CENTRO STUDI SUL FEDERALISMO

RESEARCH PAPER

NANOTECHNOLOGIES APPLIED TO ENVIRONMENT: WHERE IS EUROPE NOW?

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Abstract

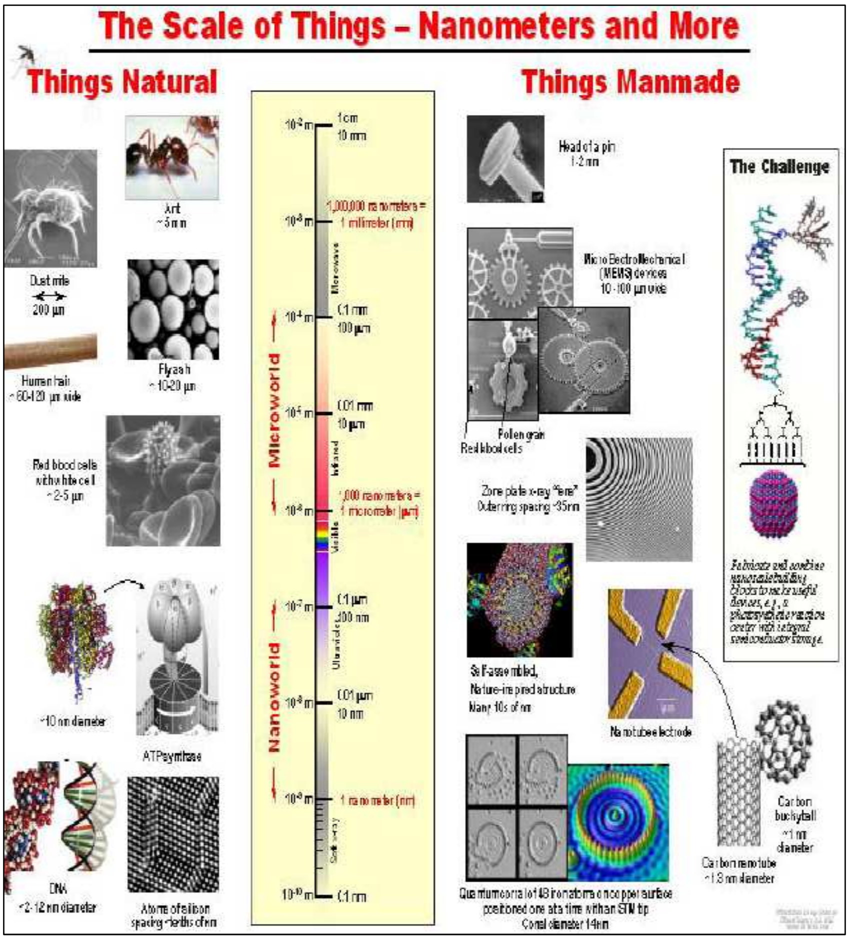
Nanotechnology is a key technology for the future of Europe in tomorrow's global knowledge-based economy. It potentially has large social and economic benefits. "Nanotechnology is an area where Europe is an acknowledged world leader. This is an opportunity we must grasp with both hands," said European Science and Research Commissioner Janez Potočnik.

In this paper we explain what a nanotechnology is and we analyze some beneficial applications to the environment and some potential risks. We ask ourseves if the European Union is going in the right direction to catch up the challenge with nanotechnology. To give an answer to this question we investigate its funding and its scientific performance. We will also try to make a comparison between the EU and other countries, in particular the US, where possible.

1. What is a nanotechnology?

The term nanotechnology was introduced by Taniguchi in 1974 to describe ultra-fine machining, or more specifically the precision manufacture of mechanical parts with finishes and tolerances in the nanometer range. *Nano* is of Greek origin and means *dwarf*. A nanometer is one billionth of a meter, or: 10^{-9} m. Taniguchi defined the range of nanotechnology as being from 0.1 nanometers (nm) to 100 nm. We may give you an idea about how small it is by considering that a human hair is between 10,000 and 50,000 nm in diameter and that ten hydrogen atoms in a line measure about 1 nm. A nanometer is a thousand times smaller than a red blood cell, or about half the size of the diameter of DNA (European Commission Community Research, 2004). Figure 1 shows a diagram indicating relative scale of nanosized objects.

Figure 1. Diagram indicating relative scale of nanosized objects



Source: National Nanotechnology Initiative website, courtesy Office of Basic Energy Sciences, U.S. Department of Energy.

In the past decade, the term “nanotechnology” has been broadened well beyond the original meaning, which limited it to the fields of physics and precision engineering. It includes now a variety of other topics and it is applied to “almost any materials or devices which are structured on the nanometre scale in order to perform functions or obtain characteristics which could not otherwise be achieved” (Meyer, Persson, Power, 2001). Nanoscience is now regarded as truly multidisciplinary and has applications in many fields of science and areas that impact our lives: biology, electronics, materials, medicine, but broadly encompasses research into the principles and properties arising at the nano-level, that is the level of atoms and molecules. These can differ significantly from the larger scale, which is why this new area of science has emerged and it is expected to lead to innovations that can contribute towards addressing many of the problems that contemporary society is facing.

Nanotechnologies make possible better products and services, helping to improve citizens' quality of life and environment. Many nanotechnology-based products are already on the market, including new electronics and chemistry components, intelligent textiles, novel functional surface coatings, new diagnostic and drug delivery systems, breakthroughs in tissue regeneration, and ever faster and more accurate sensors. Some other uses of nanotechnology are described below:

- microchips which allow laboratory experiments to be performed on a miniaturized scale will enable more efficient and more extensive research initiatives;
- nanoscale carriers can deliver drugs to specifically targeted parts of the body, leading to more effective disease treatment;
- some nanoparticles can assist chemical reactions which fulfill functions such as removing chemical contaminants from soil and water, producing alternative energy sources to fossil fuels, and enabling less wasteful or polluting production processes;
- nanofilters can be used to improve purification and desalinization of water;
- materials called nanostructured aerogels can be used to improve the strength and robustness of buildings in earthquake and hurricane-prone regions;
- nanotechnological innovations have enabled improvements in computing hardware with increased data storage and faster processing times;
- nanotechnology has also been applied to many consumer goods including tennis racquets (increased strength) and tennis balls (increased durability), eye glasses and cars (protective coatings) and sunscreen (reduced discoloration) (Chow).

2. Nanotechnology and environment: some beneficial applications and potential risks

The relationship between new technologies and the environment is a complex one. On the one hand, various human technologies, ranging from “low” technologies like slash-and-burn agriculture, to “high” technologies like nuclear weapons, have done more than their share of environmental harm. On the other hand, new technologies are often cleaner and safer than the older technologies they replace, and may offer ways of remedying environmental harms previously thought of as beyond help (Reynolds, 2001).

Described as “a new industrial revolution”, nanotechnologies have the potential to produce sweeping changes to many aspects of everyday life. Their use might be particularly beneficial in the area of environment (Depledge & Owen, 2005). It is thus not surprising that the EU have focused so much attention on nanosciences, that may represent a powerful instrument to reach one of the cornerstone of any EU action plan and of the pillars of the Lisbon Strategy: the sustainable development (Péro, 2004).

“Green nanotechnology” has two goals: production processes and products. In fact it could deliver cleaner, safer, more competitive production processes (clean production, pollution prevention, environmentally benign manufacturing), as well as smarter, more durable and more user-friendly products. This could provide innovative answers to the triple challenge of sustainable development: how to fuel economic growth, while preserving the environment, and at the same time enhance the safety, security and quality of life of the citizens.

Green Nanotechnology makes use of the principles of green chemistry, green engineering and industrial ecology to make nanomaterials and nano-products without toxic ingredients, at low temperatures using less energy and renewable inputs wherever possible, and using lifecycle thinking in all design and engineering stages.

In particular environmental beneficial nanotechnologies may be divided in: *monitoring*, *remediation and pollution*, *resource saving*.

