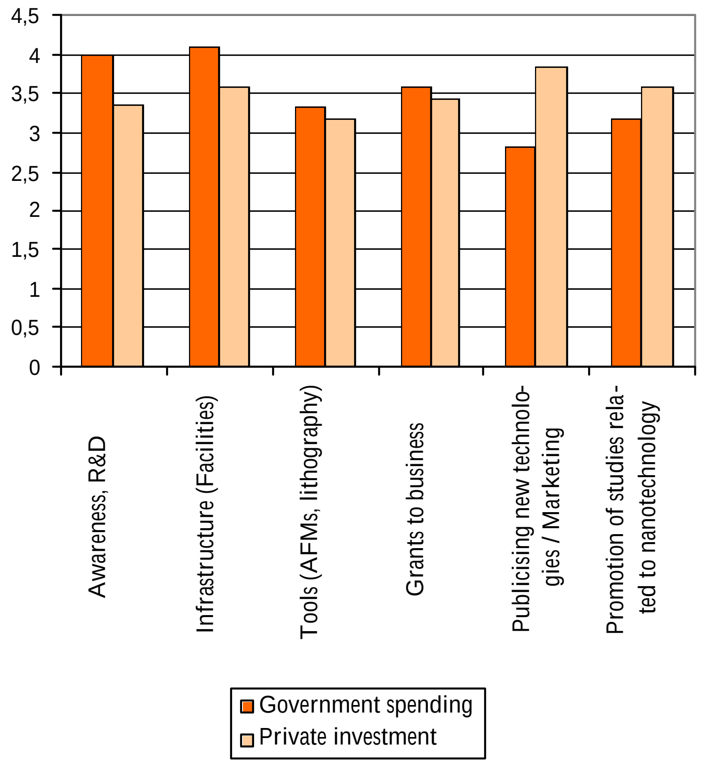


Illustration 16. Priority of spending by government and the private sector
Source: own preparation.

5

CHAPTER 5

The FTF View of Nanotechnology

5 The FTF View of Nanotechnology

This chapter sets out the opinions of FTF members on the possible development and impact of nanotechnology based on the definitions and background set out in previous chapters.

This information was primarily obtained from two sources:

- Two symposia attended by all members of the Forum, at which several presentations were given by world experts, followed by an opinions phase during which each member had an opportunity to expound their views, in groups and individually.

- Questionnaires intended to establish the overall opinion of the members of the Forum on possible developments and the impact of nanotechnology over the coming years.

The results obtained, backed by a recent bibliography, are set out in this chapter. The conclusions have been organised into the following sections: indicators which might speed up or slow down development of the industry, differences between countries or regions involved, the risks of this new science and the pressure which is beginning to be applied by society, the areas on which investment in nanotechnology focuses and a final note to make these developments more accessible to the general public.

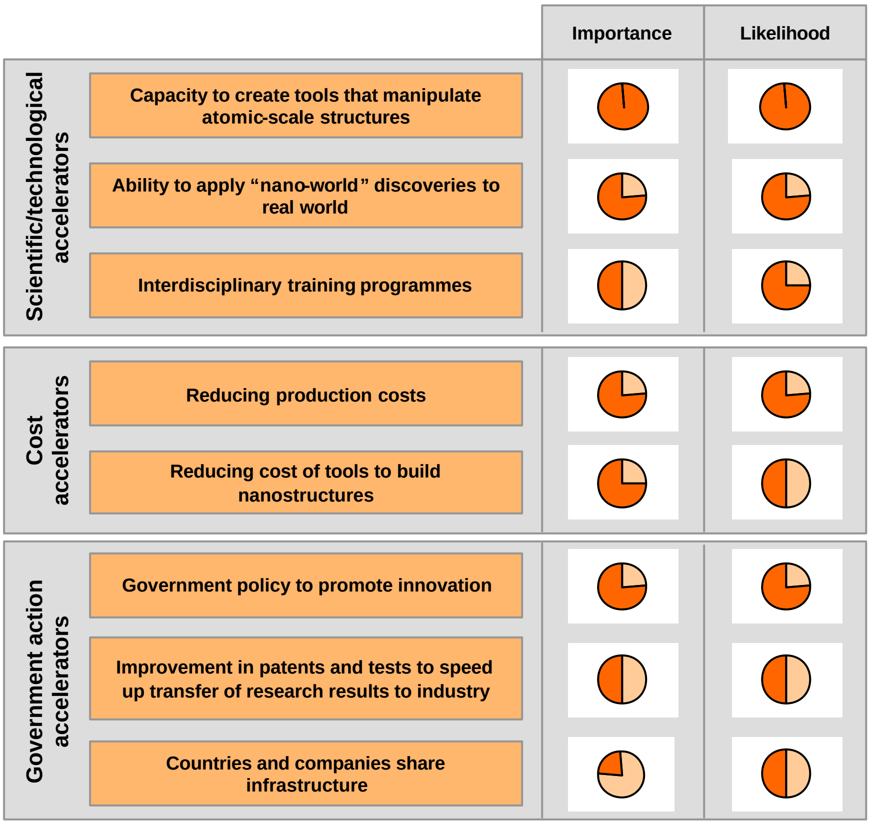
5.1. Accelerators and Barriers to Nanotechnology

The development of nanotechnology will depend on a series of factors which will play a key role in determining its success or failure. In such an unpredictable context as nanotechnology it will be the accelerators and barriers that investors weigh up when deciding whether to stake money in the industry, since they are the factors that will mark the status and speed of development.

This section will try to offer useful information to avoid investing either too early or too late. Here, the FTF members have identified a series of indicators: accelerators (or factors that will favour the development of nanotechnology) and barriers (factors that might hinder it).

What factors might speed up the development of nanotechnology?

The graph below shows the main factors that might speed up nanotech development. Listed beside each indicator is the relevance the FTF members assign to it, and the likelihood of its happening over the next five years.



Graph 1. Importance and likelihood of the Nanotech´s principal accelerators
Source: own preparation.

Notes

The accelerators that have been classified as being *scientific/technological in nature* are the ones that the FTF experts consider to be of key importance for development of the industry. The number one priority must be the development of the necessary equipment for undertaking scientific research. It is also vital to find practical applications to attract investors to nanotechnology.

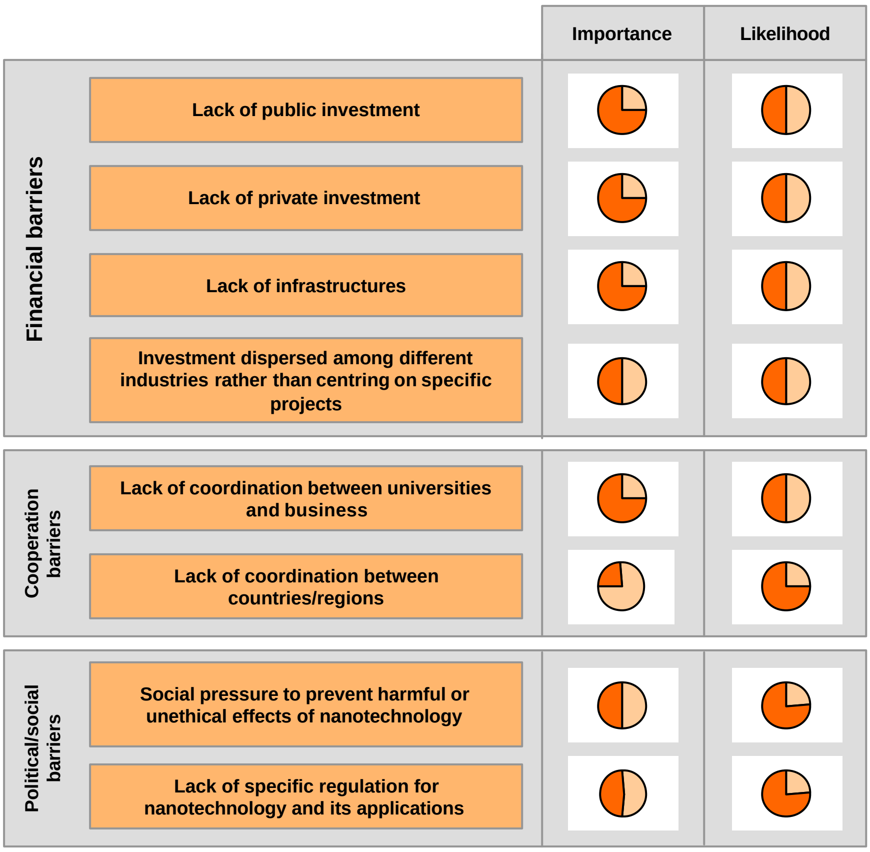
Secondly, as a natural consequence of the first indicators, *cost accelerators* seek to lower the cost of the essential tools for operating with nanostructures, and the viability of industrial processes for developing nanotech advances.

Last come the *accelerators involving government action*. In this case, the FTF experts laid particular emphasis on the need for government policies to promote innovation. As we have seen, there are now many government initiatives, but sustained support is required.

In general, the results given regarding accelerators show a clear correlation with the opinions expressed by the FTF experts on the agents in the value chain that will have be most responsibility in developing nanotechnology. In other words, this is a *push* market, in which both the universities, researching nanoscale manipulation tools and practical applications, and the government, through joint financing with companies and policies that favour innovation, will be the ones to accelerate the development of nanotechnology.

What factors might slow down the development of nanotechnology?

As with the accelerators, the barriers were assessed on the basis of their role in slowing down development and the likelihood of their occurring in the short term future.



Graph 2. Importance and likelihood of the Nanotech´s principal barriers
Source: own preparation.

The main *barriers* to the development of nanotechnology may arise in the area of financing. The FTF experts consider that both public and private investment is a key factor for the development of the value chain. In these first stages, what is particularly necessary is investment oriented towards the creation of infrastructures that will facilitate access to nanotech advances among a larger number of agents.

Second come the *barriers posed by a lack of cooperation*. Here, the experts highlight the need for close coordination between researchers (who are mainly in the universities) and the companies in charge of developing practical applications with the advances made in nanotechnology.

Finally, there are what we might term *socio-political barriers*. In all likelihood, society will apply strong pressure in the face of any uncertainty as to the possible harmful effects or unethical practises of nanotechnology. The existence of a specific regulation for such cases will be of key importance-though not in the short term, but rather when mass marketing of nanotech products begins.

The illustration shows that in general terms the FTF experts considered that the barriers identified are less important than most of the accelerators. The accelerators may therefore be presumed to have a greater weight, and one could therefore predict that in balance nanotechnology is likely to succeed.

5.2. Development of nanotechnology by regions

The development of nanotechnology currently varies greatly from one region to another. The presence of mature risk capital markets in developed countries means that it is here that there are most companies working in the field of nanotechnology.

Greater or lesser development of nanotechnology in different countries will depend mainly on public and private spending, as well as on the quantity and quality of the human resources involved in this field. The leaders of the future may not be today's largest investors; an increase in qualified professionals might give one country an enormous edge in nanotechnology.

Illustration 17 shows the nanotech presence in different countries as a percentage of total scientific publications over a recent period of time.

