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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.

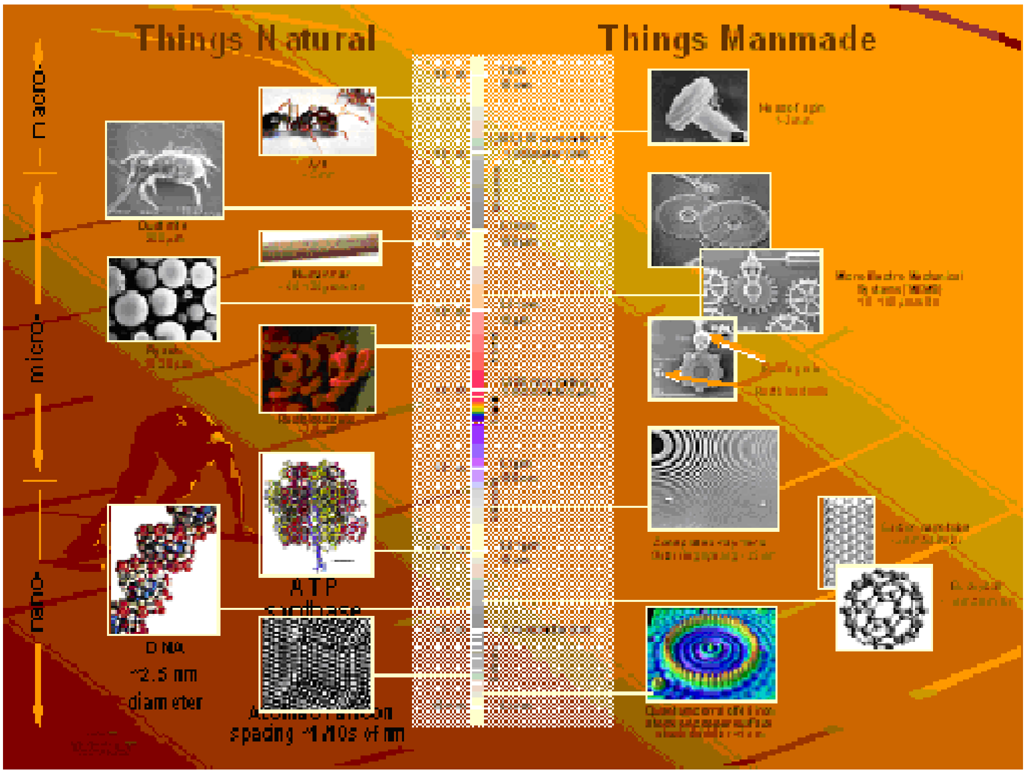

Illustration 1. Natural and artificial structures
Source: presentation at the FTF by Dr. Brent M. Segal.

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.

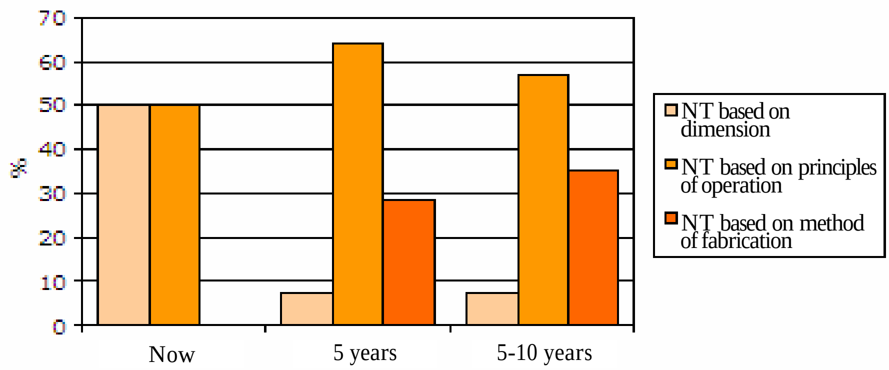


Illustration 2. Development of areas of research
Source: own preparation.

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).

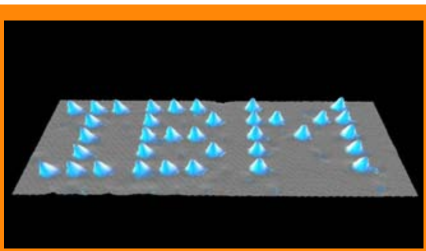
The first of the two prizes was claimed less than one year after he gave his lecture, but it took another 26 years before anyone won the second of the two.

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.

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



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

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).

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).