2.1 Monitoring

The ability to detect the presence of pathogens or toxic agents in our environment is the first step towards taking remedial action. While there are many monitoring devices for different agents, these are often expensive, bulky (or non-portable) or relatively insensitive.

Advances in nanotechnology may be able to provide more sensitive detection systems allowing environmental changes to be detected earlier, and ambient sensor networks allowing multiple environmental parameters to be monitored continuously (e.g. pollution levels, climatic conditions).

2.2 Remediation and Pollution

Our reliance on fossil fuels for energy and transport, and the by-products and waste from manufacturing industries all have a major impact on the environment, in some cases leaving land and bodies of water unsuitable for any other use, and in worst cases destroying whole ecosystems.

Nanotechnology may offer solutions both for cleaning up polluted sites and to prevent pollution like filters, etc (Nanoforum and the Institute for Environment and Sustainability, 2006). In fact researchers aim to use nanotechnology to provide efficient and effective filters for water and air, leading to reduced pollution. A membrane that can purify water and is also self-cleaning to avoid contamination should be available in the near to medium-term. Improved catalysts, composed of nanoparticles, are already in use in petrol and chemical processing, resulting in less waste in these processes.

Food, water and environmental research can advance via nanotechnology based developments including tools to detect and neutralise the presence of micro organisms or pesticides. The origin of imported foods could be traced via novel miniaturised nano-labelling. Nanotechnology research is forming part of the quest to prevent and reverse environmental damage (Geldart Wood; & Jones, 2003).

Another potential application of environmental molecular analysis is in understanding the atmospheric cycling of chemical pollutants, and the fundamental physical properties and reaction rates of gases, aerosols, and surfaces (Sharpe, 2002)

2.3 Resource Saving

Nanotechnology offers resource saving through improvements in efficiency for renewable energy sources (such as solar cells, thermoelectric devices, fuel cells); energy storage (such as rechargeable batteries and supercapacitors, hydrogen storage); reduced material consumption (e.g. providing lighter and/or stronger construction materials, or increasing the specific activity of functional materials); and the possibility of using alternative (more

abundant) materials (e.g. using nanostructured metal oxides instead of rare metals for catalysts). Ultimately, this could mean fewer emissions, less waste, and a lower demand on limited resources.
We focus now on energy production and storage. They can benefit from, for example, novel fuel cells or lightweight nanostructured solids that have the potential for efficient hydrogen storage. Nanoscale circuitry could be more efficient, offering enhanced electrical conductivity with reduced heat loss. Efficient low-cost photovoltaic solar cells (e.g. solar "paint") are another focus of nanotechnology development, with the ultimate aim being highly efficient, cheap, lightweight, possibly flexible, solar cells made from plastics. A breakthrough in this field is predicted to occur by 2020. Over fifty years, numerous studies have been performed on different design aspects and performance characteristics of photovoltaic (PV) cells with a common goal of producing fully integrated PV modules to compete with the traditional energy sources. A relatively new field of nanotechnology has opened up new and promising possibilities to improve environmental quality and economic prosperity. Developments in nano-tech solar cells via nanotubes, quantum dots, and hot carriers could reduce the cost of PV cells and modules for bulk power generation as well as improve the cell conversion efficiency. Energy savings are anticipated via nanotechnological developments that lead to improved insulation, transport and efficient lighting. Perhaps the most promising application in both the environmental and energy areas is the development of fuel cells, with many different uses. Research is being undertaken into the effectiveness of carbon nanotubes at storing hydrogen; these have the potential to power cars, amongst other things, with water as the only emission, although this is some way from commercialisation. Biomimicry is one key element in this research, as scientists attempt to copy plants' photosynthesis mechanism. The conversion of sunlight to hydrogen would bring together photovoltaics and biomimicry, and should be possible in the medium-term. Taken together, improvements in sources of renewable energy, with the development of storage of gaseous hydrogen and the improvement of fuel cells, could lead to a viable 'hydrogen economy' in which the energy needs of society were no longer reliant on fossil fuels.

What is very noticeable is the almost complete absence of scientific literature on environmental toxicity or exposure to allow the undertaking of even the most basic assessment of potential environmental and human health risks associated with environmental exposure to free, engineered nanomaterials (Depledge & Owen, 2005). It is not trivial to wonder if these substances, some of which we may currently think of as being quite benign, are actually more toxic, more mobile, more persistent than the others. In other words if they are more harmful to environment and human health (Rickerby & Morrison, 2007).

However we need to know whether our knowledge is sufficient to predict that the benefits outweigh any risks of such applications. The physical (size, shape, surface area) and chemical characteristics of nanoparticles determine their reactivity and ultimately their effect on living organisms; however it is still unclear how we can measure these parameters and how we can determine any potential environment and health impacts.

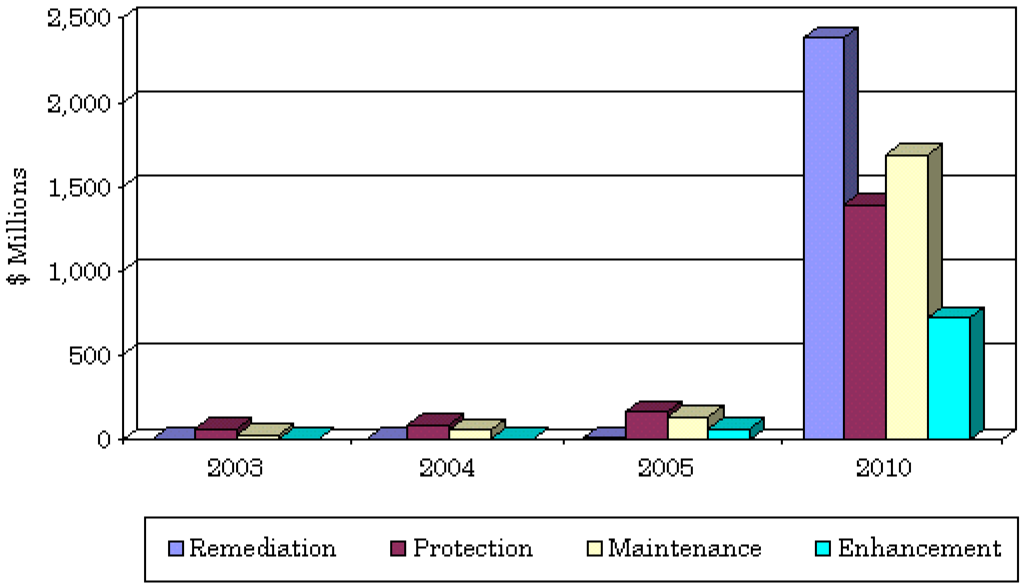
At the same time, critics warn of dangers such as terrorist use of weapons based on nanotechnology, Although there is no immediate evidence for such dangers, decision makers agree that in order to gain public support, there is a strong need for an informed debate about the safety of products at the nanoscale, how future advances can be monitored and controlled, and who may profit from them (US EPA, 2007).

The Scientific Committee (SCENIHR) report of October 2005 gives indications of major knowledge gaps and that modified test schemes are needed for materials in the nanoscale. In particular, there is a severe lack of knowledge concerning the environmental impacts. From a regulatory perspective, nanomaterials fall under legislation that was developed for their bulk materials, despite the fact that nanomaterials have novel properties which is likely to affect risk- or safety assessment methodology, standards etc. (Nanoforum and the Institute for Environment and Sustainability, 2006). We will cope with these issues in paragraph 5.

3. The US - EU race in funding

The US has developed a specific programme for nanotechnology applied to environment from 2004, when the Environment Protection Agency (EPA)'s Science Policy Council formed a cross Agency Nanotechnology Workgroup to develop a white paper examining potential environmental applications and implications of nanotechnology (US EPA, 2007).
Graph 1 shows US funding for nanotechnology in environmental application for remediation, protection, maintenance and enhancement from 2003 with forecasts for 2010.

