ObservatoryNANO Factsheets

January 2010

Introduction to Factsheets

The first set of factsheets correspond to the technology sectors covered by the ObservatoryNANO project: Aerospace, Automotive & Transport; Agrifood, Chemistry & Materials; Construction; Energy; Environment; Health, Medicine & Nanobiotechnology; ICT; Security; and Textiles.

Each factsheet provides a short description of the relevant sector before highlighting some of the most exciting nanotechnology developments and providing a summary of the following areas:

- Needs addressed by the nanotechnology developments;
- Technology Readiness Level (TRL) and time-scale to market;
- Barriers to commercialisation;
- Measure of impact;
- The competitive position of the EU;
- Other issues.

The TRL scheme adopted by the ObservatoryNANO project is a simplified five-level scheme which is visualised in Figure 1 and also shows a comparison with the defence standard nine-point scheme.

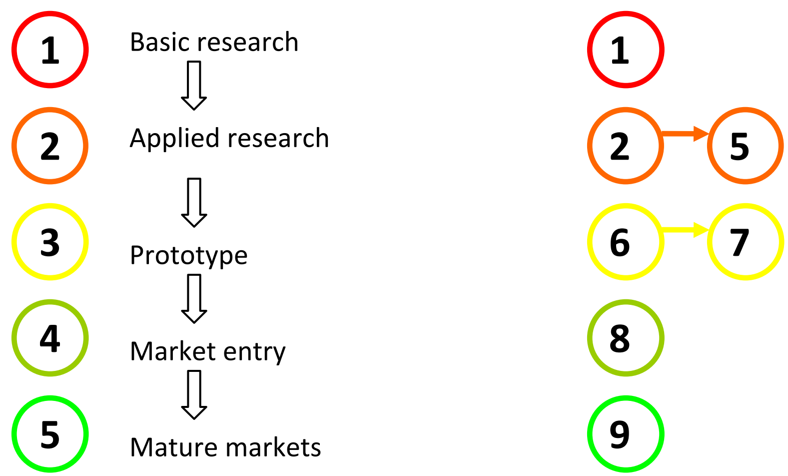


Figure 1: ObservatoryNANO TRL scheme (left) corresponding to the defence standard nine-point scheme (right).

Following the technology factsheets some results of the ObservatoryNANO's patent and publications quantitative analysis is presented. The information contained in these factsheets provides a snapshot of the full analysis undertaken by the project partners; further information and analysis can be found at www.observatory-nano.eu.

Finally a summary of the ethical, legal, and societal aspects (ELSA) associated with nanotechnology developments in the ten technology sectors is presented.

Aerospace, Automotive & Transport

Potential applications of nanotechnology in the transport sector are enormous. The match between the advantages derived from using nanotechnology (e.g. new, improved or tailored properties) and the market needs in the transport sector such as (more) sustainable, safer and economic transport modes has triggered huge public and private investments in the field. At European level, the automotive industry is a powerful contributor to the economy, generating around 5% of the Europe's gross domestic product (GDP). The application of nanotechnology in cars can be present in almost all the systems and parts such as advanced powertrain, using new energy, reducing car weight, enhancing material functions, increasing comfort degree & flexibility, raising cost efficiency.

Application	Needs addressed by nanotechnology developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Nanostructured metals	Metals with improved properties, especially high strength and high corrosion resistance Aim for tailored material properties	TRL 4 - 5 for small parts (e.g. screws) TRL 2-3 for medium/large parts (technical limitations)	High production costs Technical limitations for the production of medium-large parts Lack of automated production for large-scale series.	Currently impact is very limited. However, lighter vehicles and aircrafts are more energy efficient and therefore CO_2 consumption is reduced.	Even though Japan and USA have been leading the field, there are also a large number of active European research groups carrying out promising developments.	
Tribological nanocoatings	New products and upgrade of material properties. Surface properties, for example reduce wear, reduce UV degradation, high temperature resistance, etc.	TRL 3 - 4	Large investments needed, especially for applications in large parts. Difficult to implement in large-scale automated production.	First tribological nanocoatings products to be implemented in the market on structural parts.	Many research groups and companies have been working in the area of tribological coatings for automotive and aerospace industries in the EU.	
Polymer nanocomposites	Advanced composite materials, with improved and tailored properties that could, for example replace metal parts, avoid electrical risks or to reduce weight.	TRL 2 - 3	Cost; availability of large parts with good quality Resistance properties and robustness of new composite materials. Automated production for large-scale.	Automotive / aeronautics industry accounts for nearly 80% of polymer nanocomposite consumption together with packaging industry.	The US is leading fundamental research in this field. In the EU there have been many research groups who have been active in PNC research as well. Also Airbus and EADS have been carrying out many R&D projects in the field.	Lack of information regarding the safety of nanomaterials and their handling is stopping the investments for this technology.

Agrifood

Safety and control of unwanted species (chemical and biological) is a key driver in the Agrifood sector.