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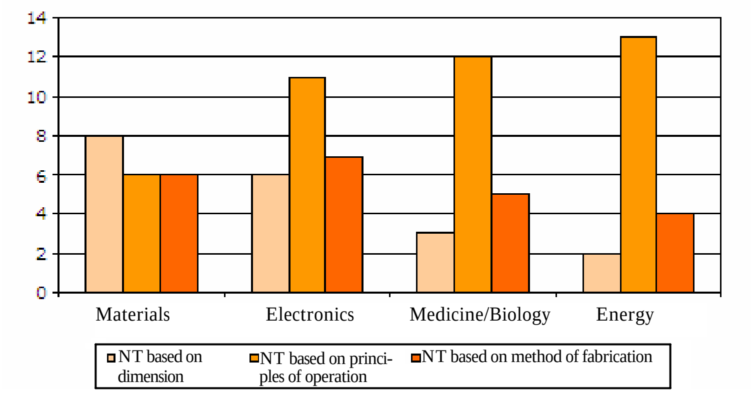


Illustration 4. Trend in nanotechnology in each area of application
Source: own preparation.

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.

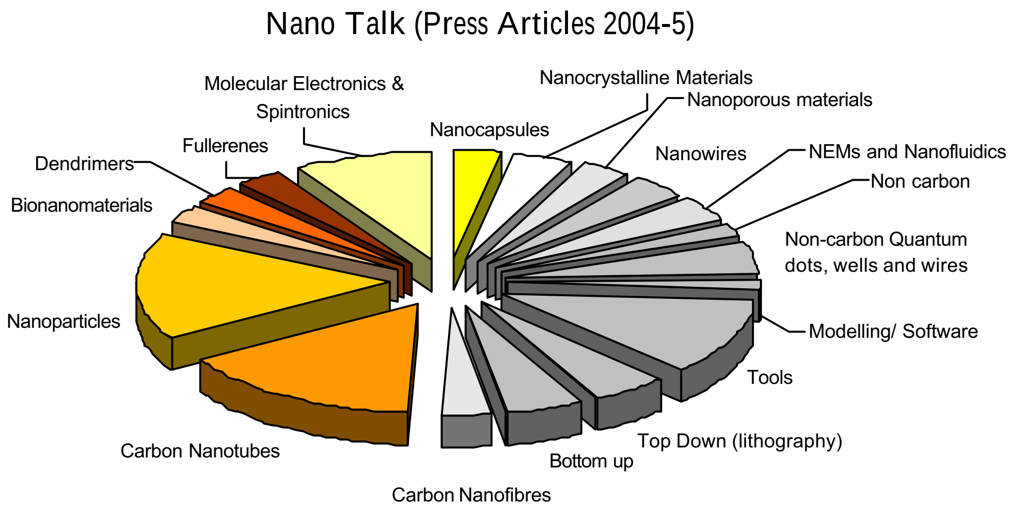


Illustration 5. Terms published in the press on nanotechnology
Source: Científica.

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 *bucky-balls* 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

Notes

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.

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

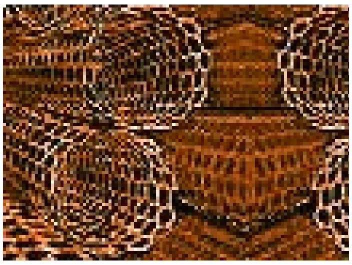
The electronics industry has long been immersed in a process of miniaturisation. Moore's Law, formulated in 1965, states that the number of transistors in the average computer will increase approximately twofold every 18 months. The law still holds today, but the limits of silicon-based technologies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

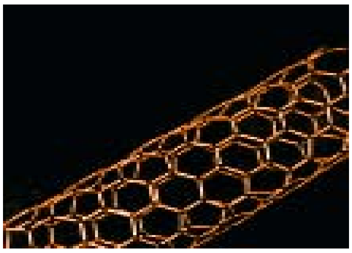
Primary governmental support to nanoelectronics

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.

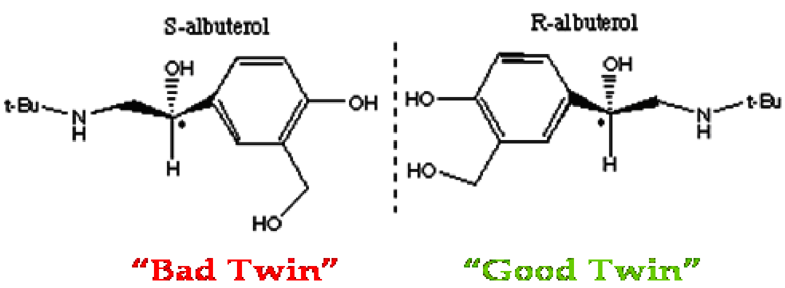


Illustration 6. Chiral drugs. *Source: presentation given at the FTF by Brent Segal.*

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 nanobiological 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 nanomedicine.