Graph 1. Public investments in nanotechnology applied to environment in the US



Source: BCC Research, Frank Boehm, 2006

It seems that the increase in investments and the growth of the sector will be sizeable.

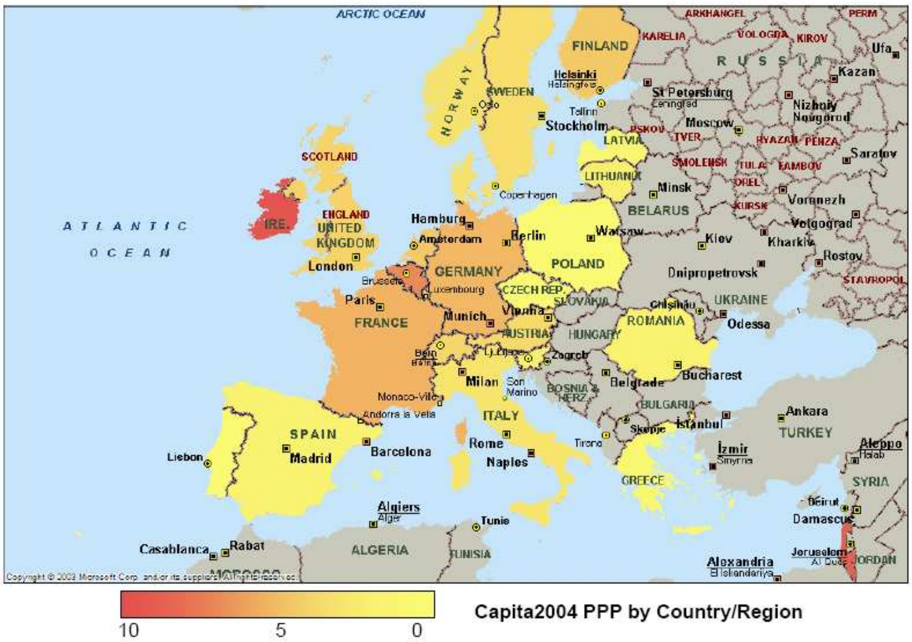
The European Union has not had a specific research initiative on nanotechnology and the environment until recently. There are some major European research projects in this area and it has been generally recognized that nanotechnology offers significant opportunities for improving the environment. The European Commission and Nanoforum have recently (2006) jointly organized a workshop to examine the potential impacts of nanotechnology on the environment (http://www.nanoforum.org). Its purpose was to discuss ways in which nanotechnology could be used for the benefit of the environment, while at the same time remaining aware of the potential risks (Morrison & Rickerby, 2007). This year the "EuroNanoForum 2009: Nanotechnology for Sustainable Economy" has been organized as official events of national Presidencies of the European Union and supported by the European Commission through the Industrial Technologies programme. The meeting has addressed the contribution and challenges of nanotechnology research for a sustainable development of European industry and society, such as the need for reduction in carbon emissions and fossil fuels dependence, the substantial increase in energy demand and material production sustainability and efficiency, pollution control, clean water management and sustainable quality of life of the European citizen (http://www.euronanoforum2009.eu).

Since in our research we cannot focus just on investments on nanotechnologies with environmental applications, because there are no data on the EU, we will take into account nanotechnology as a whole.

The European Commission funding for nanotech research has increased considerably. From the €120 million available under the 4th Research Framework Programme (FP4), the funding for nanosciences and nanotechnologies (N&N) increased to €1.4 billion in FP6 (2002-2006), for 550 projects, accounting for one third of total public funding for nanotechnology in Europe. The budget earmarked in the FP7 (2007-2013) is €3.5 billion. Under FP7, EC funding for nanotechnologies and nanosciences is expected to increase significantly. The average yearly funding is likely to be more than double that in FP6. In addition, the Risk-Sharing Financing Facility established by the Commission jointly with the European Investment Bank should provide access to new funding sources. Broadly speaking priority targets include fundamental and industrial research, human resources, nanotechnology-specific infrastructures, safety and communication.

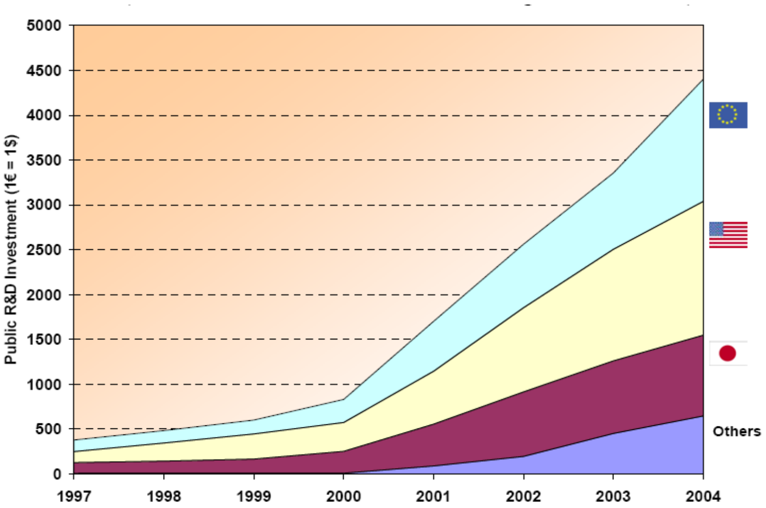
Figure 2 shows the European per capita public expenditure in 2004 (PPP corrected) by country, while Figure 3 the evolution of worldwide public expenditure.

Figure 2. European per capita public expenditure in 2004 (PPP corrected)



Source: European Commission, Unit G4 Nanosciences and Nanotechnologies European Commission, Research DG (2005), Some Figures about Nanotechnology R&D in Europe and Beyond

Graph 2. Evolution of worldwide public expenditure



Source: European Commission, Unit G4 Nanosciences and Nanotechnologies European Commission, Research DG (2005), Some Figures about Nanotechnology R&D in Europe and Beyond

The Eastern and Mediterranean countries are, as expected, the ones that invest the least in nanotechnology, while northern countries have an higher propensity in investing in this innovative field. Looking "globally" we see that the EU is the world leader in public funding, followed by the US and Japan. All over the world there has been a significant increasing in funding since 2000.

Private investment in nanotechnology R&D (that comes from two primary sources: corporations and venture capital investors) remains behind that in the US and Japan with an annual average of the order of € 20-40 million, and this level appears to have been maintained in 2008 (http://www.observatorynano.eu).

Globally in the US, corporations invested an estimated $5.3 billion in nanotechnology research and development in 2006. This figure represents a 19% increase over the 2005 estimate, a growth rate nearly twice that of global public R&D investments. Faster growth in corporate R&D may be an indicator that nanotechnology research is moving closer to commercial production.

As with public R&D investments, on a PPP comparison basis, the United States led the world in 2006 in private sector R&D investments in nanotechnology with an estimated $1.9 billion investment, led by companies such as Hewlett-Packard, Intel, DuPont, General Electric, and IBM. Japan's $1.7 billion in private investments in nanotechnology R&D, led by companies such as Mitsubishi, NEC, and Hitachi, ranks a close second behind the United States. The private investments of companies headquartered in these two nations account for nearly three-fourths of corporate investment in nanotechnology R&D in 2006 (Sargent, 2008).

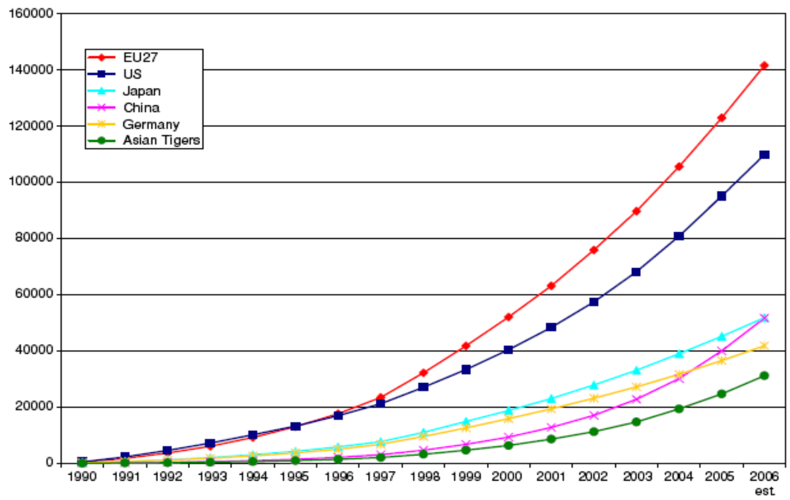
4. Indicators of scientific and technological excellence: patents and publications.