Distribution of publications and minutes of conferences on nanotechnology

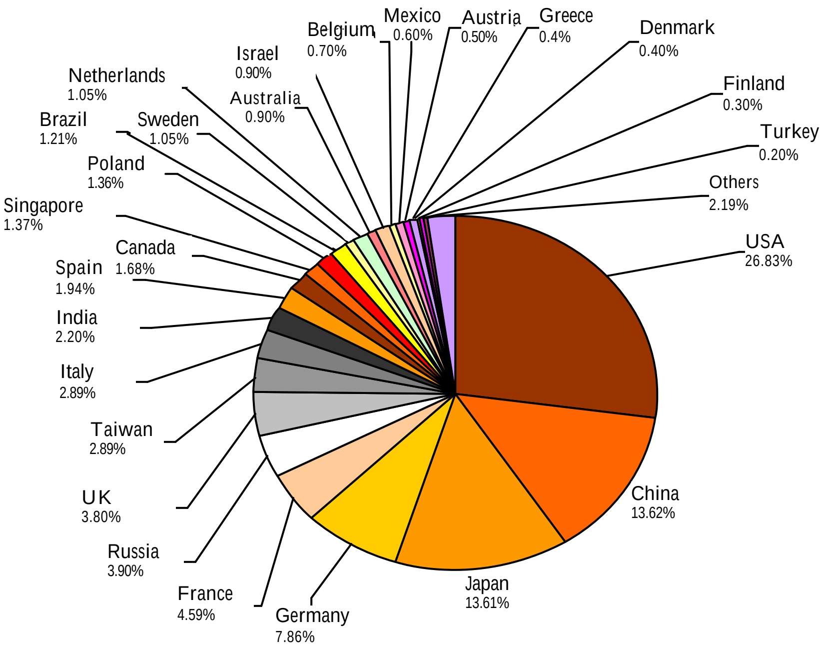
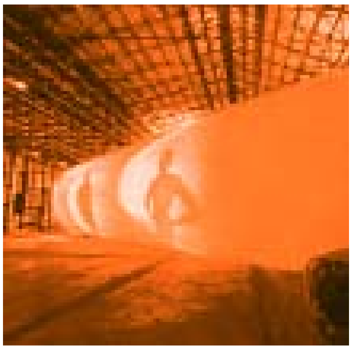


Illustration 17. Distribution by countries of publications and minutes of conferences on nanotechnology, found in INSPEC for the period 2003-2004

Source: Nanotecnología en España published by Fundación Madri+d.

Heading the list are the countries with the largest scientific and technological tradition, such as the US, Japan and Germany. They not only lead the field in nanotechnology, but are also the leading world powers in science in general. Similarly, the countries with the highest nanotech output include China and India, with economies that a priori, are more modest than the US or the EU. Given the great expectations raised by nanotechnology, these countries want to be sure not to miss the nanotech boat, with all the scientific, technological, industrial and economic delay this would imply.

Israel merits particular attention: despite not having an outstanding record in terms of publications, it has been included as a major power because of the important results it is now garnering in nanotechnology and because of the many agreements it has entered, enabling it to position itself among the regions leading nanotech development.



The race to be at the forefront of nanotechnology

One of the indicators that best illustrates the development of nanotechnology in a country is the *qualifications of its personnel*, which can vary greatly from region to region. Illustration 17 shows the regions with the most highly qualified personnel and the FTF experts prediction for the next five and ten years.

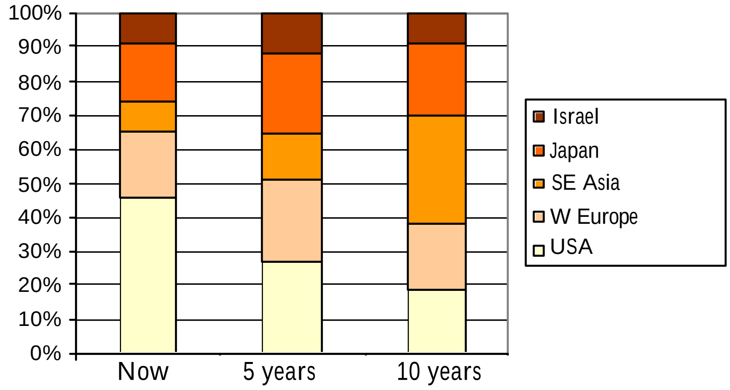


Illustration 18. Most qualified personnel by region in the short and medium term

Source: own preparation.

As can be seen, the *United States* is in first place at *present* with the greatest critical mass of qualified researchers in university centres, and the greatest number of qualified personnel in charge of projects and businesses in the field. In second place, come the *runners-up*, Western Europe and Japan, which are increasing support to nanotechnology to increase the number of qualified nanotech personnel. Finally, bringing up the *rear* are South East Asia and Israel. Countries like China, Taiwan and Singapore have huge potential to generate dedicated nanotech personnel, although they are still playing in a lower division.

Although it only has a small population, Israel could occupy an important position within a niche market. For its part, the US will remain at the *forefront* in the short term, though with a much smaller lead, since the *runners-up* (Japan and Europe) will have increased their levels of efficiency with increasingly highly qualified personnel.

In the *medium term* (in ten years time), the FTF experts predict that the position of the various countries with regard to the quality of the people involved in nanotechnology will be overturned. South East Asia will take *first place* while China will produce many more engineers and scientists than the US, many of whom will be educated abroad. The great challenge facing these countries will be to keep their qualified personnel at home. Japan, the US and Europe will *pursue* these countries, trying to snatch experienced professionals, while Israel will hold on to its market niche.

In terms of *competitiveness* by regions, the differences are very similar to those seen in the qualification levels of the workforce. Illustration 19 shows how FTF experts view competitiveness developing in the short and medium term in the various regions now developing nanotechnology.

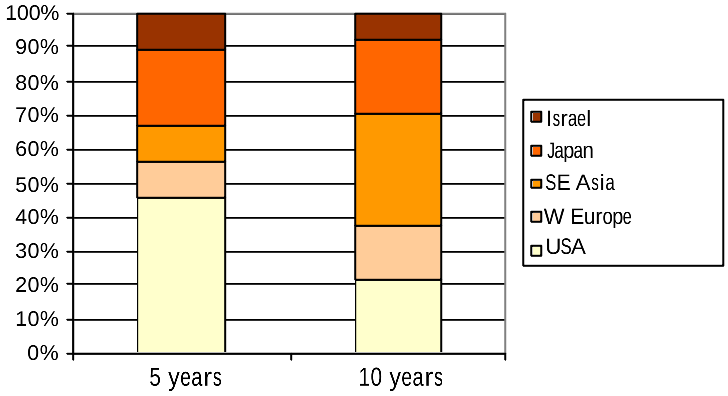


Illustration 19. Short and medium term competitiveness by region *Source: own preparation.*

In the *short term*, the US will take the *lead* position because of greater involvement by its public administration, with major funding for nanotech research and development, and because of its human talent and innovation. It is very aware that this is an industry that will play a central role in the next great "technological wave" and is capable of revolutionising industry and most of the companies in the country.

The FTF experts see Japan as an immediate pursuer in terms of competitiveness. Initiatives funded by the Japanese government tend to centre on ways of improving the materials used to manufacture conventional apparatuses and they also have a notable technological advantage in the area of carbon nanotubes for use in existing technology.

Behind it stand Europe, South East Asia and Israel, whose initiatives are expected to come to maturity in a more medium-term future.

Here, as in the previous illustration, the experts predict that in the medium term there will be a change in the lead position as a result of the strong drive anticipated from SE Asia by then. A growing number of nanotech companies and researchers, and specialisation in specific areas of this field, makes the future look promising for the region.

A number of drives have been identified which regions and countries are trying to develop in order to lead nanotech progress. Here, the FTF experts have pinpointed the strengths of each region:

■ The US is characterised by a capacity to develop all its initiatives simultaneously, although the experts also highlight this country's coordination between different disciplines and between universities and companies.

■ As for Europe, the experts consider that, while an increasing number of initiatives are being taken to develop nanotechnology in government policy and in the different industries, the continent still has a long way to go in all aspects before it can seriously challenge or even come close to the lead position of its most direct competitor, the US.

■ South East Asia's specialisation in finished products, especially in the electronics industry, and the development of infrastructures are its main competitive edges over other regions.

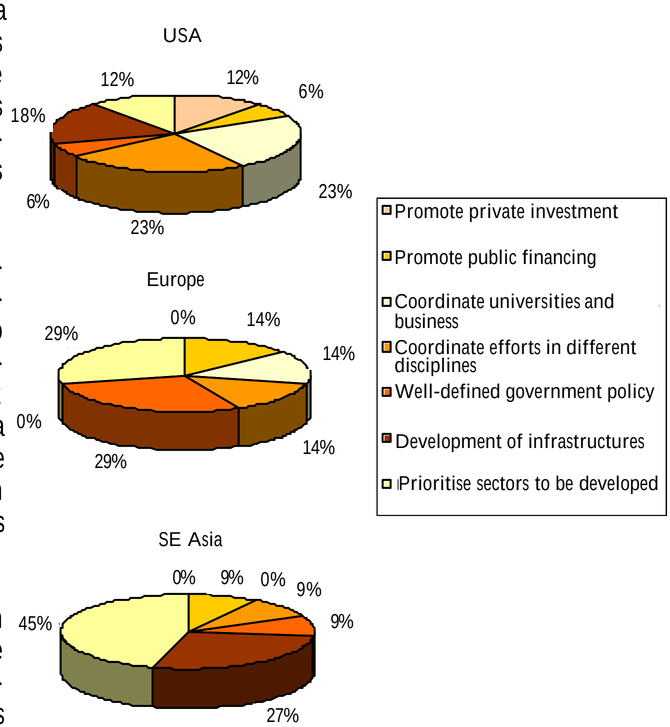


Illustration 20. Main strengths of the US, Europe and SE Asia
Source: own preparation.

Nanotechnology, the great hope for developing countries

Developing countries face certain restrictions on nanotech research projects, which will cause them to import nanoproducts and processes from developed countries. In the light of this situation, nanotechnology could, on the one hand, worsen the situation of these countries, since it will probably reduce the demand for their exports, particularly raw materials; At the same time, however, it could be the key factor in solving many of the problems they now face.

Few nanotech projects today are targeted at solving issues related to poverty. However, nanotechnology could offer major benefits to developing countries. The United Nations' International Centre for Science and High Technology addressed this issue at a meeting held in February 2005 on "North-South Dialogue on Nanotechnology"[60], which was founded on three basic premises: "a) we do not think it is correct to just assume that nanotech is too difficult or too expensive to be developed in developing countries; b) nanotechnology may offer important benefits to developing countries, can be a critical tool for R&D and can address needs in areas such as health, environment and economy; c) if we do not face these problems, the gap between developed and developing countries will increase".

60. Website: "North-South Dialogue on Nanotechnology: Challenges and Opportunities", International Centre for Science and High Technology (www.ics.trieste.it).

Notes

The Canadian programme on global health and genomics (CPGGH)[61] has also made progress in this area. This programme identified ten areas of nanotech application with an impact on developing countries to the threshold of 2015, related to water, arable farming, nutrition, health, energy and the environment.