Application	Needs addressed by nano developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Enhanced bioavailability Improving solubility or delivery of a substance for application in functional foods.	A large number of healthy substances in food are poorly absorbed by the human body; nanoemulsions and nanomicelles provide a means for improving the bioavailability.	TRL 1 – 4 Major growth is expected over the next 5 to 10 years through transfer from parallel efforts in the drug delivery sector.	Limited knowledge of in vivo testing. For the majority of delivery options there has been limited in vivo testing.	A proliferation of R&D but limited commercialisation due to its nascent stage. A micelle system is on the market in Europe.	EU development is limited with regards to food; but parallel activities are occurring in the drug delivery sector where major advances are predicted that will catalyse food sector developments.	Although nanotechnology solutions are emerging, US estimates of the nutraceutical market quote a $120 billion industry with a 7% CAGR.
Antimicrobial Nanocomposites A nanomaterial permeated with killing agents, growth inhibitors or antibiotics.	Promises substantial improvement in controlling the growth of pathogenic micro-organisms which lead to spoilage or disease spread, coupled with improved structural properties of nanocomposites. .	TRL 1 – 3 Food packaging thin films and coatings are actively being explored and steady growth is predicted in the next 5 to 10 years.	There are limited tools to ascertain the degree of migration of antimicrobials into food.	Although there is a wide recognition of the potentially substantial impacts on food safety, the lack of characterization of migration of antimicrobials into food means that the food industry remains cautious.	The EU has comparable R&D activity in this area with other key players such as the US and Korea. Similarly, innovation in terms of new product development is hampered by the caution of the food industry itself with the concerns on migration.	A major bottleneck concerns tools and standards for characterising the extent of nanomaterial toxicity and the degree of migration into foods. For nanocomposites there should be limited transfer because the antimicrobial is fixed; however, the degree of fixation and the life-cycle analysis is still not well known.
Biopolymer nanocomposites and nanofibres Biopolymers (plant derived material) processed into nanoscale fibres or combined with nanomaterials to create composites.	Provide opportunities for biodegradable and sustainable options for plastics; nanofibres and composites enhance barrier and structural properties, making biopolymer functionally competitive with fossil fuel derived options.	TRL 1 -4 A wide variety of materials are being investigated, but slow growth is predicted unless advantages over fossil fuel derived options are seen and supported.	Low demand leads to stifled growth in manufacturing capacity. Life-cycle analyses of nanobio composites are still limited.	Proliferation in R&D, growth in patents, and a number of small firms (often connected with R&D centres) providing material production services.	Shift towards sustainability bringing down the relatively high cost of biopolymers. Europe has a strong position in biopolymer R&D, with a (slowly) growing capacity for production.	Sustainability linked incentives could provide an innovation impetus. The low cost, wide availability and environmental compatibility of the biopolymers used in these materials make these an attractive alternative to fossil fuel based polymers.

Chemistry & Materials

Chemistry & Materials, in many respects, represents the basis for the applications of nanotechnology as covered by the other nine more application oriented technology sectors. The technology sector is split into a number sub-sectors according to nano-material families. With respect to the more fundamental character of this technology sector, the most relevant nano-materials instead of applications are described in the table below.

Nano-material	Needs addressed by nanotechnology developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Carbon Nanotubes	New applications and markets based on the multitude of outstanding properties	TRL 1 for nano electronics, drug delivery TRL 4 for composites, electrode materials, displays TRL 5 for Technical production	Still quite expensive production involving nano arrangement, purification, separation, dispersion of CNT.	First commercial products based on CNT composites (life style products, car body parts, electrodes etc.)	EU in leading position in industrial CNT production. CNT research in Europe is highly valuable; however, research activities are more extensive in the US and East-Asia.	Biocompatibility and potential health risks issues.
Nano diamond	For galvanic coatings, polishing pastes, lubricating oils, coolants, filler in polymer composites, and greases.	TRL 5	Production process is slow, energy consuming and thus expensive	Nano diamonds represent a mature niche market.	EU not leading in innovation but ranking behind the US on a second position on a comparable level with Japan	
Non-carbon Aerogels	For thermal and acoustic insulation, lightweight construction, catalysts, filtration, particle sensors, and shock absorbers.	TRL 4-5 for thermal insulation TRL 2 for acoustic insulation TRL 3 in average for other applications	High brittleness Demand for aerogels that are mechanically stable and more water resistant. SiO_2 aerogels have to be protected against humidity, which is costly. Reliable, cheap volume production remains an issue.		Research activities mainly focused in the US; Europe playing only a minor role	
Oxide nanoparticles	Heat, wear and UV-resistant coatings, paints and lacquers, photo resists, catalysts, MRI-contrast agents etc.	TRL 3-4 in general. TRL 5 for SiO_2, TiO_2 and Al_2O_3 (in widespread commercial use)	TiO_2: additional research effort required concerning spectral shift and solar cell applicability. Large scale production of oxide semiconductors remains too energy consuming.		European research institutions and companies among global innovation leaders especially concerning photocatalytic applications; however, Japan seems to slightly dominate	