4.1 Publications on nanotechnology: a comparison between the EU and the "others"

In this paragraph we investigate the relative positions with respect to nanotechnology research publications (quantity and quality) of the European Union (27 members), the United States (US), Japan, Germany, China and three Asian Tigers (Singapore, South Korea, and Taiwan). Germany is investigated separately, even though it is also part of the EU27, because it is the fourth largest producer of publications.

In Graph 3 we show a trend line with the cumulative number of publications by country based on the location of any author/co-author's affiliate organization.

Graph 3. Cumulative number of publications by country based on the location of any author/co-author's affiliate organization



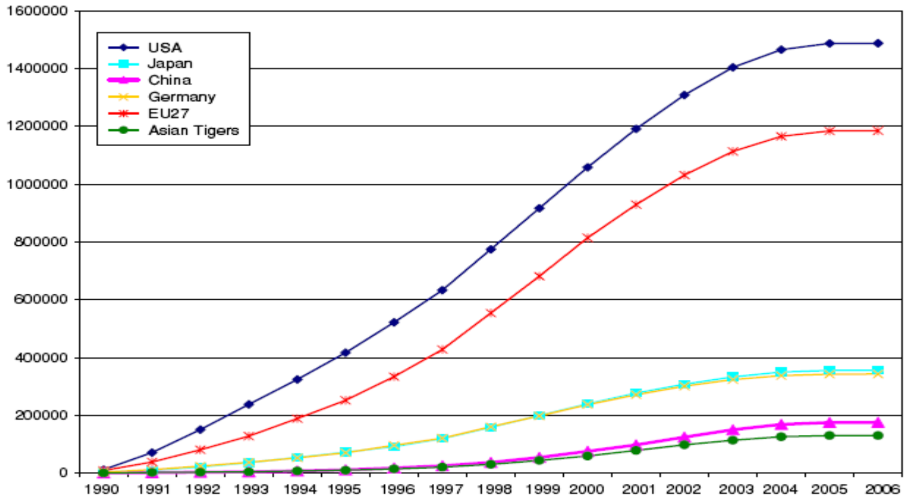
Source: Porter, Youtie & Shapira, 2008

The EU27 has the largest number of publications since 1994. In terms of individual countries, the US is at the top followed by Japan, China, and Germany.

In terms of country trajectories, China's publication slope is particularly steep: its cumulative publication count increased by more than 300% from 2001 to 2006.

The quality of the publication is measured through citations. Graph 4 represents the cumulative number of citations by year for each geographical area taken into account. The number of citations is based on the times which individual papers are cited, then combined by country. To avoid duplication, only the first author's country is reported.

Graph 4. Cumulative number of citations by year for geographical area



Source: Porter, Youtie & Shapira, 2008

The quality-related measures place the US in the strongest position in the nanotechnology field, followed by the EU.

In both the figures the EU27 and the US have the largest number of nanotechnology publications and citations, but recently some Asian countries (China and the Asian Tigers) have increased their publications (Porter, Youtie & Shapira, 2008).

Graph 5 shows the volume of scientific publications in the EU.

Graph 5. Eu nanotech article volumes comparison over time (1990-2004)

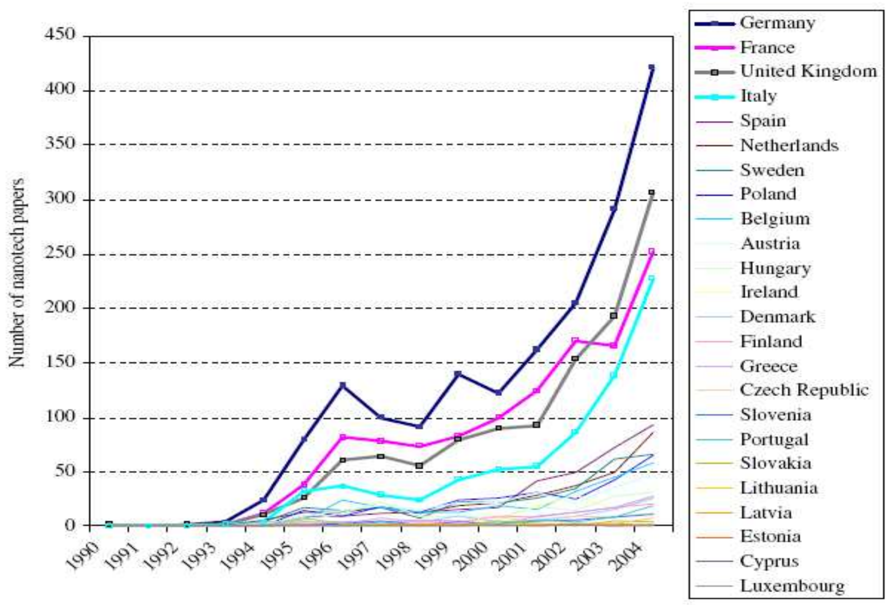


Fig. 5. EU nanotech article volumes comparison over time (1990–2004).

Source: Miyazaki & Islam, 2007

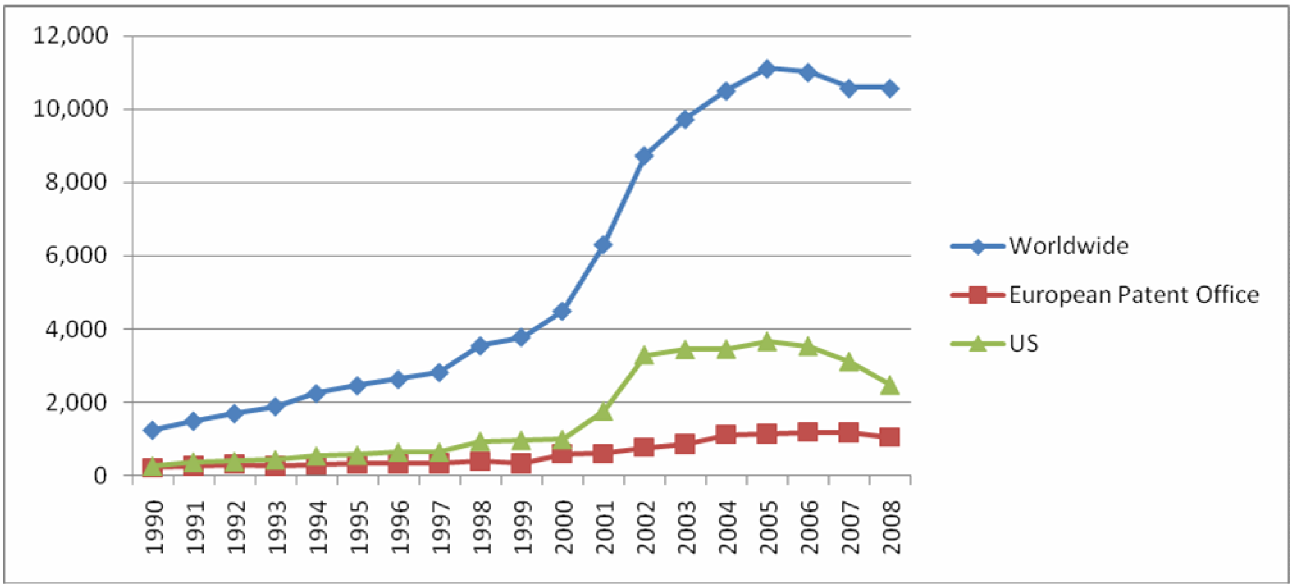
Shares of individual countries in EU varied with particularly strong position of Germany, France UK and Italy observed in nanotech research by the other EU countries (Miyazaki & Islam, 2007).