Illustration 21 shows the opinion of the FTF experts on the different impacts of these areas depending on the type of country. As can be seen, arable farming, water treatment and food storage and processing are the areas that could make the most difference in developing countries. Applications related to nanobiomedicine (drug delivery, diagnosis of diseases and personalised patient monitoring) will have a greater impact in developed countries where the necessary infrastructure already exists to introduce such advances.

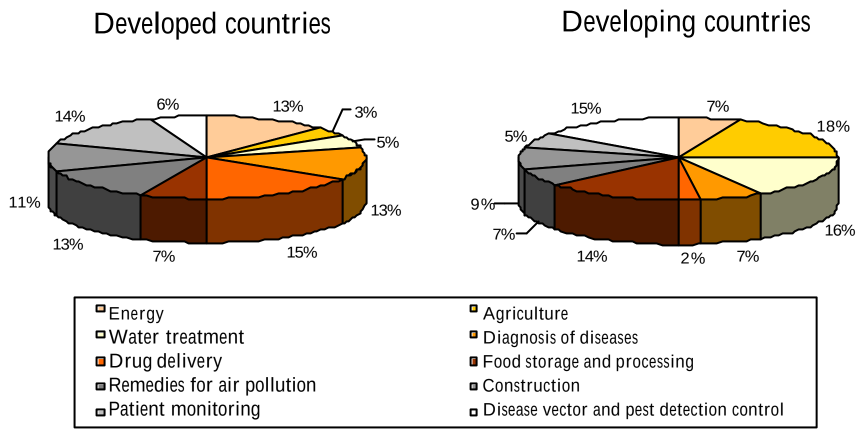


Illustration 21. Areas of application with greatest impact in developed and developing countries
Source: own preparation.

In any case, the contributions nanotechnology will make to developing countries include clean and plentiful energy, more efficient medical diagnoses and new water filtering methods. Some day, in a remote village in one of the developing countries, a doctor will take drop of blood from a patient and put it onto a piece of plastic the size of a coin and, in a few minutes, will get a complete diagnosis for analysing infectious diseases such as malaria, AIDS or even cancer.

Various developing countries have already launched their own nanotech initiatives. China comes third in the world-only behind the US and Japan-in the number of nanotech patents it has filed. India plans to increase its investment in nanotechnology considerably over coming years, while Brazil is another developing country that is planning large scale investment in nanotechnology in the short term.

A more pessimistic view argues that nanotechnology will face the same difficulties as other technologies before it. The multinationals are patenting most nanotech products. Patents are guarantees of a monopoly, bringing revenue for twenty years and hindering rapid dissemination of the potential benefits of nanotechnology in developing countries.

61. Website: http://www.utoronto.ca/jcb/home/documents/PLoS_nanotech.pdf.

5.3. Risks resulting from nanotechnology and social pressure

By now, the reader will have an idea of the broad range of applications nanotechnology now offers or will offer in the near future. This chapter analyses how legislation and public opinion may affect its development and what the scope of nanotechnology is in different areas: the economy, society and the environment, among others.

Areas in which nanotechnology presents risks

Those involved in the different nanotech processes are interested in keeping the risks under control. Due to the immense potential of nanotechnology, it is essential to ensure that nothing gets in the way of its progress. The risks relate to areas such as ethics, the health services and competition. It is therefore necessary to oversee the applications and development of nanotechnology in the most affected areas.

The following points illustrate how nanotechnology might affect different areas:

- *Personal freedom:* the marketing of very small inexpensive super-computers would allow continuous surveillance of any country, city, building or home the user wants. An added danger is the possibility that a private company might gain a monopoly of the market.

- *Sociology:* nanotechnology will facilitate the dawn of new lifestyles which will change the way we employ our leisure time, and which particularly affect drugs and body-alterations. The potential for social imbalance is enormous. What ethical principles should be used to set the limits?

- *Armaments:* the process of manufacturing nanoweapons is much more discreet than that used to make nuclear weapons, but the weapons produced could be far more deadly. For example, one hundred nanograms of the botulism toxin is lethal for one person. A suitcase could hold 50 billion artefacts containing the botulism toxin, capable of wiping out the entire planet. To quote US Admiral David Jeremiah[62], "Military applications of molecular manufacturing have even greater potential than nuclear weapons to radically change the balance of power"[63].

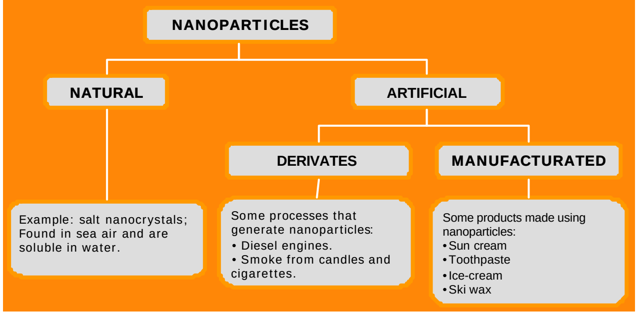
- *Economics:* it is always complicated to make macroeconomic predictions of any new technology. In the case of nanotechnology, major changes are predicted in the industrial structure that will affect all kinds of business. We do not know how unemployment will develop and this could pose a risk for the economic development of the different countries.

Particular attention needs to be paid to the fields of medicine and the environment, where the risk is most imminent. To understand them better, a brief explanation of the origin of the risk is required: nanoparticles.

62. Admiral David E. Jeremiah was the Vice Chairman of the US Joint Chiefs of Staff.
63. Website: http://www.euroresidentes.com/futuro/nanotecnologia/nanotecnologia_responsable/riesgos_nanotecnologia_armas.htm.

In the short term, the main risk comes from nanoparticles, since any type of nanoparticle can be harmful. According to the European Union, "The danger depends on the nature of the nanoparticle, its size and active surface area, the individual who absorbs it, the organ studied, and often varies depending on whether the exposure is isolated or regular."[64]. This once again corroborates the need for a study of each of the particles to be used, investigated or produced, in order to determine any beneficial or harmful effects.

Nanoparticles can be divided into two groups- natural or artificial. The latter group are in turn divided into manufactured nanoparticles (those that come from production) and those derived from industrial processes, road pollution, etc.



We will now look at two areas where there is a potential and imminent risk:

- *Toxicology/medicine:* the most immediate concern for medicine is the toxicity of nanoparticles. Free nanoparticles can enter the human body through inhalation, ingestion or through the skin. Medical research needs to perform stricter clinical trials in the first phase of drug development and introduce applications to ensure the health and safety of workers and, in future, of the public at large. To date there is no proof that nanoparticles represent a human risk, but not all the necessary information has yet been prepared[65].

  Because of this, laboratories and research centres currently centre on research into pulmonary and cardiovascular diseases caused by the inhalation of nanoparticles, the accumulation of non biodegradable nanoparticles in the liver and the absorption of nanoparticles towards the brain.

- *Ecotoxicology/environment:* the most immediate risk that may arise in this field is the environmental pollution caused by nanoparticles generated, for example, in combustion processes. Will we be capable of creating a nanotech tool to solve this problem?

64. See http://europa.eu.int/comm/research/rtdinfo/47/01/print_article_3570_es.html.
65. More information at: www.nanoforum.org.

Preventative measures against the risks of nanotechnology

In its development, nanotechnology will have to address a number of real and imaginary legal and ethical risks.

Legislation

Suitable regulation in the field of nanotechnology is an effective tool for addressing real and perceived risks, and also in ensuring health and environmental protection in particular.

In this regard, the legislation must be adapted to meet the needs of nanotechnology. Due to the fact that production volumes or masses are regulated to a given threshold, under which it is free from regulation, it will be necessary to draw up specific standards for nanotech products and applications. To do this, it is first necessary to build the necessary instruments of measurement, using a discipline known as *metrology*.

At present, only people whose work is related to nanotechnology are exposed to the toxicity of nanoparticles.

The European Union advises prudence in this area; in other words, we should establish the real position of nanotechnology rather than heeding calls for a moratorium on research.

Ethical

The ethical values that may prevent the development of negative nanotech applications are respect for dignity, the principle of individual autonomy, the principle of justice and charity, the principle of freedom of research and the principle of proportionality[66]. In this field, unlike the area of legislation, it may be helpful to look at existing documents, such as the European Union's Charter of Fundamental Rights[67].

Social Pressure

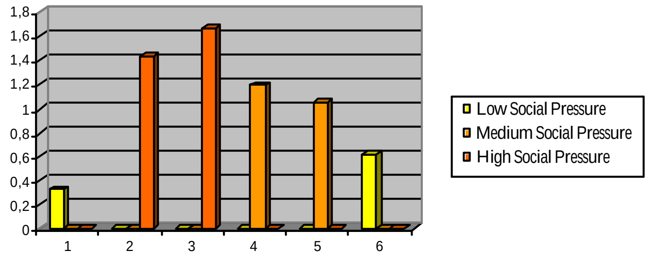
The political debate on nanotechnology has not yet reached the wider public. However, political parties, NGOs, the media and other interested parties have already begun the process. It is only a question of time before the general public comes on board.

In the interim, the European Commission, the European Parliament and the organs of national government know that they need to make full use of this short space of time. Lessons have been learnt from the public opposition to and rejection of genetically modified food.

66. For further information, see the Commission's communication: Towards a European Strategy for Nanotechnology, May 2004, Brussels.
67. See http://www.europarl.eu.int/charter/default_es.htm.

Social pressure according to the FTF

The FTF experts say that social pressure will centre particularly on issues of safety and the environment. Consequently, the risks that will be seen as being most controversial will be the emission of uncontrolled nanoparticles representing a risk to the environment and the use of invisible nanosensors that violate individual privacy, closely followed by the long term reliability, and detection, elimination and prevention of potential defects in nanocomponents.



1. Copyright at risk
2. Invisible nanosensors that violate individual privacy
3. Emission of uncontrollable nanoparticles a hazard for the environment
4. The long-term reliability, detection, disposal and prevention of potential defects of nano-components may represent a hazard
5. The safety of workers and consumers may be at risk because of the existence of undetectable nanoparticles
6. Political risks given the impact of NT on the economic development of different regions

Illustration 22. Focus of social pressure. *Source: own preparation.*

The great leap forward is still to come

Although the debate has already begun in the European Union and the risks that might potentially attract most controversy have already been identified, social pressure –like the nanotech revolution– has yet to arrive, though it is imminent.

Religious groups, NGOs, trade unions and the press will exert pressure to enhance public interest in the nanotech debate. Today two pressure groups are active in the field of nanotechnology:

- *ETC group*[68], , frequently quoted in the press, publishes reports on nanotechnology to heighten public awareness of the problems this new technological dimension may involve.

- *Greenpeace Environmental Trust*[69], whose aims are to promote investment to research the area of health and commit industry to ensuring that its practices do not harm the environment.

68. See http://www.etcgroup.org.
69. See http://www.greenpeace.org.uk/contentlookup.cfm?SitekeyParam=C-B.

It is possible that without the right information, social pressure will centre on unfounded or phantom risks. "A phantom risk is a phenomenon that the population perceives as a threat, even though no cause-and-effect relation has been scientifically demonstrated"[70]. This should be prevented by public authorities and public bodies through the dissemination of information.