Polymer and metal- matrix nanocomposites	Material design with light weight, wear resistance, high thermal and conductivity properties.	TRL 2-3 (average) market maturity within 5-10 years TRL 3 for metal-matrix nanocomposites (MMC) TRL 5 for rubber clay nanocomposites (filler in tyres)	Remaining difficulties in dispersion processes during large scale fabrication. Cost: Nanoclay-composites still very expensive; production of nano MMCs remains difficult and pricy. Difficulties in production up-scaling.			
Nanostructured polymer films and polymer nanocoatings	Thermal and chemical insulation, surface coatings for multiple applications, and bio-medical coatings;	TRL 3, in average 5 -10 years to market maturity. TRL 5 for nanostructured PMMA-film	Transition from lab-scale to volume production. Lack of suitable industrial high volume fabrication methods. Long-term decomposition by oxygen.			Question of biocompatibility
Dendrimers	Drug-delivery, transfection, protein modelling, bio-medical coatings, additives to paints, inks, toners, glues etc	TRL 2 in general TRL 3 for additives; 5 - 10 years to market maturity	Additional research required particularly for bio-medical applications.		EU lagging behind the US particularly in the bio-medical research areas.	
Nano-particulate metal powders and nano-crystalline metals	Improved powder metallurgy and in coating technologies. Very high robustness steels and lightweight components	TRL 2-3	Agglomeration and sensitivity to oxygen. High production cost "Nanoplasticity" mechanisms and targeted design need further investigation. Immature fabrication methods.		EU R&D institutions among global innovation leaders; however, USA, Japan, China are comparably strong.	

Construction

Construction is one of the most strategic industries for Europe providing building and infrastructure on which all sectors of the economy depend. It is a settled, cost driven and a traditional sector; however, both economical and environmental considerations have been reshaping the landscape leading to the adoption of new technologies. Nanotechnology has a significant impact in the construction sector. Several applications have been developed for this specific sector to improve the durability and enhanced performance of construction components, energy efficiency and safety of the buildings, facilitating the ease of maintenance and to provide increased living comfort.

Application	Needs addressed by nanotechnology developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Construction ceramics	New properties such as: easy to clean surfaces; scratch resistance surfaces; and antibacterial. In addition to improvements such as ease of maintenance, hygiene, resistance to harsh environments, and safety.	TRL 5	Cost: driver is the running cost of the tools used to apply coatings (rather than the cost of the nanomaterial). Increased energy costs.	A number of companies in Europe have products on the market. Market penetration of nano-enhanced construction ceramics is less than 0.5%.	EU is currently world leader in construction ceramics, but Asia is becoming a strong contender.	Consumer resistance due to societal concerns regarding the toxicity of nanomaterials.
Cement based materials	Improving the mechanical properties and service life of cement based materials. Further enhanced properties include: self-healing, easy-to-clean, and graffiti-resistant. Reducing pollutants through photocatalytic activity (TiO_2).	TRL 5 for enhanced properties. TRL 4 for photocatalytic activity.	Cost: UHPC is more expensive than normal concrete; however, its exceptional mechanical properties rival steel, which is even more expensive. Nano-enhanced cement is still too expensive to become a construction standard.	In Europe, a number of construction companies include nano-enhanced cement or nano additives for cement/concrete among their products. Photocatalytic cement is in use, mainly for small-scale high-profile projects such as churches or bridges.	France has a leading position in this field.	Benefits are closely linked to environmental issues and legislation. Stricter environmental requirements form a key motivation for the market uptake (e.g. of low-polluting cement, or air-purifying cement products).
Windows - Glass	Self-Cleaning window panes (TiO2); low emissivity coatings (low-E); smart glazing; and electrochromatic windows developments are: energy saving; insulating; easy-to-clean; UV controlling; photovoltaic, and fire-resistant.	TRL 5 for TiO_2 TRL 5 for low-E coatings. TRL 4 for electrochromatic windows.	Cost: 30-80% higher than traditional glass. Cost is also the main barrier of dynamic or switch-able glazing. Privacy glass is also high cost, at around €1700 per m^2.	In general the increase in market penetration. The market for electrochromatic glass in construction is expected to reach $218.3 million in 2013.	European companies lead the field in the development and production of nano-enabled glazing products.	

Energy

The development of new energy sources is vital in reaching targets of reductions in the use of fossil fuels. New functionalities and new ways of communication require new power sources performances. Nanotechnologies have the ability to improve the performances of energy generating systems.

Application	Needs addressed by nano developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Batteries for electric vehicles	Performance: - high power battery - quicker charge/discharge processes Lifetime: - compensation of material expansion caused by Li intercalation. Reduction of CO_2 g/kWh	TRL 3 for first battery generation: LTO ($Li_4Ti_5O_{12}$) or LFP ($LiFePO_4$) TRL 2 for second battery generation	High cost: 300€/kWh by 2015 and less than 150€/kWh by 2020. Short lifetime: 15 years or 5000 deep charge/discharge cycles by 2020 Distance range too short: 150km by 2015 and 200km by 2020 Performance insufficient: 150Wh/kg by 2015 and 200Wh/kg by 2020.	Development of the market share: EV and hybrid electric vehicles will account for 9-10% of the global automotive market by 2020 (in 2009: 70 millions vehicles has been manufactured worldwide)	Most of EV batteries manufacturers are American (A123, Altair Nano) or Asian (Nissan, Mitsubishi) The "come-back" of batteries manufacturers in Europe will be supported by collaboration of automotive and battery industries.	Lack of industrial experts in battery for electric vehicles in EU. New models of ownership should be developed (renting, sharing …) Competing technologies can compensate material expansion. Development of infrastructures (recharging stations)
Organic & Dye sensitised solar cells	Low weight, flexible, large area, and low cost solar cells for portable and flexible outdoor structures, and semi-transparent BIPV (Building Integrated PhotoVoltaic).	TRL 4 for portable power and flexible outdoor structures TRL 3 for BIPV	Ratio cost/efficiency too high: 0.4 to 0.5$/Wp by 2020 Lifetime too short: 20 to 30 years by 2020. BIPV: existence & growth to be validated.	Potential market: 7.5 billon € by 2023	Solar Cells production: key industrial players in US and Japan with a few promising European start-ups. Strong European industry and R&D background.	Necessity to strengthen its own markets: portable power & flexible outdoor structures: niche market => to be developed.
Inorganic thin film solar cells	High electricity generating systems for single/multi family houses, public facilities or commercial buildings to be competitive with grid electricity. Reduction in CO_2 emissions.	TRL 3-4: CIGS with nanoparticles TRL 2-3 nanowires, CNT … TRL 1-2 : hot electrons, quantum dot solar cells	High cost: objective of 1$/Wp in the short term. Integration of nanotechnologies should validate several developments steps before being considered inside commercial modules	Total market: €12 to 13 billion by 2023. Employment: 2.2 million jobs by 2030 (2009: 190000 direct and indirect jobs)	80% of global PV market in Europe. Germany is a leading manufacturer. Active R&D: key research institutes in Europe	Policies regarding feed-in tariffs in the short and long term should remain coherent. Use of rare or toxic materials requires the development of a specific recycling processing industry.