4.2 The Intellectual Property Rights

Patents are generally regarded as output indicators of applied research and technological development. They represent intellectual property rights and are thus legal documents. A patent application has to fulfill various criteria to be granted. First, the described invention has to be new on a worldwide level. It is not sufficient that an invention is new for the company or new in a specific country. Secondly, the new product or process must be distinctly different compared to the state of the art; it must imply an inventive step. So for someone experienced in the state of the art, the solution suggested by the invention must not be obvious. Thirdly, the invention has to be exploitable in commercial terms. Scientific discoveries without a practical purpose are not patentable (Heinze, 2004).
The awareness of the importance of the IPR issues seems to be insufficient, especially at universities and public research institutes, but sometimes even at the Small and Medium Enterprises level. Moreover patenting and licensing strategies differ between sectors. For instance there is a tendency to issue easily licences in electronics. On the contrary in the pharmaceutical industry licenses are more difficult to get. This is a problem for nanotechnology licence agreements, which are, because of nanotech's interdisciplinary nature, on the crossroad between these sectors (Frycêk & Hullmann, 2007).

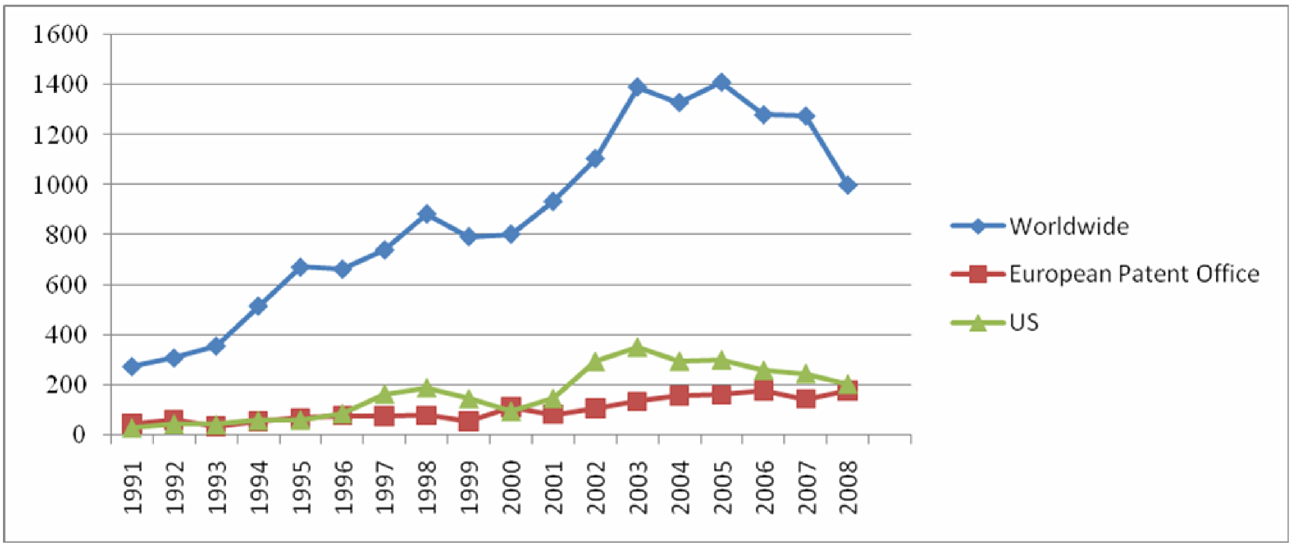
Graphs 6-12 show the evolution of patenting in nanotechnology and in its sub-categories at the worldwide, US and EU level.

Graph 6. Nanotechnology



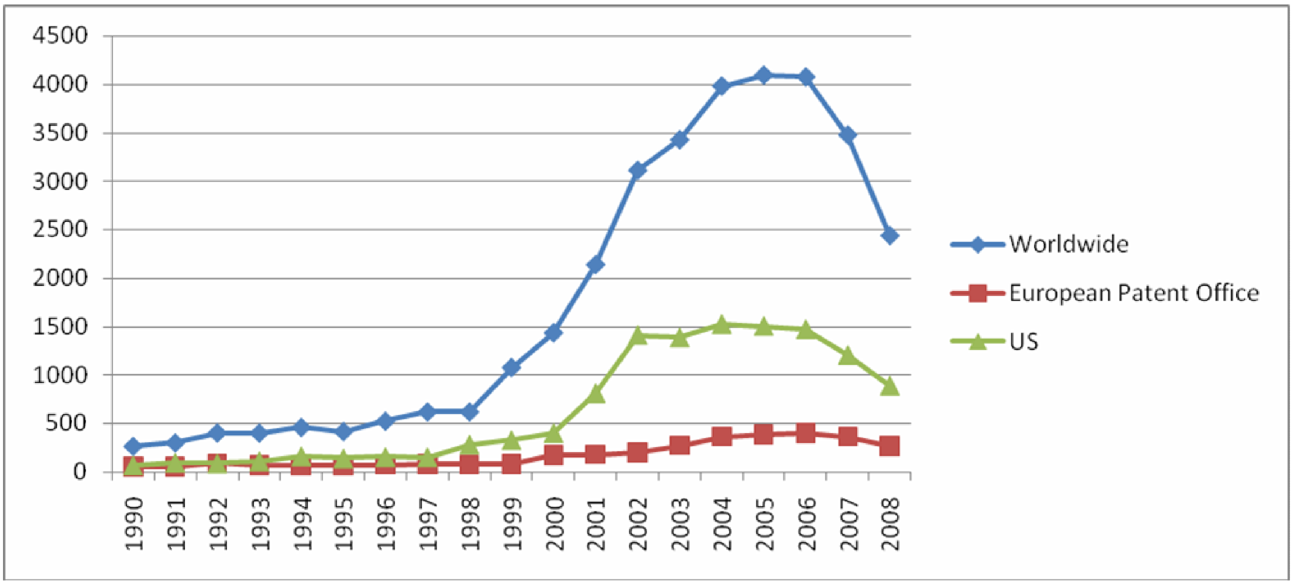
Source: Author's elaboration on data from European Patent Office

Graph 7. Nanobiotechnology



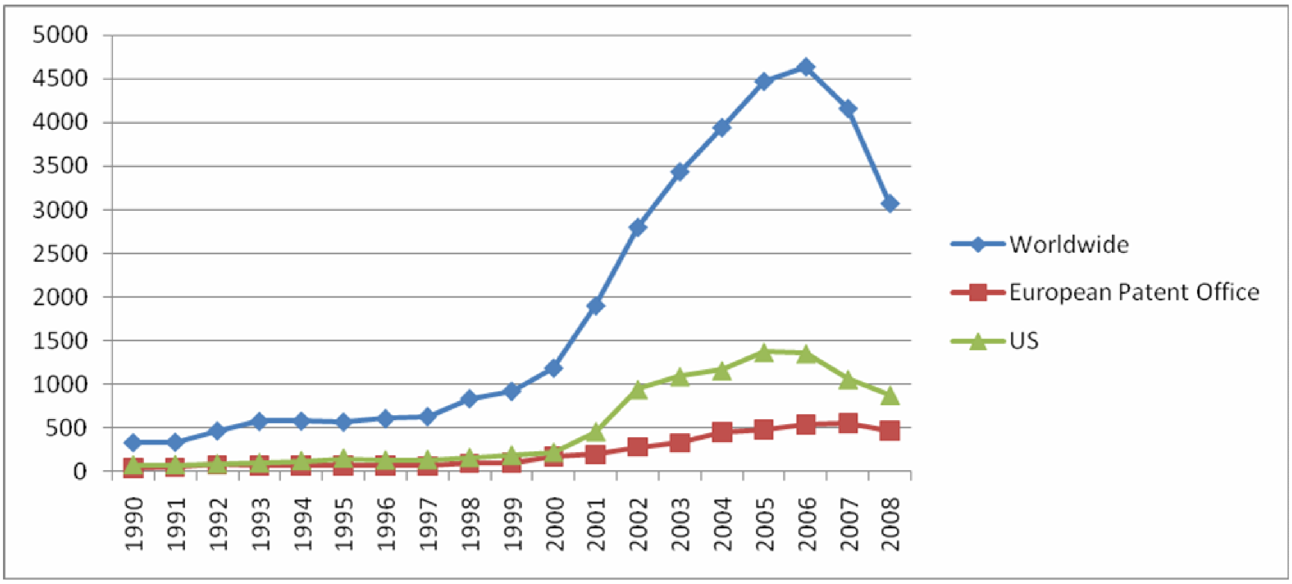
Source: Author's elaboration on data from European Patent Office