How to integrate the social dimension of nanotechnology

Likewise, governments and nanotech developers must make use of the lack of knowledge to create a positive view of nanotechnology and ensure that the debate begins with a proper understanding.

The final goal is to demonstrate to the general public the safety nanotechnology can offer, and thus to build confidence in it. If the greater public were to perceive nanotechnology as something negative, its development could be slowed. How can true information be offered?

- *Encouraging dialogue.* The scientific community has often been accused of being cut off and of having no connection with the outside world. It is therefore essential to encourage free-flowing dialogue between all parties involved.

- *Offering transparency* on the results of research. Because it will take years before the risks of exposure to nanoparticles can be assessed, the only available reflection is knowledge.

Expanding on this line of responsible development, in 2004 the European Commission's Directorate General for Health and Consumer Protection[71] brought together a group of experts in a workshop called *Mapping Out Nano Risks*. Its report recommends a series of actions, including:

- Creating a *nomenclature*, on the one hand, to classify nanomaterials currently being researched and, on the other, to regulate the nanoparticles manufactured using a single access number assigned by the Chemical Abstracts Service[72]. Assignment of this number to each nanoparticle would involve performing toxicology tests -a further safety measure.

- Developing instruments of *metrology*.

- Founding a supranational institution to monitor development of nanotechnologies and assesses the advisability of more specific regulation in the future.

- Establishing smooth dialogue with the public and industry in order to ensure that both play a part in the decision-making process.

70. In Nanotechnology: Small matter, many unknowns, p. 40, published by Swiss Re., 2004.
71. See http://europa.eu.int/comm/dgs/health_consumer/index_en.htm.
72. See http://www.cas.org.

5.4. A few guidelines on investment in nanotechnology

The major impact that nanotechnology is expected to have on the economy will require financing for successful development. In order to develop new products and processes, and to penetrate new markets, major investment will be needed, especially at the current embryonic phase. Public investment by governments and private venture capital will both be essential.

What is the current state of investment?

Investment in nanotechnology is currently at a growth phase. The constant growth reflects increased interest among governments and the business community in the potential of nanotechnology, although it is public financing that is boosting development, as we saw in the section on the value chain. At this stage in research, the public sector is financing actions that will foster the development of nanotechnology and allow the private sector to become involved. The current trend is for a change in investment, with the private sector as the main financier of any activity related to this field.

Global spend on nanotechnology

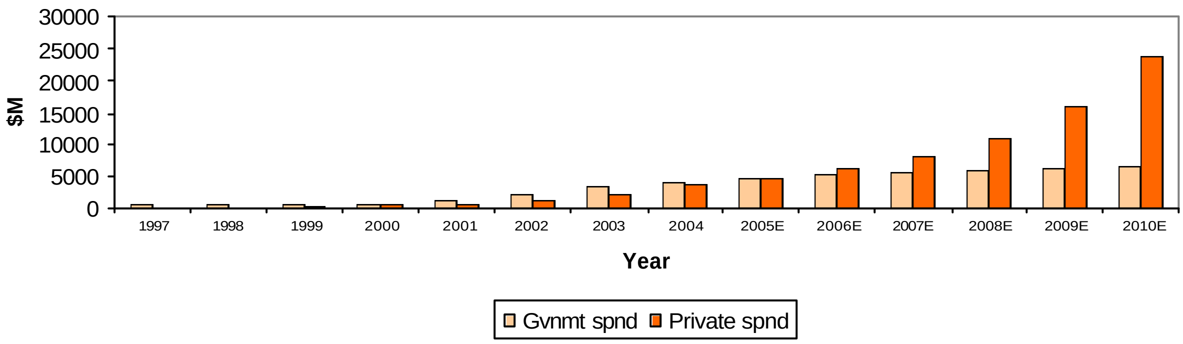


Illustration 23. Global spend on nanotechnology (1997-2010). *Source: Científica.*

It is forecast that from 2006 the trend will be towards greater involvement by the private than the public sector, with the latter distancing itself further as time goes by.

To put this situation in context, the figures below show the level of public and private investment in 2004 by regions. According to figures from Científica[73], the public sector invested around $4.1 billion in 2004. This amount was distributed by regions as follows:

- United States: $1.149bn
- Japan: $960m

73. In its publication Where has my money gone?, January 2006.

- Europe: $1.38bn
- Rest of the world: $644m

A report published by Lux Research[74], suggests that the private sector invested approximately $3.8bn in nanotech research and development in 2004. By regions, this spending was distributed as follows:

- American companies: 1.7bn
- Asian companies: 1.4 bn
- European companies: 650m
- Companies in other regions: 40 m

Total spend on nanotechnology

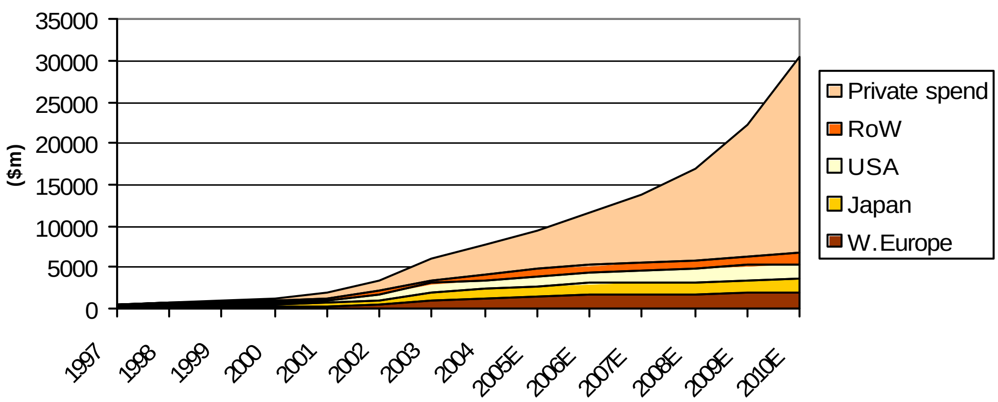


Illustration 24. Total spend on nanotechnology (1997-2010). *Source: Científica.*

We can see Europe has the highest level of public financing, whereas private investment is greatest in the US. It is worth highlighting the great difference between private sector and public sector investment in Europe, a situation which is quite different to that of its competitors, and which partially explain reduced nanotech development.

The private sector is now preparing to take over nanotechnology

As we can see, the private sector still lags behind government in terms of investment, although during 2006 this position is expected to be turned round. The expectations created with regard to nanotechnology will attract ever greater investment from business, while government outlay will fall steadily.

74. Website: http://www.luxresearchinc.com/.

Private spend on nanotechnology

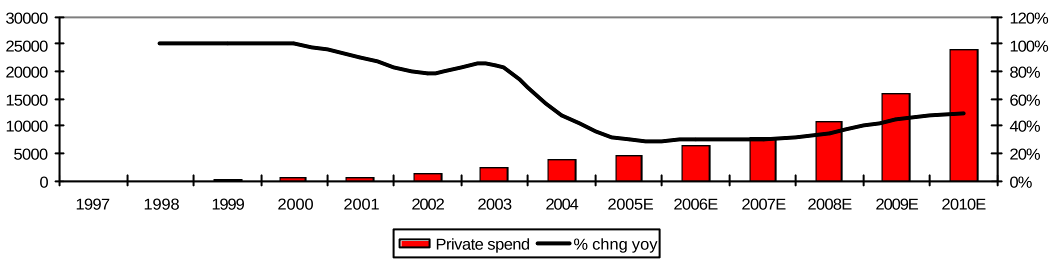


Illustration 25. Private spend on nanotechnology (1997-2010). *Source: Científica.*

Since 1997, private investment has grown spectacularly, doubling in the first years. Proportional increases are now beginning to be seen in investment, an upward trend which is expected to continue into the future with an ever clearer presence of private investment.

By regions, as we saw before, the role of private investment is greatest in the US, a country which has traditionally been less averse to risk-taking. Generally speaking, American companies are more willing to become part of an embryonic industry with a high level of uncertainty. There has been a significant increase in the number of nanotech companies being created in Asia, especially in China, making the continent one of the leaders in private investment. Europe, on the other hand, is a long way from having a consistent business fabric with backing for nanotechnology.

Illustration 26 shows levels of private investment 2005 in a range of countries.

Private Nanotech Spend by Country 2005

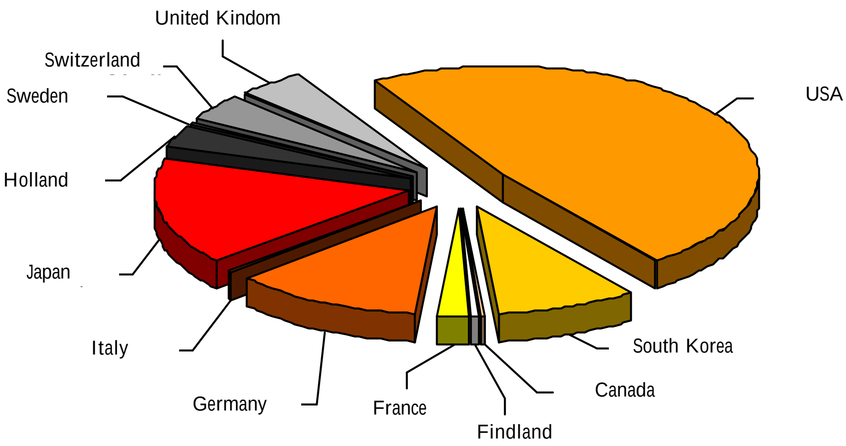


Illustration 26. Private Nanotech Spend by country in 2005. *Source: Científica.*

Two factors will be critical to the success of private investment: Choosing the right target and the right time. The question is not whether nanotechnology will come to market, but how long it will take to have the greatest impact with real products, thus achieving movements and profits. In this case, the time will depend on the product and the multidisciplinary nature of the nanotechnology in question.

Choosing the right target for investment will be vital in order to minimise the risks associated with the initial stage of nanotech. This requires meticulous analysis, not only of the market and of legal and financial aspects, but also of technical and environmental factors. In most cases, scientific expertise, combined with business skills in marketing will be of key importance.

Venture capital

Venture capital firms will play a key role in transferring expertise from the research centres to industry and the markets. To date, venture capital for financing the early steps of nanotechnology has been notable by its absence. Investment is growing steadily, however. According to Lux Research[75], institutional venture capital investors paid out $480 million in 2005 to finance nanotech start-up (total investment since 1995 comes to two billion dollars).