Environment

The Environment technology sector summarises the applications of nanomaterials for environmental remediation and the treatment of contaminated air, water and soil. According to Boehm (Boehm, 2006) the projected world market for applications of environmental nanotechnologies by 2010 is approximately $6 billion. Claire (Claire in (Rickerby and Morrison, 2007)) expects the market for soil and groundwater remediation to grow to around €23.6 billion worldwide with the UK and Japan as expanding near-term markets, and central and eastern Europe as important mid-term markets.

Application	Needs addressed by nanotechnology developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Nano Zero Valent Iron (NZVI) for groundwater and soil remediation	Providing a cheaper, shorter treatment period, with improved performance, and less above ground infrastructure required	TRL 4-5: In the U.S. already 10% of all remediation projects; in Europe only a few full scale projects so far	Scepticism by governments (fear of public backlash). Lack of knowledge on possible negative impacts on environment. Lack of experience with the technology in the EU	More sustainable remediation (less costs, most probably less impact on environment), creation of jobs, new product	The US has greater experience with this technology. No projects in Asia known.	No regulations for the application of NZVI. Long-term effects on environment are not known
Photocatalysis with nanoTiO_2	Possibly less toxic and cheaper alternative for the treatment of air and water.	TRL 4-5: Some products (such as cement, air filters, water purification systems) are available especially in Asia.	Lack of knowledge on chemical reactions (toxic intermediates?). No need at the time to replace existing/conventional water treatment systems Dependent on future regulations and laws.	Possibly all cement/concrete is enriched with nanoTiO_2 to reduce air pollutants; nanoTiO_2 in water treatment may have positive impact on water quality (especially also in developing countries)	Many more applications in Asia due to cultural differences in public hygiene.	Technology adoption driven by regulation – particularly air quality standards. Concerns on possible toxic intermediates.
Nanofiltration	Possibly less costly/toxic alternative for wastewater treatment (especially from industries)	TRL 4: Only a few applications for wastewater treatment, desalination, and reductions of hardness so far.	Problems with membrane fouling. No need to replace existing/conventional water treatment systems at the time. Product costs.	Installation of nanofiltration systems to remove hardness in many communities/ cities; desalination of sea water	EU is in a relatively strong position	Regulations on minimal water quality will influence the development/spread of the technology.

Health, Medicine and Nanobiotechnology

Many approaches to nanomedicine being pursued today are already close enough to fruition that their successful development is almost inevitable, and their subsequent incorporation into valuable medical diagnostics or clinical therapeutics is highly likely and may occur soon. However, the market for nano-medical products is currently very fragmented, and is at best a niche market, when compared with the larger medical market.

Application	Needs addressed by nano developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Drug delivery	Delivery across blood-brain barrier. Better formulation and specific administration. Intracellular drug delivery. Decreased toxicity.	TRL 2 - 3 for targeted delivery via new pathways. TRL 4 - 5 for established drug delivery like chemo-therapeutics.	Long lead time of clinical trials for safety and efficacy of novel nanoscale delivery platforms. Increasing costs and changing demographics.	Increasing share of nanotechnology in the pharmaceutical market. (Global market growth from $109 billion in 2008 to $157 billion in 2012). Opportunity to extend the patent and commercial life of existing drug molecules.	The EU has a high level of research expertise in this sector. Major competitors include the USA and Japan which have highly-funded R&D and commercialisation programmes. Also increasing competition from China and India.	Highly targeted drugs are expected to offer significant advantages in term of higher efficacy and lower toxicity; however, there is a risk of negative perception by patients and general public of nanotechnology.
In vivo imaging	Nanoscale contrast agents can improve the resolution and performance of existing medical imaging systems, and facilitate new generations of minimally invasive medical imaging techniques such as MRI.	TRL 2 – 4, although several companies now have nanoscale products on the market (TRL 5).	Restrictive patents and licenses. Need for safety and efficacy testing under the medicinal products regulatory system.	Early diagnosis, e.g. in cancer, can significantly improve patient prognosis and recovery reducing healthcare costs. The MRI contrast market is estimated to be worth more than $1 billion annually.	Many companies developing diagnostic methods for in vivo imaging are already situated in Europe. Good perspective for further growth in Europe.	For some potential nanoscale materials there may be a lack of previous clinical experience.
Regenerative medicine	Tissue regeneration by ectopic application. Implant interfaces for better biocompatibility. Bioresorbable scaffolds for in vivo and in vitro tissue regeneration.	TRL 3-4 for treatment of general burns and skin abrasions by nanomaterial. TRL 4 for tissue engineering	Highly fragmented market. Where cells, growth factors or other active biomolecules are added, there is potentially a longer route to market involving pre-clinical and clinical safety trials.	Large potential global market for ectopic application of bioresorbable nanomaterial. Enhanced compatibility of implants will improve patient care and thus reduce healthcare costs.	High level of expertise in the EU at research level. Less so at industry level although some (mainly smaller) companies are active. Major competitor is the USA.	Need for medical professional retraining and challenges in changing medical practice. New industry business models must address the individual patient-centric needs of regenerative medicine.