Graph 8. Nanotechnology for information processing, storage and transmission



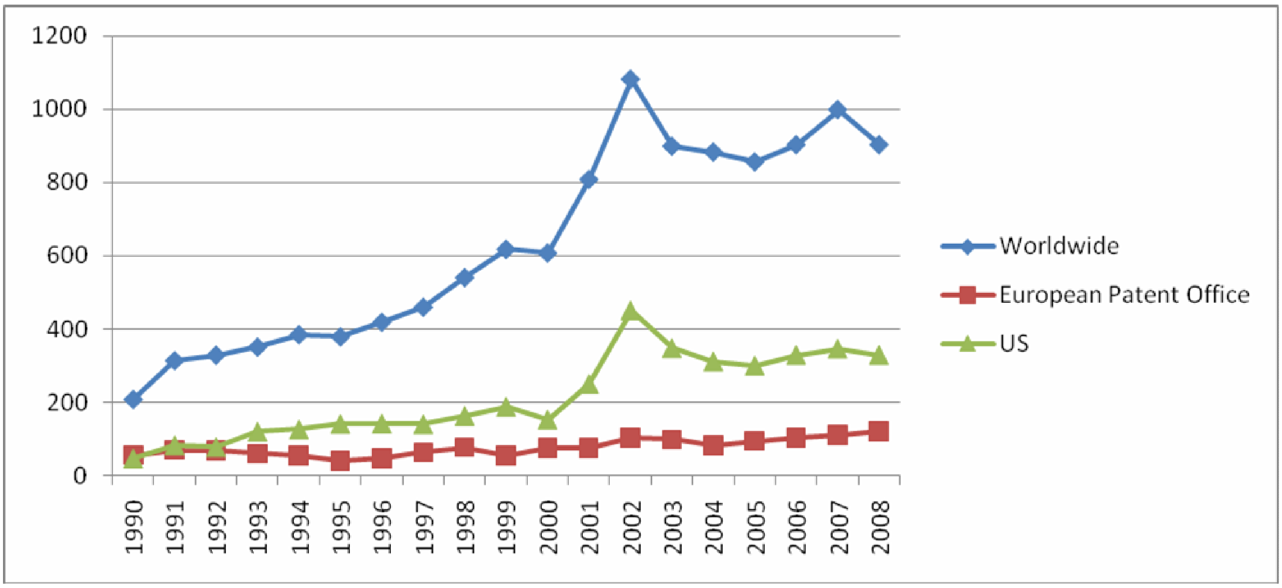
Source: Author's elaboration on data from European Patent Office

Graph 9. Nanotechnology for materials and surface science



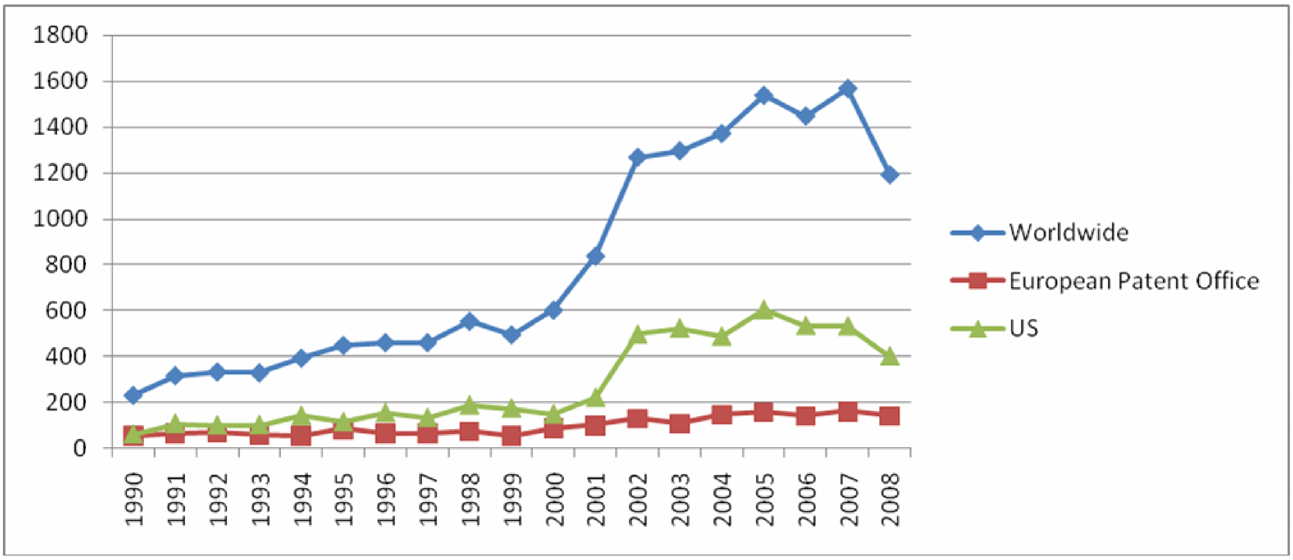
Source: Author's elaboration on data from European Patent Office

Graph 10. Nanotechnology for interacting, sensing or actuating



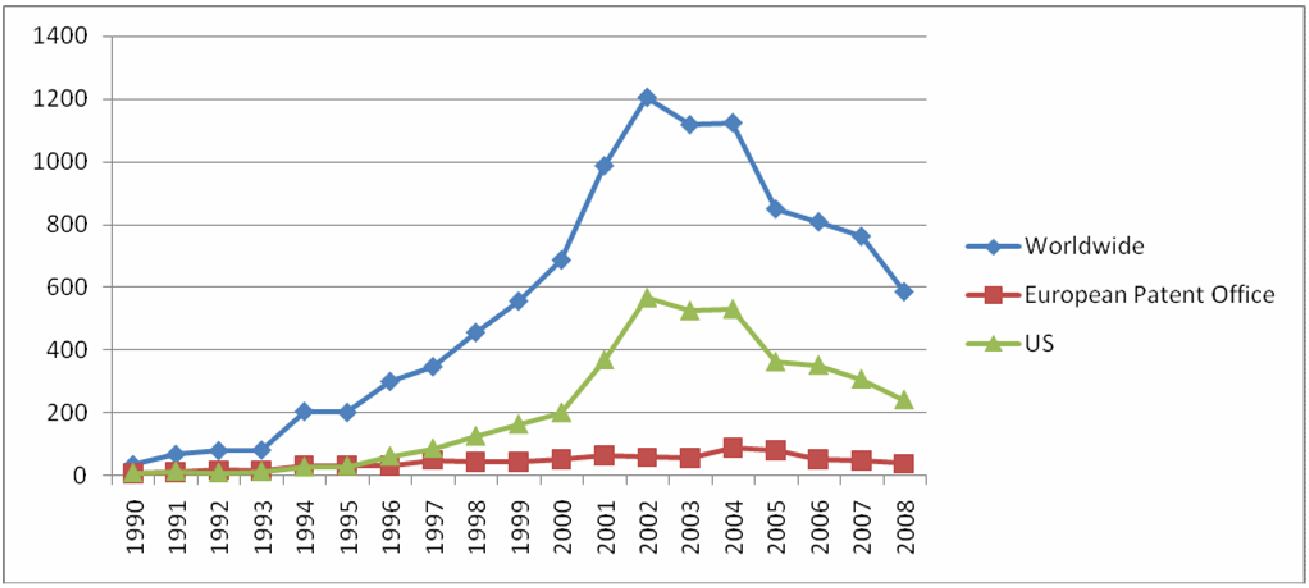
Source: Author's elaboration on data from European Patent Office