75. Report entitled Making Sense of Nanotech Venture Capital.

Notes

Venture Capital Investment In Nanotechnologies 2005 (Cumulative)

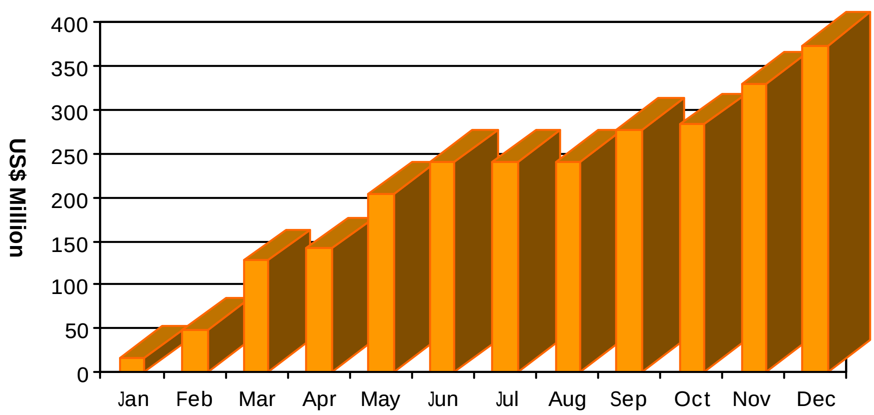


Illustration 27. Venture capital investment in nanotechnologies in 2005 *Source: Científica.*

During 2004, a total of 1,500 companies announced their intention to implement nanotech-related strategies. Despite these figures, venture capital investment continues to account for only a minute part of overall investment in nanotechnology, far outstripped by business spending on R&D and government funding. Investors are still reluctant to make a grand entrance into nanotechnology given the uncertainty that surrounds this early phase of the industry. The main focus of attention for new investors will be to get the timing right. In short, it is still very early to proclaim the success of venture capital in nanotechnology: only 9% of nanotech start-up projects backed by venture capital have been acquired or gone public: 83% continue to operate and 8% are dead or un danger[76].

However, the figures are not the same for all countries. US venture capital investors spend six times more than Europeans in this field, despite operating in a market of a similar size with similar amounts of public financing.

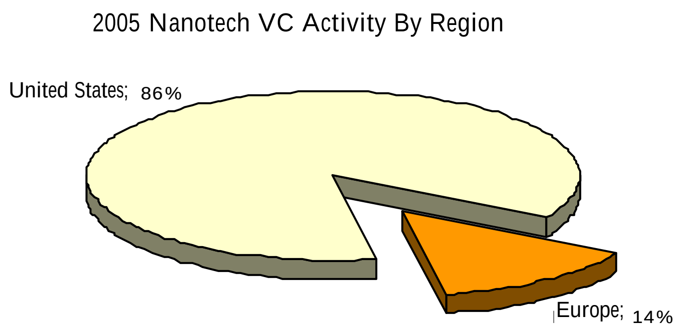


Illustration 28. Nanotech venture capital activity by region in 2005

Source: Científica.

So while European investors tend to be more hesitant about risk than their American counterparts, the risks associated with nanotechnology (the market, consumer resistance and a lack of knowledge among investors) have created this situation.

It is also increasingly evident for investors that future profits will not come from the companies making nanomaterials –carbon nanotubes for example– but from companies using them to create new products in medicine, energy, food and the textile industry. In 2005 an emerging trend saw nanomaterial companies pushing companies in demand sectors, such as the healthcare industry.

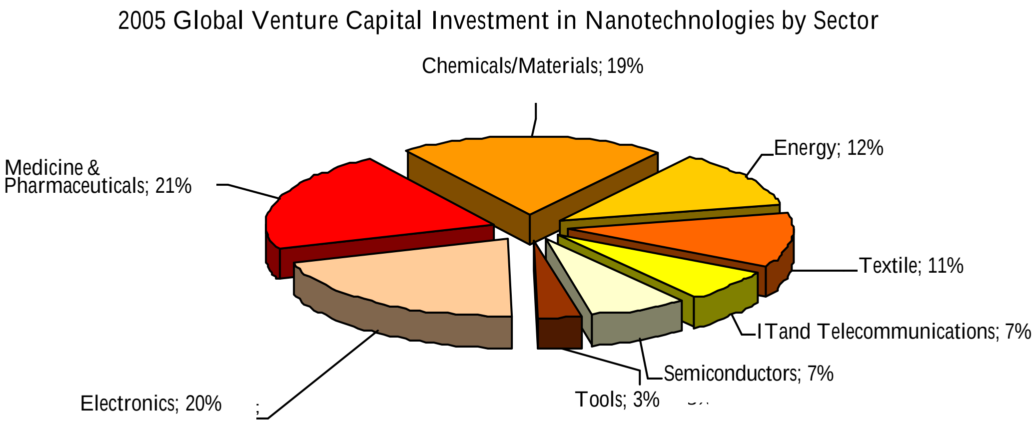


Illustration 29. Venture capital investment in nanotechnology by sector in 2005

Source: Científica.

76. Information taken from a publication by Lux Research Venture Capital pours into Nanotech, but exits are uncertain, January 2006.

As Illustration 29 shows, the greatest level of venture capital goes to the medical and pharmaceutical industries, along with electronics, chemicals and materials.

Future scenario for private investment

Given the multidisciplinary nature of nanotechnology, the private sector now faces a doubt as to where it should be investing in this field. Shown below are the possible scenarios that FTF experts have identified for the different industries in the short and medium term, depending on the impact of nanotechnology.

Over the next five years, the industry most likely to head the field is materials, in view of the applications they will find in most other sectors. Electronics and telecommunications, energy, products, pharmaceuticals and areas related to other raw materials will also be important.

Impact of the areas of application of nanotechnology on industries over the next five years

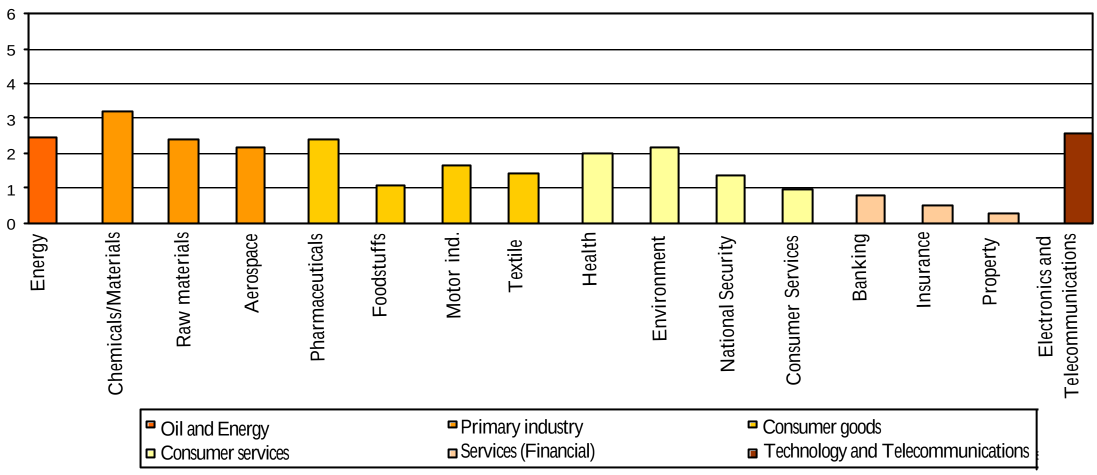


Illustration 30. Impact of the areas of application of nanotechnology on industries over the next five years
Source: own preparation.

In the medium term, investors should be on the look-out for possible variations in the impact on industries where new advances have been made in research. The experts consider that both electronics and the pharmaceutical industry will continue to ride the wave in terms of practical applications, while the raw materials sector will tend to stabilise. However, the areas that are likely to see the greatest change are the environmental and healthcare industries, where it is forecast that nanotechnology will play a greater role in the next five to ten years. We can therefore deduce that the consumer services industr–and in general all things health-related– will be the areas where nanotechnology will have the greatest medium-term impact.

Impact of the areas of application of nanotechnology on industries over the next five to ten years

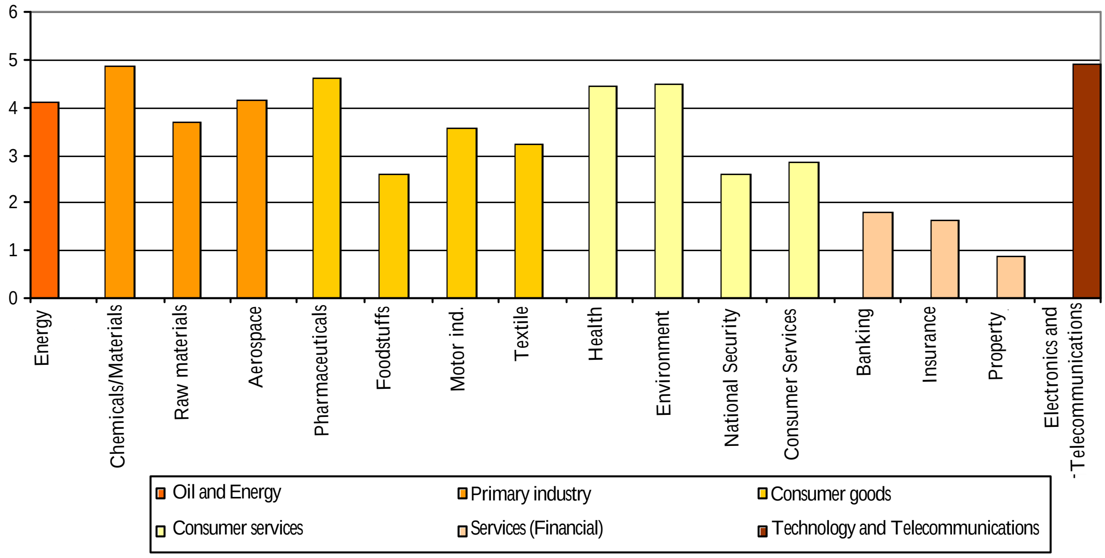


Illustration 31. Impact of the areas of application of nanotechnology on industries over the next five to ten years
Source: own preparation.

Finally, it is interesting to see what FTF experts say about the possibilities for entrepreneurs in nanotechnology. It is forecast that the pitch will be dominated by venture capital firms and entrepreneurs capable of finding the right investment at the right time. It will not only be the big corporations with large financing capacity that are likely to succeed in this new industry; small and medium-sized enterprises with convincing business projects will also be able to attract the capital, required to succeed in a market that is likely to be very competitive.

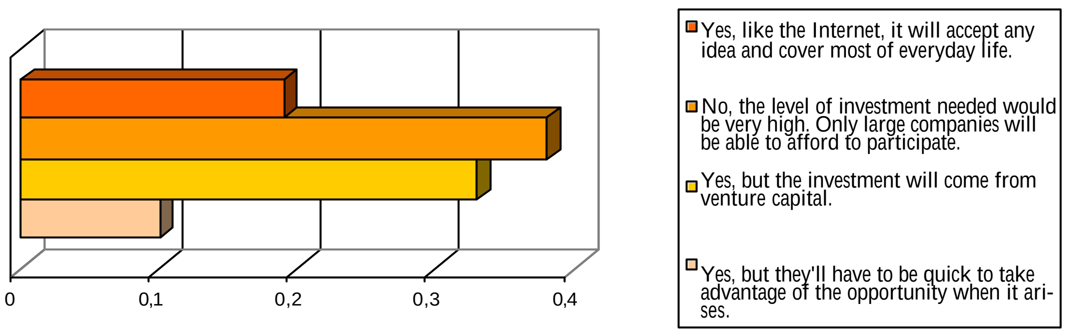
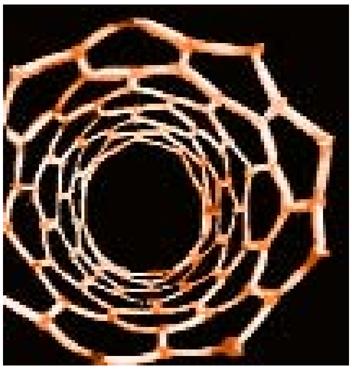


Illustration 32. Will there be a place in nanotechnology for entrepreneurs?
Source: own preparation.