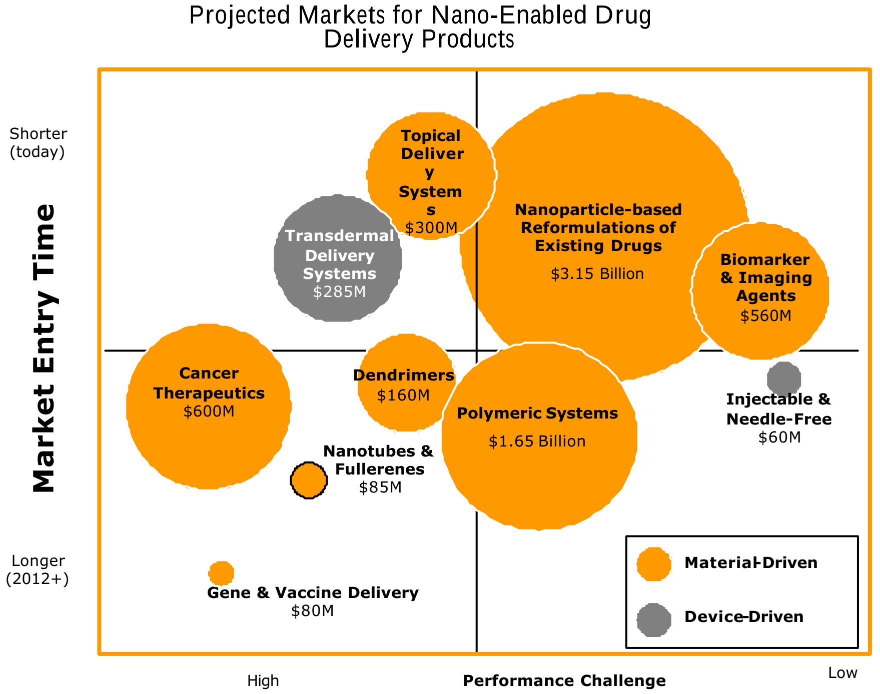
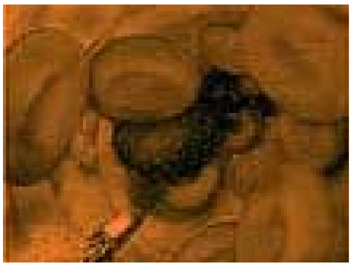


Illustration 7. Projected markets for nano-enabled drug delivery products
Source: presentation given at the FTF by Michael Moradi.

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/).

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.

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

■ *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: s*upercapacitors 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

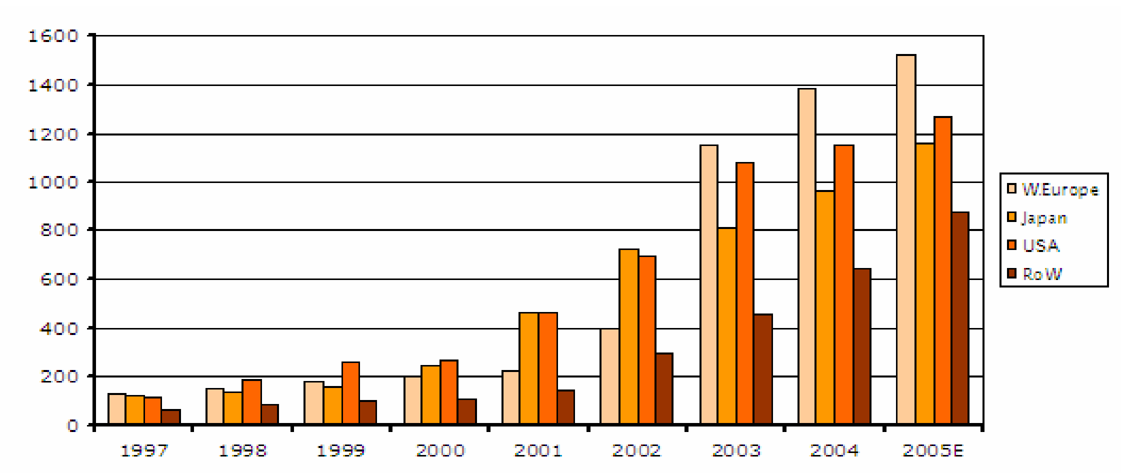


Illustration 8. Government annual spending on nanotechnologies (1997-2005) *Source: Cientifica.*

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.