Graph 11. Nano optics



Source: Author's elaboration on data from European Patent Office

Graph 12. Nanomagnetics



Source: Author's elaboration on data from European Patent Office

Broadly speaking we observe a significant increase in nanotechnology patents from the year 2000, such as a much better US performance with respect to EU. Europe's patents are alarmingly low in comparison to the US, although its total public investments in nanotechnology are the highest ones, as highlighted in paragraph 3. Since the EU is not suffering a shortfall in funding, the scarsity of patenting activity is certainly a cause of concern. This incongruity can be explained saying that probably in Europe there is not a strong search for the commercial protection. This attitude is in contrast with the advantage of the intellectual property, since the commercialization of new patented methods and products could guarantee a valuable reward against the efforts and huge investments done, especially in light of the dominance that this discipline of technology is likely to hold for the future (Escoffier, 2006).

In Europe there is not, historically, a cooperation between the business world and the universities aimed at getting commercial rewards in the way that is typical in the US. Moreover there is still a strong attitude to maintain publicly funded research in the public domain, and the belief that requiring some form of commercial return is inappropriate.

By contrast in the US, where universities are heavily reliant on private finance as opposed to public money, there is more pressure to make money from research. This is a major factor in the comparative oversight regarding patenting this side of the Atlantic. As a result, US universities have been using IP for many years to generate a revenue stream. A lot of small US nanotech start-ups are also backed by venture capitalists (early-stage equity investment, generally characterized by high risk and high returns), increasing pressure to protect the private investment (Kinsler, 2006).

Another point supporting this view is that patent law is not to blame. It offers enough room to patent nanotechnological inventions. The possibilities for patenting nano are not too much inhibited by existing non-nano prior art (Maurice Schellekens, 2008). In any case it would be more efficient to adopt a community patent.

5. Issues concerning regulation

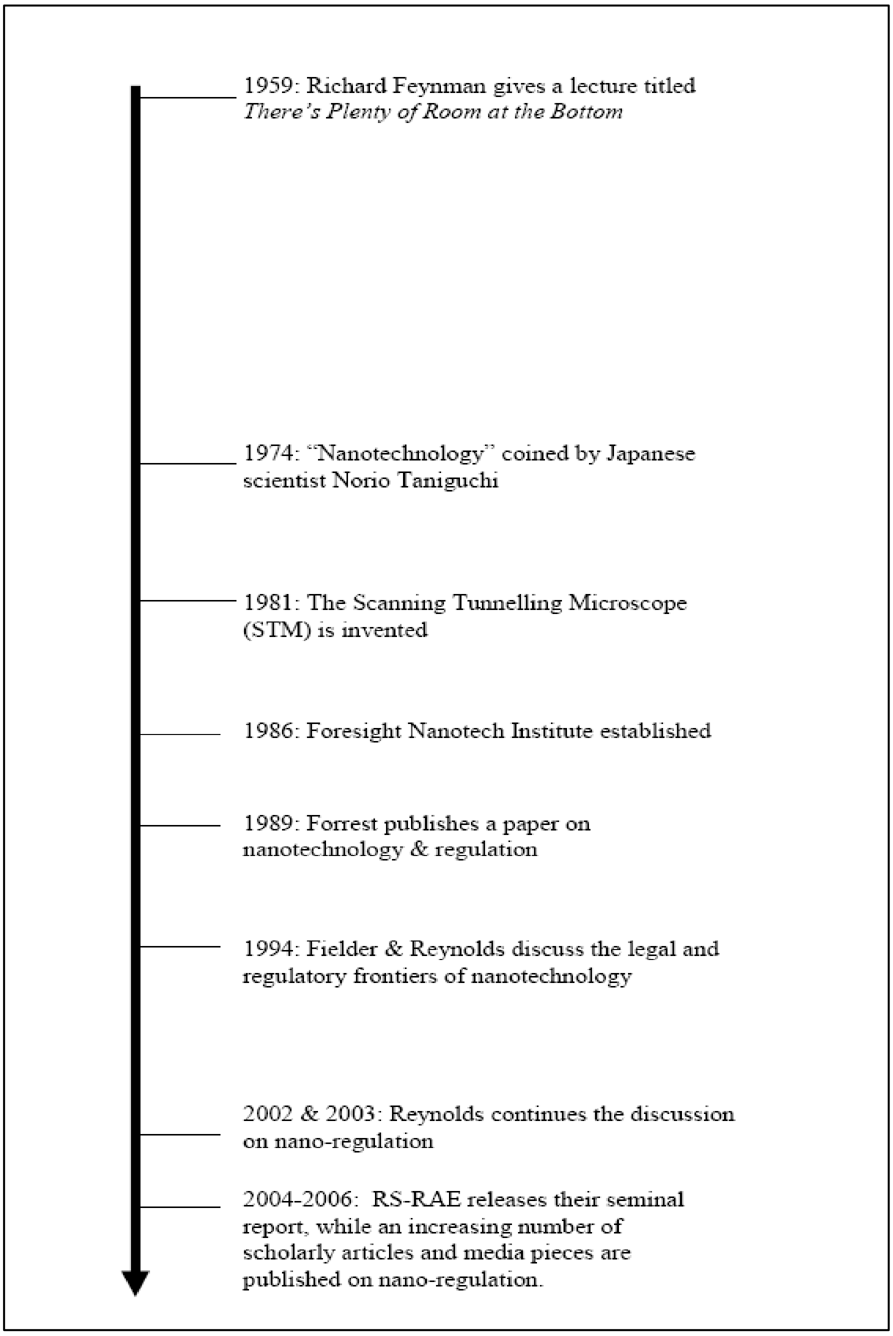
There are unanswered questions about the impacts of nanomaterials and nanoproducts on human health and the environment. As products made from nanomaterials become more numerous and therefore more prevalent in the environment, the attention on how to best leverage advances in nanotechnology to enhance environmental protection, as well as how the introduction of nanomaterials into the environment will impact the EU environmental programs, policies, research needs, and approaches to decision making (Commission of the European Communities, 2004).

Both the increasing commercialization of products with manufactured nano-particles as well as the limited understanding of technological impacts, such as human and environmental toxicology, suggest that the emerging regulatory debate on nanotechnology cannot be postpone any more.

Harmonized regulation plays a key role not only in avoiding market distortions but also in minimizing risk and ensuring health and environmental protection. Existing regulation relies frequently upon parameters that may turn out to be inappropriate for certain applications of nanotechnology. For example, thresholds are often defined in terms of production volumes or mass, below which a substance may be exempt from regulation. The relevance of such thresholds should be revisited and, when appropriate, changed (European Commission, 2004).

Bowman and Hodge (2006) suggest six regulatory frontiers: product safety, privacy and civil liberties, occupational health and safety (OH&S), intellectual property (IP), international law and environmental law. They propose a range of regulatory mechanisms, coming from hard law through licensing, codes of practice, guidelines to other “soft law” roles. Figure 3 show the timeline of the Nano-Regulation debate (Bowman and Hodge, 2007).

Figure 3. A timeline of the Nano-Regulation debate



Source: Bowman and Hodge, 2007

For a regulatory framework to evolve at the international or national level some degree of "technical standardization" seems to be necessary, but without an agreement on definitions, common nomenclature and standards for classification and testing of nanotechnology and nanomaterials, it is extremely difficult to define or classify the products or processes to be regulated (Bowman & Hodge, 2007).