The creation and development of start-ups will be a priority, and will depend largely on the following factors[77]: a highly skilled workforce, cooperation with universities, private financing (venture capital), access to public financing, and low-cost protection of knowledge.

5.5. Nanotechnology in our lives

Previous chapters have shown how nanotechnology has crept into our lives without our being aware of it, and how it will continue to play an ever greater role. It will have an enormous impact in nearly all industries, not only in large corporations, but also our everyday life. Offering everything from new types of television to more eco-friendly dishwashers, nanoscale innovation will revolutionise our lives.

The possibilities of the new research are boundless and because this is a multidisciplinary science, any new discovery could have on impact on nearly every other field. New insecticides to improve crop yields, systems to show milk and other foodstuffs have gone off, much faster computers and new more effective diagnoses and treatments are just some examples of what the future holds.

The FTF experts have assessed the various fields of our everyday life that might be affected over the next five to ten years. As Illustration 33 shows, the results are significant.

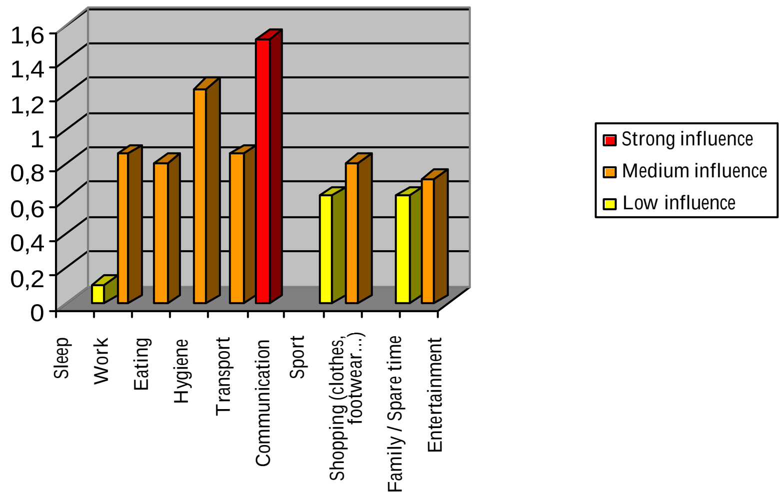


Illustration 33. Impact of nanotechnology on daily routines
Source: own preparation.

The industries that will see the greatest impact will be communication, hygiene, work and transport. Those that will be least affected are rest, sports and leisure. To a great extent, this general evaluation coincides with the work of the industry.

77. Information taken from the European Nanotechnology Gateway (2005).

A vision of the future

Reading the information in this booklet, it might be easy to think that nanotechnology belongs to the domain of science fiction. Nothing could be further from the truth. It may help to give a little vignette of what our lives, or those of our children, might be like in just a few years time.

Despite only getting a couple of hours rest, you start the day feeling fine, thanks to pills containing nanoparticles that make you feel as if you've had a good night's sleep. Your bed and your pillow have also helped improve your rest, with improved hygienic features and the capacity to trap sweat and damp.

In the shower, your bath gel and shampoo act at a cellular level. They not only clean you better, they also contain a host of healthful new properties, targeted at your specific skin type. Nanotechnology can be found in anti-wrinkle creams, acne creams and shaving foam, greatly improving their effectiveness and the speed of results.

Breakfast time comes and the first thing you do is check the colour of the milk carton, which contains nanoparticles that change colour if the milk has gone off.

You set out for work: new forms of transport offer an easier ride. Vehicles are safer, with more resistant and flexible bodywork. Driving in the rain isn't as much of a bother as it used to be: cars have nanosensors to detect water on the road and the glass repels the drops, improving visibility. The windows also control the amount of light entering the vehicle, so you don't get blinded by the lights of oncoming vehicles.

Care for the environment is guaranteed too. With new energy sources, cars no longer need petrol. Indeed, they are driven by the energy created in the paintwork using solar nanocells. That's not all, though. Your mobile phone also has nanosensors to detect certain chemical substances in the air. These can then be cleaned away by the anti-bacterial properties of nanoparticles emitted by your phone.

When you get to work, you may find a water cooler with nanomolecules to increase your performance and, although it's Monday, the new ionised ventilation systems will soon cheer you up.

It's almost impossible for the battery in your mobile, your laptop or your e-book to run down, because they all use much longer-lasting (and eco-friendly) fuel cells.

Lunchtime comes and any possible deficiency in vitamins, oligoelements, etc. can be solved thanks to the nanotechnology incorporated in certain types of food, which you're bound to find in one of the restaurants in or around the office. And in a great revolution, you can choose from interactive drinks made to order!

If it's winter, you'll be kept warm with anti-cold fabrics containing nanoparticles, while in spring, new types of clothes trap the pollen and isolate bacteria to help prevent hay fever. In the world of textiles, too, fabrics have been improved: they can now be fireproof, change colour or fight unpleasant odour by using nanoparticles to trap the microbes. And of course, if you get egg on your tie, you don't have to take it to the laundry, because it's made from a stain-resistant fabric.

New nanotech materials are being used in the sports industry as well, to improve the performance of tennis rackets, bicycles, golf clubs and balls; protective helmets are much more resistant too.

And you need less time for housework, with self-cleaning surfaces, not only on furniture, but also in showers, dishwashers, ovens, etc., which will have incorporated nanoparticles to eliminate bacteria and rust.

Homes are more eco-friendly and consume less energy, thanks to the use of new materials that hold in the heat and a combination of new energy sources.

We hope that this and the other information in this book have helped give you a clearer idea of what nanotechnology is all about. The development of industries and strategic adaptation by business to these new developments will continue, and it will bear fruit when the market is ready.

6

Appendices

FTF members

Speakers

Brent Segal.
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Darío Gil.
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C.J.M. Eijkel.
Managing Director of the Mesa+ Research Centre, Twente University.
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Michael Moradi.
Executive director of Atomic Venture Partners, LP.
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Lawrence Grumer.
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Ren Ee Che.
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Country: Singapore.

Ivan K. Schuller.
Director of AFOSR-MURI, Nanosensors, University of California.
Country: United States.

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Gaspar Taroncher-Oldenburg.
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Country: United States.

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Marcelina Cancho Rosado.

Executive, Innovation Area.

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Glosary

A

Angstrom: Unit of measurement equivalent to one ten-billionth of a metre (0.0000000001 m), Abbreviated as Å, it is used mainly to represent the wavelengths of visible light. There are 10 million angstroms to a centimetre.

Atom: The term comes from the Latin *atomum* which in turn comes from the Greek ??????, 'indivisible'. It is the smallest possible particle of a chemical element that retains its identity or properties, and which cannot be divided using chemical processes. The atom consists of a positively-charged nucleus made up of protons and neutrons, together known as "nucleons", around which lies a cloud of negatively-charged electrons.

Atomic Force Microscope (AFM): The atomic force microscope (AFM) is a mechano-optical instrument capable of detecting forces at a level of nano-newtons. When a sample is analysed, it can continuously record the height on the surface of a probe or pyramid-shaped crystallised tip. The probe is joined to a microscopic cantilever just 200 µm in length which is highly sensitive to the effect of the forces. The atomic force can be detected when the point is very close to the surface of the test piece. It is then possible to record the minute deflection of the cantilever by means of a laser beam reflecting off the top of the cantilever. An auxiliary piezoelectric system moves the sample piece three-dimensionally (in the z-axis), while the tip regularly scans the surface. All movements are controlled by a computer. The instrument has a precision of under one nanometre and the viewing screen makes it possible to distinguish details on the surface of the sample piece with an amplification of several millions.

Atomic resolution storage: Devices that use individual atoms to represent bits of logic (0 and 1) for storing data.

B

Bionanotechnology: Branch of nanotechnology based on the use of biological structures such as the proteins ATP, DNA, etc. Often called "wet/dry technology", where the term *wet* refers to the biological components and the *dry* part is the engineering of inorganic nanoparticles. It is based on so-called "artificial cells" and is one of the most promising fields of nanomedicine.

Buckyballs/fullerenes: Nanostructures consisting of sixty atoms of carbon (their chemical name is C60) in a closed and perfectly

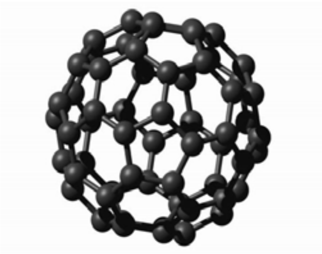


Illustration 34. Buckyball

Source: http://homepage.mac.com/jhgowen/research/nanotube_page/C60.jpg

symmetrical arrangement. They have extraordinary properties, especially as superconductors. Geometrically they are like an icosahedron, with a football-shaped structure. Superconductors buckyballs have the highest critical temperature found in organic compounds and in nanotechnology are associated with nanotubes. They were discovered by Robert F. Curl, Jr., Harold W. Kroto and Richard E. Smalley.

C

Catalyst: Substance (composite or element) that can speed up a chemical reaction, while remaining unaltered itself (they are not consumed during the reaction). This process is called "catalysis". Many catalysts act by increasing the surface area, thus allowing two or more chemical reagents to come together and unite or separate. Catalysts do not alter the final energy balance of the chemical reaction; they simply allow balance to be achieved at a greater or lesser speed.

Carbon nanofibres (CNFs): A carbon nanofibre is the same type of structure as a conventional carbon fibre, but with a nanometric size. Carbon nanofibres are a form of graphite in which the carbon atoms are grouped in thread-shaped structures with a diameter of between 50 and 400 nanometres. Carbon nanofibres are used mainly as a charge in a polymer matrix to form a nanostructured material known as a carbon *nanofibre nanocomposite.*

Chip: A chip is an electronic device formed on the surface of a small semiconductor silicon crystal, manufactured to perform a series of electronic functions in an integrated circuit.

D

Dendrimer: The word *dendrimer* comes from the Greek dendron ('tree') and the suffix *-mer* ('segment'). Dendrimers are built in the nanoscale from layers of monomers (a single molecule with the capacity to combine with identical or similar molecules) to create a tree-structure. The first layer of monomers, the nucleus, is known as "Generation 0". Dendrimers are studied in polymer chemistry. Their applications and functions include catalyzation and biology.

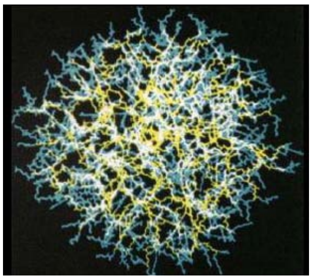


Illustration 35. Dendrimer
Source: www.ifmo.ru/mv/foto/ foto/nauka/dendrimer.gif

E

Electrode: An electrode is a conductor used to establish a contact with a non-metallic part of a circuit; e.g., a semiconductor, an electrolyte, a gas (in a neon light), etc.