Information and Communications Technology

This sector covers applications of nanotechnology in electronics and photonics for the production of electronics components and devices for a range of end-use markets.

Application	Needs addressed by nanotechnology developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Nano-photonics in computing	Enabling high-speed photonic connections on chip level.	TRL 1 for plasmonics TRL 1-2 for quantum dots	Compatibility with existing manufacturing processes Stability	Increasing European nanotech share of the $800 million photonic interconnects market.	EU has strong research capabilities, several companies involved in photonics	Potential risks of nanoparticle release in manufacturing or end of use.
Memory	A 'unified memory' combining high performance and density with non-volatility	TRL 2 for MRAM and phase change TRL 3 for FeRAM and NRAM	Achieving cost-competitiveness with Flash memory.	Outside Europe leadership in Flash memory	Strong European research base; however, relatively weaker industrial involvement.	Potential risks of nanoparticle release in manufacturing or end of use.
Beyond CMOS	Fundamentally new paradigm for design of electronics, new information carriers.	TRL 1 for nanowires, and molecular electronics	New materials, new production process, new design rules, systems integration	Preserving or improving European position in semiconductors (currently contributes to 10% of Europe's GDP)	EU has strong research capabilities across a range of beyond CMOS approaches and a well coordinated approach.	Potential risks of nanoparticle release in manufacturing or end of use.
Continued CMOS downscaling	Improved materials understanding, new tools.	TRL 5 for Atomic Layer Deposition TRL 2 for novel substrates	Cost Challenge of introducing new techniques to highly optimised production process.	Amount of semiconductor market impacted by nanotechnologies	Very competitive, but some European poles of excellence.	
Solid State Lighting	Improving efficiency, performance and competitiveness.	TRL 1-2 for nanowires TRL 2 for III-V Photonic Crystals TRL 4 for OLED	Technology obstacles. Cost-effective mass manufacturing. Improving durability	Increase nanotechnology market share of $6.8 billion (2009) solid state lighting market.	Europe well represented in research and industry.	

Security

There are numerous challenges facing societies in protecting civilians and civilian infrastructure; events such as the London and Madrid bombings have revealed the weaknesses of security provisions in civilian zones. Nanotechnology developments have the potential to offer improved protection to the civil population from terrorism and crime, and to the emergency responder in their duties.

Application	Needs addressed by nano developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Sensors for explosives detection	Growing demand for miniature, more sensitive and integrated detection platforms for real-time detection and quantification of different explosives, combining sensing and warning functions. Nanomaterial based sensors capable provide sensitivity down to the single molecule level.	TRL 3 for conductive polymer based explosive sensors (1-3 years) TRL 2-3 for cantilever-based explosive sensors (3-5 years) and integrated single platform detection (5+ years).	Cost and availability of high purity raw materials. Lack of collaborative research between security agencies, academia & industry. Technology transfer gap	Increasing nanotechnology market share of global explosive detection market (US market alone forecast to be $420M in 2014)	US trends allow for government validation, whereas EU grants lack resources allocated to fully validate the developed technology; this often inhibits successful technology transfer.	No standardised testing for explosives detectors. Cost effectiveness and reliability of detectors. Lack of skilled personnel availability.
Nanoparticles for forensics analysis	More detailed and accurate detection of fingerprints at crime scenes (engineered silica nanoparticles provide 30% enhancement in performance over existing powders). Potential for more detailed profiling to enhance suspect elimination from future developments.	TRL 4-5 for suspect identification (commercially available) TRL 3 for suspect elimination (expected within 1-3 years)	Specialised laboratory service required for suspect elimination technology. Public perception of nanoparticle safety.	Potentially a very large global market. Pilot studies of the commercialised technology are underway within law enforcement agencies in Australia and Singapore.	Europe is on par with the US and Asia. An increase in forensics publications from China has been observed in recent years.	Ability to apply forensic technique at the crime scene. Issue of privacy of the individual and storing of personal data.
Anti-ballistic protective clothing	Existing technologies provide adequate protection but are bulky. Reduction in weight (carbon nanotubes (CNT) composites lighter than current technologies) and increased shock protection (inorganic fullerenes (IF) have up to twice impact resistance of existing materials).	Both CNT and IF are mass produced (TRL 5); however, CNT composites for these applications are TRL 1-2, and inorganic fullerenes are at TRL 4.	Understanding of physical characteristics of CNT composites is still being investigated. Cost of product validation for developers. Central procurement can stifle innovation.	Large potential global market for protective clothing. The wider Personnel Protective Equipment (PPE) is worth €9.5-10 billion in the EU, and employs 200 000 people globally.	Protective textiles identified as European lead market with considerable political support; however, must compete with high levels of US defence spending driving development.	Highly fragmented market. Potential for dual use commercial applications in extreme sports to provide additional market and drive for technology development.