In some countries, such as the UK, since environmental regulators have little information on toxicity and exposure, they are given little option but to adopt a precautionary approach. The so-called “precautionary principle” forms the basis for all environmental directives that are under consideration or have been issued by the EC. The precautionary principle may be invoked when the potentially dangerous effects of a new product or process, such as those related to the development of nanomaterials and nanoproducts, have been identified through a scientific evaluation that does not allow the level of risk to be determined with a sufficient degree of certainty. In such a case, the burden of proving that a material is “safe” is shifted to the manufacturer, and distribution of the material can be halted unless the manufacturer can “prove the negative” and meet this burden of proof (Kalpin & Hoffer, 2005).

The UK Government has recommended a voluntary moratorium by industry on deliberate release of engineered nanoparticles into the environment for remediation purposes and has asked industry to minimise release of engineered nanoparticles and nanotubes in waste streams until the risks have been more comprehensively assessed. The use of nanotechnology applications for remediation (e.g. of contaminated groundwaters) is a good example of an instance where there is urgent need to obtain robust exposure and toxicity data; here is a technology that can potentially remediate polluted waters containing persistent chemicals, but in the absence of a robust risk assessment responsible environmental management dictates a precautionary approach and delays the use of this potentially beneficial technology (Depledge& Owen, 2005).
At the supranational level, the European Union and its member states have turned their attention to the issue of nanotechnology and the need for safeguards against potential risks posed by nanotechnology. The European Commission is funding a range of research projects examining epidemiological studies looking at nanoparticle toxicity and risk and it is committed to an integrated and responsible approach to developing nanotechnologies, taking into account all aspects: safety, acceptance by society, ethical implications and so on.

The EU executive has also adopted a recommendation on Code of Conduct for responsible nanotech research. It calls on member states to respect the precautionary principle in research on nanoscience in order to protect not only researchers but also professionals, consumers, citizens and the environment. A Code of Conduct for responsible nanosciences and nanotechnologies (N&N) research was released by the European Community in February 2008.

The Code of Conduct invites all stakeholders to act responsibly and cooperate with each other, in line with the N&N Strategy and Action Plan of the Commission, in order to ensure that N&N research is undertaken in the Community in a safe, ethical and effective framework, supporting sustainable economic, social and environmental development.

The Code of Conduct encompasses seven general principles on which Member States are invited to take concrete action to ensure that nanotechnologies are developed in a safe manner:

- meaning: N&N research activities should be comprehensible to the public. They should respect fundamental rights and be conducted in the interest of the well-being of individuals and society in their design, implementation, dissemination and use;
- sustainability: N&N research activities should be safe, ethical and contribute to sustainable development. They should not harm or threaten people, animals, plants or the environment, at present or in the future;
- precaution: N&N research activities should be conducted in accordance with the precautionary principle, anticipating potential environmental, health and safety impacts of N&N outcomes and taking due precautions, proportional to the level of protection, while encouraging progress for the benefit of society and the environment;
- inclusiveness: governance of N&N research activities should be guided by the principles of openness to all stakeholders, transparency and respect for the legitimate right of access to information. It should allow participation in the decision-making processes of all stakeholders involved in or concerned by N&N research activities;
- excellence: N&N research activities should meet the best scientific standards, including integrity of research and good laboratory practices;
- innovation: governance of N&N research activities should encourage maximum creativity, flexibility and planning ability for innovation and growth;
- accountability: researchers and research organisations should remain accountable for the social, environmental and human health impacts of their work (http://cordis.europa.eu).

6. Cooperation between the EU and other States

Some kind of cooperation has been developed between the EU and other States: Latin America (NanoforumEULA The project aims to foster lasting research relations between European research organisations and research organisations in Latin America specialising in nanotechnology), Russia (The European Union and the Russian Federation signed a new "Agreement on co-operation for Science and Technology"). This agreement is key to ensuring the participation of Russian scientists in the EU Sixth Research Framework Programme (FP6 2002-2006), the U.S. (Nanotechnology research is covered by the EU-USA Agreement on Scientific and Technological Co-operation and, in particular, by the Implementing Arrangement between the European Commission and the National Science Foundation (USA) for co-operative activities in the field of materials science), Canada EU-Canada Co-operation Agreement on Science and Technology, Australia, India ("EuroIndiaNet", designed to promote stronger collaboration between the EU and Indian scientists and industrialists in the nanotechnologies and nanosciences), Cina (Scientific links between the EU and China were strengthened with the adoption of a Joint Declaration on EU-China Research Cooperation), South Africa (The European South African Science and Technology Advancement Programme (ESASTAP), Egypt (science and technology (S&T) action plan) . In 2007 the Environmental Protection Agency (EPA) of the United States government and the European Commission have agreed on an "Implementing Arrangement on Environmental Research and Ecoinformatics" and among the collaborative research topics included there is the use and impact of nanotechnology.

7. Conclusions

Nanotechnology could be used for the benefit of the environment, with applications in many different fields. However, at this point not enough information exists to assess environmental exposure for most engineered nanomaterials. This information is important because policy makers will need a sound scientific basis for assessing and managing any unforeseen future impacts resulting from the introduction of nanoparticles and nanomaterials into the environment. In addition, there is a need to understand how to best apply nanotechnology for pollution prevention in current manufacturing processes and in the manufacture of new nanomaterials and nanoproducts, as well as in environmental detection, monitoring, and clean-up. This understanding will come from scientific information generated by environmental research and development activities within government agencies, academia, and the private sector.

The comparison between the European Union and the US in the nanotechnology field shows that they are quite close with respect to public funding and publications, while the advantage of the US in patents and private funding is very high. The problem for the EU is the attitude of the private sector not to invest in R&D and the general tendency not to search for the commercial protection.

In this perspective the public-private partnerships are a possibility that the EU cannot miss to advance in the promising research field.

It is worth stressing that beyond funding, it is necessary an integrated and responsible approach for the successful development of nanotechnologies. European citizens should benefit from nanotechnology, while being protected from possible adverse impacts. Commitment to ethical principles is a cornerstone of such an approach. To reach full potential, nanotechnology development must be attuned to society's expectations, making communication and dialogue an absolute priority. This is the reason why in addition to information activities in all Community languages for different target groups, the Commission has systematically promoted public dialogue, particularly with NGOs. It has launched an open consultation on a Code of Conduct for responsible nanotechnology research. Similarly, assessing the safety of nanotechnology-based products and processes is a central issue for European policy, and has direct impact on their access to the market. Nanoparticles and their potential impact on health and the environment are being studied in close coordination with Member States and international bodies such as the UN, OECD and International Standards Organisation. In addition to projects specifically devoted to safety, all nanotechnology research projects include an ethical and safety assessment component. The European Commission is currently undertaking a review of existing legislation to see whether the current regulatory framework appropriately addresses health, safety and environmental risks. Moreover, it has taken steps to establish an observatory to provide decision-makers with dynamic assessments of scientific and market developments.

Future research could focus on an integrated approach of technology: the four major "NBIC" (nano-bio-info-cogno) provinces of science and technology, each of which is currently progressing at a rapid rate: (a) nanoscience and nanotechnology; (b) biotechnology and biomedicine, including genetic engineering; (c) information technology, including advanced computing and communications; (d) cognitive science, including cognitive neuroscience (Bainbridge & Roco, 2002).

Sustainable resources of food, water, energy, and materials are achievable through converging technologies. In particular the convergence of nano and biotechnologies could improve environmental protection. As an example, researchers have extracted photosynthetic proteins from spinach chloroplasts and coated them with nanofilms that convert sunlight to electrical current, which one day may lead to energy generating films and coatings (US EPA, 2007). The addition of information and cognitive capabilities will provide additional features including programmability, miniaturization, increased power capacities, adaptability, and reactive, self-correcting capacities.

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