Electron lithography: Lithography by means of electron beams. Used to build nanostructures of between 5 and 10 nanometres.

Electron: A light particle with a negative charge found in all atoms. Electron energy can be increased and electrons can even be removed from the atoms using certain ranges of light or by means of a collision. Electrons are responsible for many electrical phenomena in solid matter and plasmas.

F

FLOPS: In computer science, FLOPS stands for *Floating Point Operations Per Second*. The unit is used to measure a computer's performance, especially in scientific calculations that require a large number of operations. It is of particular interest in computing, since it allows users to work with decimal numbers in wide ranges, although decimal truncation is also used. Computers have a wide range of floating point rates and as a result, units larger than FLOPS are often used. Standard IT prefixes can be used for this purpose, to give megaFLOPS (MFLOPS, 10^6 FLOPS), gigaFLOPS (GFLOPS, 10^9 FLOPS), teraFLOPS (TFLOPS, 10^{12} FLOPS) and petaFLOPS (PFLOPS, 10^{15} FLOPS).

Focused Ion Beam (FIB): An FIB system operates in much the same way as a scanning electron microscope (SEM). It uses a beam of gallium ions to launch localised ionic attacks on materials and localised deposits of various materials. It makes it possible to view and create three-dimensional structures, controlling the processes with a precision in the tens of nanometres.

Fuel cell: Electrochemical device that continuously transforms the chemical energy from a fuel (hydrogen) and an oxidant (oxygen) directly into power and heat, without combustion. The electrical process makes the hydrogen atoms shed their electrons. It is similar to a battery in that it has electrodes, an electrolyte and positive and negative terminals. However, it does not store energy in the same way as a battery does. Because there is no combustion, fuel cells have fewer emissions and, because there are no moving parts, they are silent. They produce power through a combination of: hydrogen and oxygen, which they convert into water. This is their great appeal, since fuel cells produce clean energy that does not harm the environment.

Fullerenes: See *buckyballs*.

I

Integrated circuit: A block or chip containing all or nearly all of the electronic components necessary to perform a function. These parts are mostly transistors, but also include resistances, diodes, condensers, etc.

Intelligent materials: New generation of nanotech materials, whose properties can be controlled and changed on demand. It is one of the main lines of research in nanoscience, with applications in many industries (ranging from textiles to defence). Intelligent materials will be capable of changing colour, shape and electronic properties in response to changes and alterations in the environment or tests (light, sound, temperature, voltage, etc.).

L

'Lab-on-a-chip': The integration of micro apparatuses and nanofluids holds out the prospect of automating chemistry in a minute system. Through this nano-opening analyses and experiments can be carried out on the patient without the involvement of the lab technician.

M

Millipede: The millipede is a high-density data storage system being created by IBM. It is based on micromechanical systems (MEMS) manipulated using the atomic force microscope (AFM). Incisions are created in a polymer using the tip of the AFM. These incisions represent stored data bits which can be re-read or erased by the tip of the microscope. The polymers can be re-used thousands of times over. The millipede has a storage capacity of over 1 Terabit per square inch, far greater than the maximum capacity of a magnetic disc.

Molecular electronics: Any system of electronic appliances with atomic precision at the nanoscale, especially if it is manufactured with molecular components instead of the continuous materials found in today's semiconductor apparatuses.

Molecular production: Production using molecular machinery. Controls the product and its derivates molecule by molecule, by means of chemical synthesis. Molecular production promises to be more effective than traditional production. The products will be of greater quality, because they will be assembled from the smallest possible parts: atoms and molecules.
Molecule: The smallest amount of a substance that retains all its chemical properties. It is made up of atoms.

N

Nanite, nanobot or nanorobot: Also sometimes called a "nanoagent" , this is an imaginary machine or "nano robot" a few hundred nanometres in size built for specific tasks. The prototype for most of these (essentially futuristic) concepts is specific cells (for example, phagocytes that ingest external matter) and molecular cellular machinery (DNA self-reproduction process).

Nano: Extremely small measurement used in working with and manipulating molecular structures and their atoms. The suffix "Nano-" refers to dimension: 10 to the power of -9; i.e., 1 nanometre = 0.000000001 metres.

Nanoagent: A probe used to examine a cell, capable of perforating and explore individual living cells. Antibodies are placed on the sharp end. Once they have been inserted into the cell, these antibodies associate with the specific chemical substances the researchers want to study. The combination of the antibodies with the laser light at the end of the probe causes a reaction in these internal chemical substances, making them shine. Developments in nanoscale probe techniques are expected to revolutionise the detection and treatment of diseases allowing them to be combated at a molecular scale.

Nanobalance: A nanoscale weighing scales. It is small enough to weigh viruses and other particles at a sub-micron scale. For example, the resonance frequency of a mass located at the end of a nanotube changes. If the nanotube is calibrated, it is possible to measure the mass of the accompanying particle.

Nanocables: Solid cylinders (unlike nanotubes, which are hollow) with a diameter of between 10 and 100 nanometres. Nanocables can be defined as molecular structures with electrical or optical properties. Nanocables are used as semiconductors or light-emitting diodes (LEDs), depending on their chemical composition. They are one of the key components in creating electronic molecular chips. Easy to produce, they can be linked up in grids to form the basis for nanoscale logic circuits.

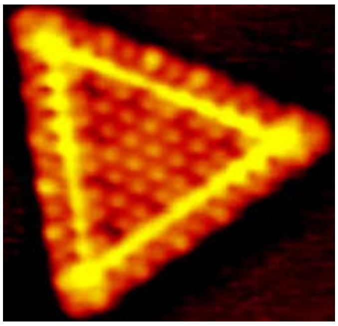
Nanocapsules: Structure in the form of a capsule or spherical particle with a diameter of under one micrometer.

Nanocatalysts: Groups of particles that can replace organic solvents, reducing industrial costs and pollution. The industry is investing in research in this new technology, which could provide an alternative to the present method used in fossil-fuel refineries. Nanocatalysts raise the chemical reaction capacity, prevent in particular the emission of carbon monoxide and are much less pollutant than today's energy sources. They can also be reused.

Nanocomposites: A lighter, harder and more rigid material at low temperatures than traditional thermoplastics. Nanocomposites are created by introducing a solid material into a plastic resin to make it stronger. Because there is less additive material, they recycle better than other thermoplastics.

Nanocones: Structures of graphite created from carbon. Some consider them to be the "buffers" of a nanotube, but they can also be seen as structures in their own right.

Nanocrystal: Nanoparticle containing anywhere between a few hundred and tens of thousand of regularly arranged atoms, in a crystallised structure. Because this crystallised arrangement has to end at the surface of the nanocrystal, the surface atoms have fewer "neighbours" than those in the nucleus. Nanocrystals must therefore be shaped in such a way as to minimise the spare energy or surface tension.



Ilustration 36. Nanocrystal
Source:http://www.nanotech-now.com/images/nanocrystal-large.jpg

Nanoelectromechanical systems (NEMs): Electromechanical systems built using nanoscale components. Today, most NEMs are natural, such as ribosomes or mitochondria.

Nanoelectronics: Electronics applied at a nanometric scale that marks a development towards molecular and quantum computers. Intensive research is required at this scale, given that it crosses the threshold into quantum physics with a change in the properties and results of the operations performed.

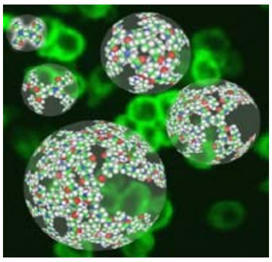
Nanofluids: Refers to the use of silicon nanostructures which can analyse individual molecules with characteristics that are comparable, in terms of size, to DNA and proteins.

Nanomaterials: Nanoscale materials with structural characteristics of a dimension of between 1 and 100 nanometres. By manipulating their characteristics at an atomic scale new properties can be created which are not found in the same materials at a larger scale.

Nanomedicine: One of the most promising areas of potential new developments is in technological applications for medicine. It could be defined as the branch of nanotechnology that will allow diseases to be cured from inside the body at a cellular or molecular scale.

Nanooptics: Nanoscale interaction between light and matter. The reason for linking optics to nanoscience and nanotechnology is that developments in nanoscale optics are offering a host of fields of interest, given that light energy of is based on a range of electronic and vibratory transitions of matter. The interaction of light and matter gives unique information on the structural and dynamic characteristics of matter. These unique spectroscopic capacities are hugely important for studying solid state biological nanostructures. On the technological side, there are issues such as nanolithography and high-density optical data storage. The area of basic sciences includes subjects such as atom-photon interactions and their potential uses for experiments in intercepting and manipulating atoms.

Nanoparticle: Particle with a size of less than 100 nanometres. The exceptional properties of nanoparticles are largely due to the material on the surface, which does not have the same properties as the same material in larger volumes. Because they are so small they can reflect light instead of absorbing it. Huge advances are being made in nanoparticles, with new discoveries almost every day on many fronts. This is the case of biosensors, iron-based nanoparticles used to fight cancerous tissues, etc. In general, bio-medicine and biotechnology are two very promising fields in terms of their potential applications.



Ilustration 37. Nanoparticle
Source: http://www.cienciaviva.pt/rede/space/home/nano.jpg

Nanoporous materials: Materials manipulated at the nanoscale; the size of their pores has been altered to almost perfect levels. It will also be possible to manipulate their physical and chemical characteristics. They will be used especially in medicine and pharmacy.

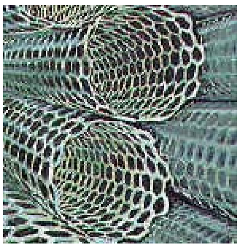
Nanoscience: Science that studies the behaviour and manipulation of materials at atomic or molecular scale to understand and exploit their properties, which are significantly different to the properties of the same materials at a larger scale.

Nanosensors: Probe or sensor with nanometric accuracy. They are currently experiencing rapid development thanks to developments in nanotechnology. Because of their many applications, nanosensors can also be said to have the potential to trigger revolutionary changes in nearly all areas of science and technology.

Nano solar cells: The smallest electrical device, it generates power when exposed to the light. Not only will it be possible to integrate it with other construction materials, it also promises cheap production costs which will help make solar power a cheap and feasible alternative.

Nanotechnology: An interdisciplinary science that encompasses scientific and technological activities carried out at atomic and molecular scale and the new scientific principles and properties that can be understood and controlled when operating at this scale.

Nanotube: Cylindrical structures of sheets of graphite, one hundred times harder than steel and six times lighter. They also have other properties: they are as efficient at conducting heat as diamonds, can be just as effective as copper at conducting electricity or take on the properties of semiconductors. Some nanotubes are closed at the end in a half-sphere of 'Fullerenes', while others are open-ended. There are single-wall and multi-wall nanotubes (SWNTs and MWNTs, respectively). They are only a few nanometres in diameter, but can be up to a millimetre in length. This very high length-width ratio is unprecedented.