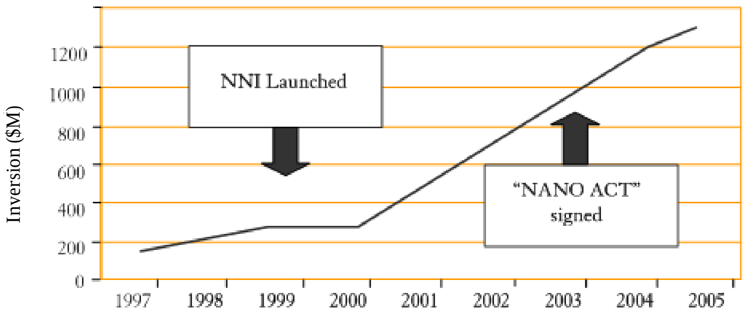


Illustration 9. U.S. Nanotech R&D spending
Source: presentation by Dr. Brend M. Segal at the FTF.

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

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.

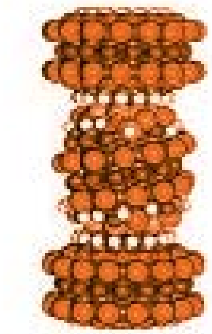
Responsibility for implementing the national nanotechnology programme lies with the National Nanotechnology Coordination Office with a Director and full-time staff. The guidelines and investigation to be pursued are established by the Advisory Panel.

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)

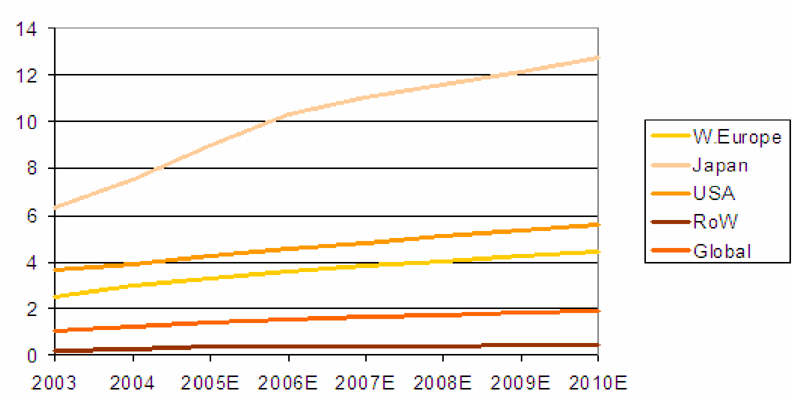


Illustration 10. Government spend per capita.
Source: Científica.

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.

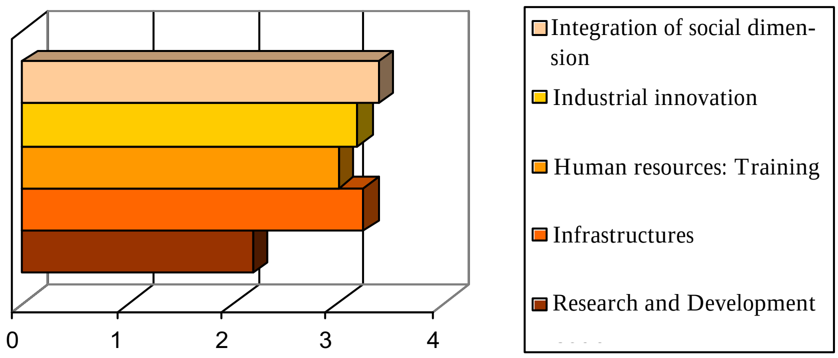
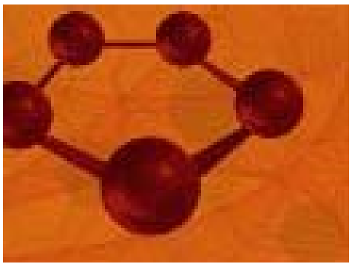


Illustration 11. FTF experts' assessment of the priority of European initiatives
Source: own preparation.



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.

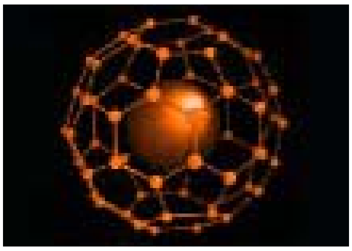
- In *Galicia*: NanoGalicia is an initiative of the Galician government.

- 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.