Textiles

The European textiles and clothing community has recognised that traditional products are no longer sufficient to sustain a viable business, and the EU players, to compete effectively, have to move upward, to more innovative, high quality products. The ability to manipulate individual atoms, and arrange them in a desired structure, at the nanoscale can lead to the development of a new generation of products having new features, performances and functionalities, so enhancing the competitiveness of the innovative players and opening new markets.

Functionality & Application	Needs addressed by nanotechnology developments	TRL and time-frame	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Water repellence (Self-cleaning textiles) Fields of application: Sport & Outdoor Clothing Transport Medical textiles	Nanotechnology unique characteristic is to provide the textile with a new functionality while keeping textile physical properties (softness, appearance, etc.) Consumer demand for high performance/ multifunctional textiles.	TRL 5 for coatings, which are already on the market. TRL 3-4 for products incorporating plasma technology (1 – 5 years to market).	Technical limitations for coating technologies: difficult to achieve the desired particle dispersion; degree of attachment of particles and coatings to the textile. High production costs for plasma technology associated to the purchase of new equipment and the scale-up of the process.	This is the nano-enhanced functionality with a wider market penetration together with antibacterial properties. Market penetration is lower than 1% (Together self-cleaning and antibacterial); however, a number of products are on the market.	USA has a leading position in this sector. Most active countries in Europe are Switzerland and Germany.	Scepticism of industry concerning the added value of coating technology. The Hohenstein institute (DE) is developing a quality label for textile products incorporating this nano-enhanced functionality
Anti-bacterial & Moisture Management Fields of application: Clothing & apparel Sport & Outdoor Technical textiles (medical textiles, transport textiles)	Consumer demand, due to changing lifestyles, for high performance/ multifunctional textiles Unchanged physical properties of products. Synthetic fibres provide wicking and drying capabilities for high performance materials.	TRL 5 for anti-bacterial properties. TRL 4 for moisture management	Possible health and safety concerns of consumers. Increase of cost associated with production of moisture management materials.	There is a wide selection of antibacterial products which have reached the open market, and there are also a number of moisture management products available.	USA leads in the clothing sector, including sports & outdoors, followed by China and Japan; however, Switzerland and Italy are active. Europe has a good position in the medical, and moisture management, textiles field with main competition coming from China.	Several studies are being carried out to analyse the possible side-effects of silver ions. The Hohenstein institute (DE) is developing a quality label for textile products incorporating this nano-enhanced functionality

Figure 2: WOS publication in four main regions by year

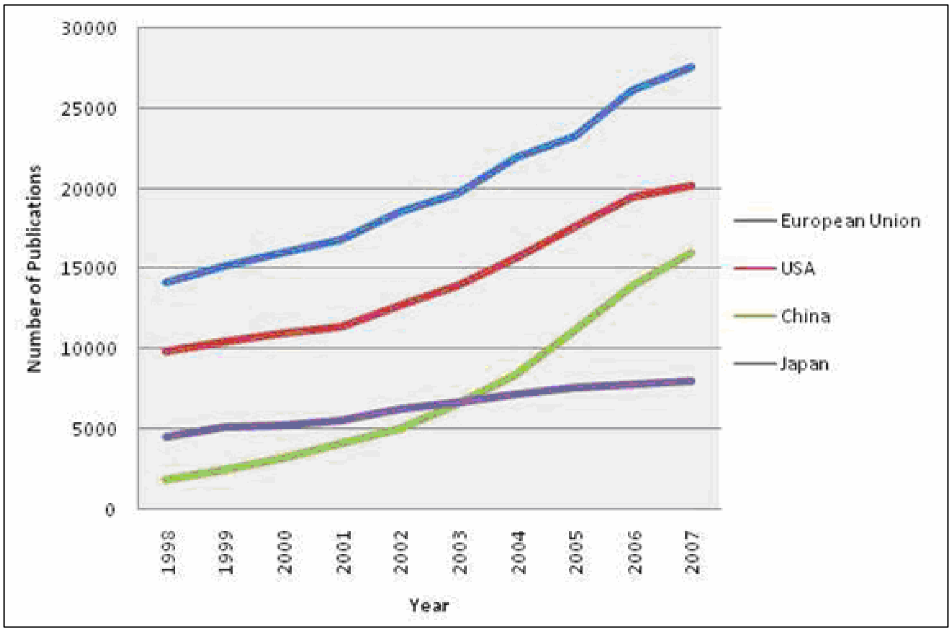


Figure 3: EU countries with more than 2000 Nano publications (1998-2007)