Ilustration 38. Nanotube
Source: http://www.hispamp3.com/images/diseno/nanotubo.jpg

O

Optoelectronics: This is the discipline that converts power into optical energy (light) or vice versa. Examples: photocells, solar cells, LEDs (light emitting diodes), etc.

P

Photolithography: Photolithography (also known as "nanolithography") is a process that is very closely related to conventional lithography and photography. Photolithography is a process used to build semiconductors. The purpose is to transfer a pattern from a mask to the surface of a substratum. A common substratum used is a silicon crystal chip, but it is also possible to use glass, sapphire or metals. The form and size of the object created have been accurately controlled using lithography. The disadvantage is the need to use a substratum and the difficulty of creating figures that are not flat.

Polymers: Substances (macromolecules) with a high molecular weight: formed by the repetition of simple chemical units called "monomers". The molecules of polymers can be joined in lines or branches to form three-dimensional reticules.

Q

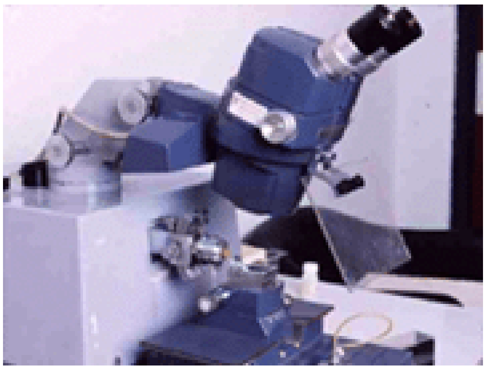
Quantum computing: Area of study that focuses on developing computer technology based on the quantum theory. According to the laws of quantum physics (atomic and subatomic), the quantum computer would have a major capacity for data processing because it would be capable of being in multiple states at the same time and of carrying out tasks using all possible permutations at the same time.

Quantum dot: A quantum dot is a particle of matter so small that the addition of a single electron would change its properties. The *quantum* attribute serves to remind us that the behaviour of the electron in such structures needs to be described in terms of quantum theory. Quantum dots are sometimes called single-electron transistors, quantum bits or *qubits*.

S

Scanning electron microscope (SEM): In a scanning electron microscope, the sample is coated with a thin layer of metal and scanned with electrons emitted from a cathode. A detector measures the number of electrons emitted giving the intensity of the sample surface and producing three-dimensional figures, which can be projected in a television picture. It has a resolution of between 3 and 20 nanometres, depending on the microscope. Invented in 1981 by Ernst Ruska, Gerd Binnig and Heinrich Rohrer, it allows a closer view of the atomic world.

Scanning Tunnelling Microscope (STM): Machine capable of revealing the atomic structure of particles. It has a tip so sharp that it ends in a single atom. A weak electric current flows through this tip, which is brought close to the material to be studied until it is located less than a nanometre (a billionth of a metre) away, maintaining a power difference of one volt with the sample. As it crosses the surface, the tip moves up or down, reproducing the atomic topography of the piece. The techniques applied are also known as "scanning tunnelling" techniques and are associated with quantum mechanics. They work by using the capacity to trap escaping electrons in this tunnel effect, to give a high-resolution image of the atomic structure of the matter, in which each atom can be distinguished. Once the surface of the object has been scanned and by making a map of the distance between various points, a three-dimensional image is generated. The scanning tunnelling microscope has also been used to change the molecular composition of substances. This is a fundamentally important instrument in the field of nanotechnology and nanoscience. It was invented in 1981 by Binning and Rohrer, who were awarded the Nobel Prize in 1986 for their discovery.



Ilustration 39. Scanning Tunnelling Microscope
Source: http://www.profes.net/rep_imagenes/Noticias/Microscopio_efecto_tunel.gif

Self-assembling machines: Production of nanoscale molecular structures. A set of molecules acts as a "molecular machine" capable of building other molecular structures. In real-life, this problem has only been resolved in theoretical terms.

Self-assembly: A process that starts with a nanometric structure - such as a molecule- and, by means of a process of assembly or self-assembly, goes on to create a larger structure. This approach, which some consider to be the one "true" nanotech approach, has made it possible to control matter very precisely.

Semiconductors: *Insulators, such as germanium and silicon, which are transformed into conductors by adding certain impurities. They are used to make transistors, chips and derivates. They act as conductors or insulators depending on the electrical field they are in. The most commonly-used semiconductor is silicon.*

T

Textronics: Term coined from textile and electronics. It refers to new tissues created using nanoelectronic reengineering with astonishing properties: "intelligent fabrics" capable of changing colour, reacting to cold or heat, etc. It is calculated that 20% of European textiles will incorporate nanotechnology by 2010.

Transistor: Small electric devices that can be found in many appliances from radios to robots.
They have two essential properties:

1. They can amplify an electrical signal.
2. They can be switched on and off, letting the electric current through or not as necessary.

U

Ubiquitous computers: With nanometric miniaturisation it is likely that powerful computers will be integrated into wrist watches and mobile phones with something that today's computer do not possess-a hard disk. Technological developments are expected to provide hard disks just one square centimetre in size, with a capacity running into gigabytes.

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Prizes for nanotechnology

The work of researchers in the field of nanotechnology has been acclaimed by the internatio-nal community, starting with the 1965 Nobel Prize which went to Sin-Itiro Tomonaga, Julian Schwinger and Richard P. Feynman for their work on quantum electrodynamics. This had enormous repercussions for subsequent studies. The possibility of arranging atoms was first raised nearly forty years ago.

One of the three laureates, the American Richard P. Feynman, created further prizes for the advancement of nanoscience, the Feynman Prizes. He offered $1,000 dollars out of his own pocket to anyone who could build an electric motor in a space of 0.4 mm cubed (the prize was won in 1960) and another $1,000 to the first person to reproduce a text at a scale of 1/25,000, sufficient to allow the entire *Encyclopaedia Brittanica*, to be reproduced on the head of a pin (1985, with a page of Charles Dickens's *A Tale of Two Cities*).

The Feynman Prizes are now awarded by the Foresight Institute. Every year prizes of 5,000 or 10,000 dollars, plus the much coveted scientific recognition, goes to the researchers whose studies have significantly contributed to Feynman's nanotechnological goal: to build preci-sion atomic products using systems of molecular machines.

In 1996 the "Feynman Grand Prize" was created to encourage scientists and engineers to design and build a nanometric robot arm with specific functions set out in the rules of the competition. The prize has not yet been won, despite the incentive of a quarter of a million dollars.

There follows a list of the most significant prizes in the history of nanotechnology:

Notes

Nobel
1965
Physics
Sin-Itiro Tomonaga, Julian Schwinger and Richard P. Feynman.
For their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles.

Nobel
1986
Physics
Ernst Ruska, Gerd Binnig and Heinrich Rohrer.
For his fundamental work in electron optics, and for the design of the first electron microscope and for their design of the scanning tunneling microscope.

Nobel
1996
Chemistry
Robert F. Curl, Jr., Sir Harold W. Kroto and Richard E. Smalley.
For their discovery of fullerenes, a new form of the carbon element in which the atoms are arranged in a closed form.

Nobel
2001
Physics
Eric A. Cornell, Wolfgang Ketterle and Carl E. Wieman.
For the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates.

Feynman
1993
Dr. Charles Musgrave.
For his work on modeling a hydrogen abstraction tool for nanotechnology.

Feynman
1995
Dr. Nadrian C. Seeman.
For his pioneering experimental work on the synthesis of 3-dimensional objects from DNA.

Feynman
1997
Experimental
Team from IBM Research Division Zurich Research Laboratory and the French state research laboratory CEMES-CNRS.
For work using scanning probe microscopes to manipulate molecules.

Feynman
1997
Theoretical
Team at the NASA Ames Research Center.
For their work in computational nanotechnology.

Feynman
1998
Theoretical
Ralph Merkle and Stephen Walch.
For their computational modelling of molecular tools for atomically-precise chemical reactions.

Feynman
1998
Experimental
M. Reza Ghadiri.
For groundbreaking work in constructing molecular structures through the use of *self-organization*, the same forces used to assemble the molecular machine systems found in nature.

Feynman
1999
Theoretical
Team at Caltech, led by William Goddard III.
For their work in modelling the operation of molecular machine designs. Proposed designs for future molecular machine systems can be tested today on powerful supercomputers using sophisticated programs that accurately model the laws of chemistry.

Feynman
1999
Experimental
Dr. Phaedon Avouris.
Leader in the development of carbon nanotubes for potential computing device applications. This work is considered directly on the pathway to molecular-scale computation-necessary for the computer industry to stay on the Moore's Law curve, which predicts atomic-level precision before 2015.

Feynman
2000
Theoretical
Dr. Uzi Landman.
For his pioneering work in computational materials science for nanostructures. He has given computational sciences a scientific base on the nature and properties of matter at the nanoscale. Such computer modelling is essential in predicting what could be built at the molecular level, reducing time spent on expensive "wet" lab experiments.

Feynman
2000
Experimental
R. Stanley Williams, Philip Kuekes and James Heath.
For building a molecular switch, a major step toward building entire memory chips that are just a hundred nanometres wide, smaller than a bacterium.

Feynman
2001
Theoretical
Mark A. Ratner.
For his contribution to the development and success of nanometre-scale electronic devices. His work has been of key importance in understanding the mechanisms and magnitudes of conduction in molecular junctions, and in particular, the nature of charge transport in single-molecule nanostructures.

Feynman
2001
Experimental
Charles M. Lieber.
For his pioneering experimental work in molecular nanotechnology. He has created new tools for molecular nanotechnology.

Feynman
2002
Theoretical
Don Brenner.
For his significant collaboration in advancing computer modelling of molecular machine systems and for the design and analysis of components likely to be important in future molecular manufacturing systems.

Feynman
2002
Experimental
Chad Mirkin.
For opening up new possibilities for the fabrication of molecular machine systems. By selectively functionalizing nanoparticles and surfaces, particularly with DNA, he enabled the self-assembly of entirely new structures.

Feynman
2003
Theoretical
Dr. Marvin L. Cohen and Dr. Steven G. Louie.
For their contributions to the understanding of the behaviour of materials, especially properties like structure, surface conditions, and interactions with other materials.

Feynman
2003
Experimental
Dr. Carlo Montemagno.
For his pioneering research into methods of integrating single molecule biological motors with nanoscale silicon devices.

Feynman
2004
Theoretical
Dr. David Baker and Dr. Brian Kuhlman.
For their development of RosettaDesign, a program that has a high success rate in designing stable protein structures, and a milestone on a path to molecular machine systems. Professor Baker has altruistically made RosettaDesign freely available to the research community.

Feynman
2004
Experimental
Dr. Homme Hellinga.
For his achievement in the engineering of atomically precise devices capable of manipulating other molecular structures. As part of his contribution to computationally directed protein engineering, he has built an enzyme.

Feynman
2005
Theoretical
Dr. Christian Joachim.
For developing theoretical tools and establishing the principles for design of a wide variety of single molecular functional nanomachines.

Feynman
2005
Experimental
Dr. Christian Schafmeister.
For developing a novel technology synthesizing macromolecules of intermediate sizes (between 1000 and 10,000 Daltons) with designed shapes and functions.

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