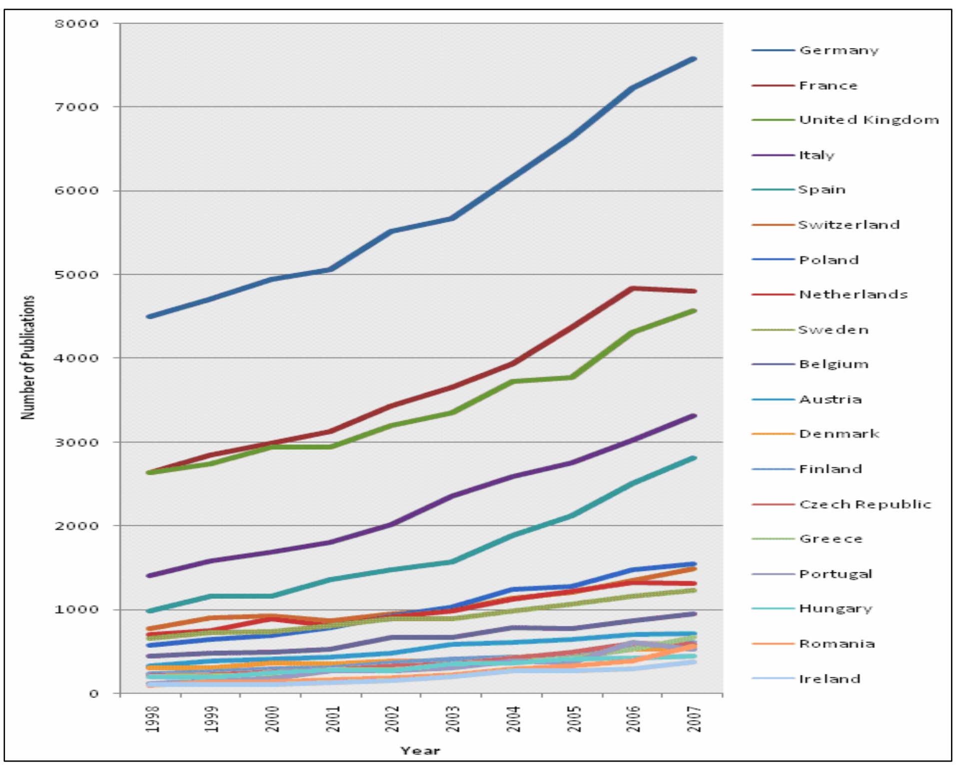


Figure 4: Nano-publications by sector in EU, 1998-2007

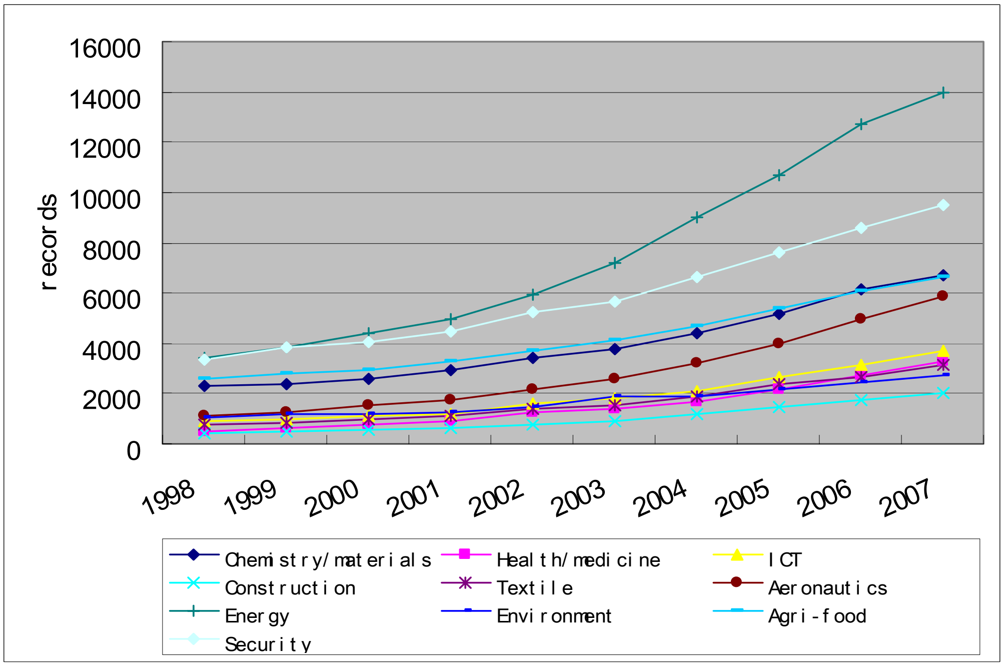
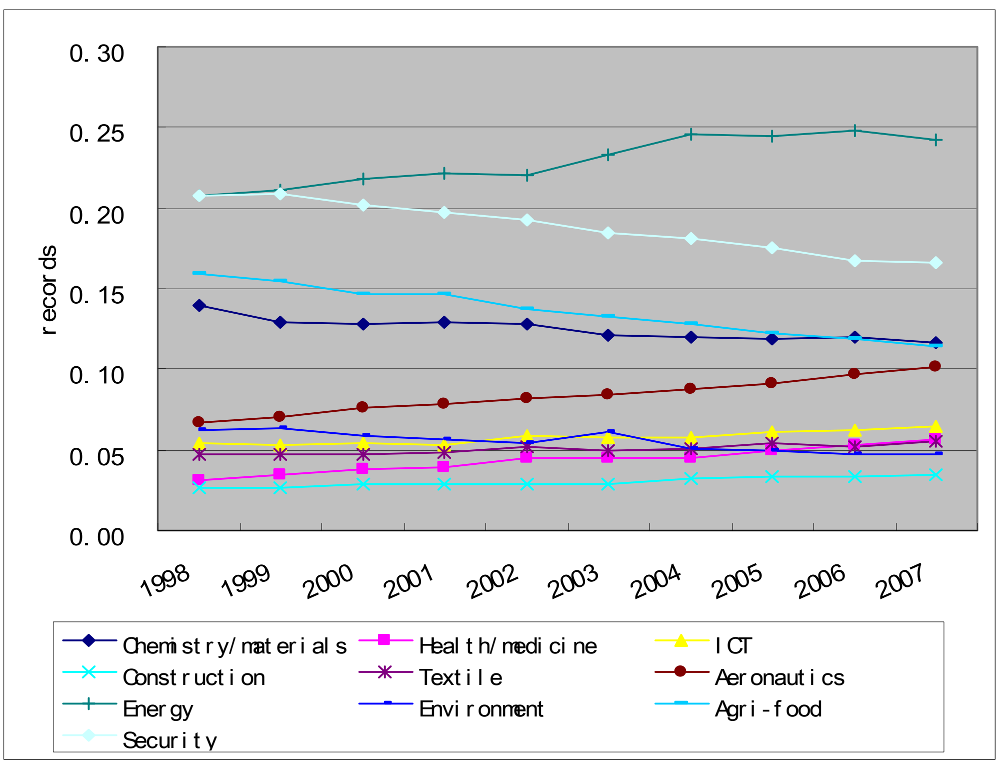
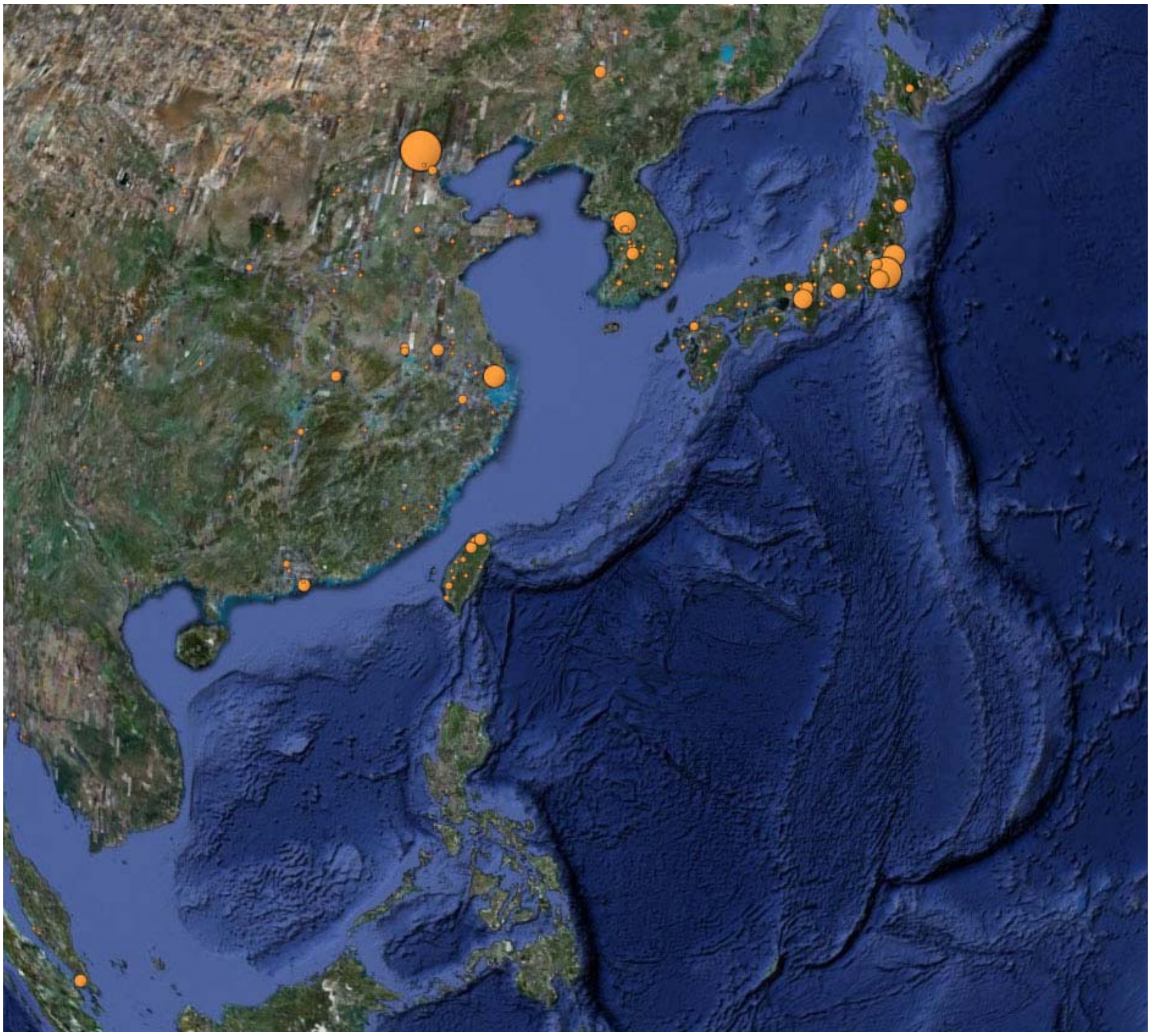


Figure 5: Percentage of Nano-publications by sector in EU, 1998-2007



Utilising Google Earth, Figure 6, 7 and 8 show the publication activities in East Asia, Europe and North America respectively. All cities with at least 100 Nano publications between 1998 and 2007 are highlighted.

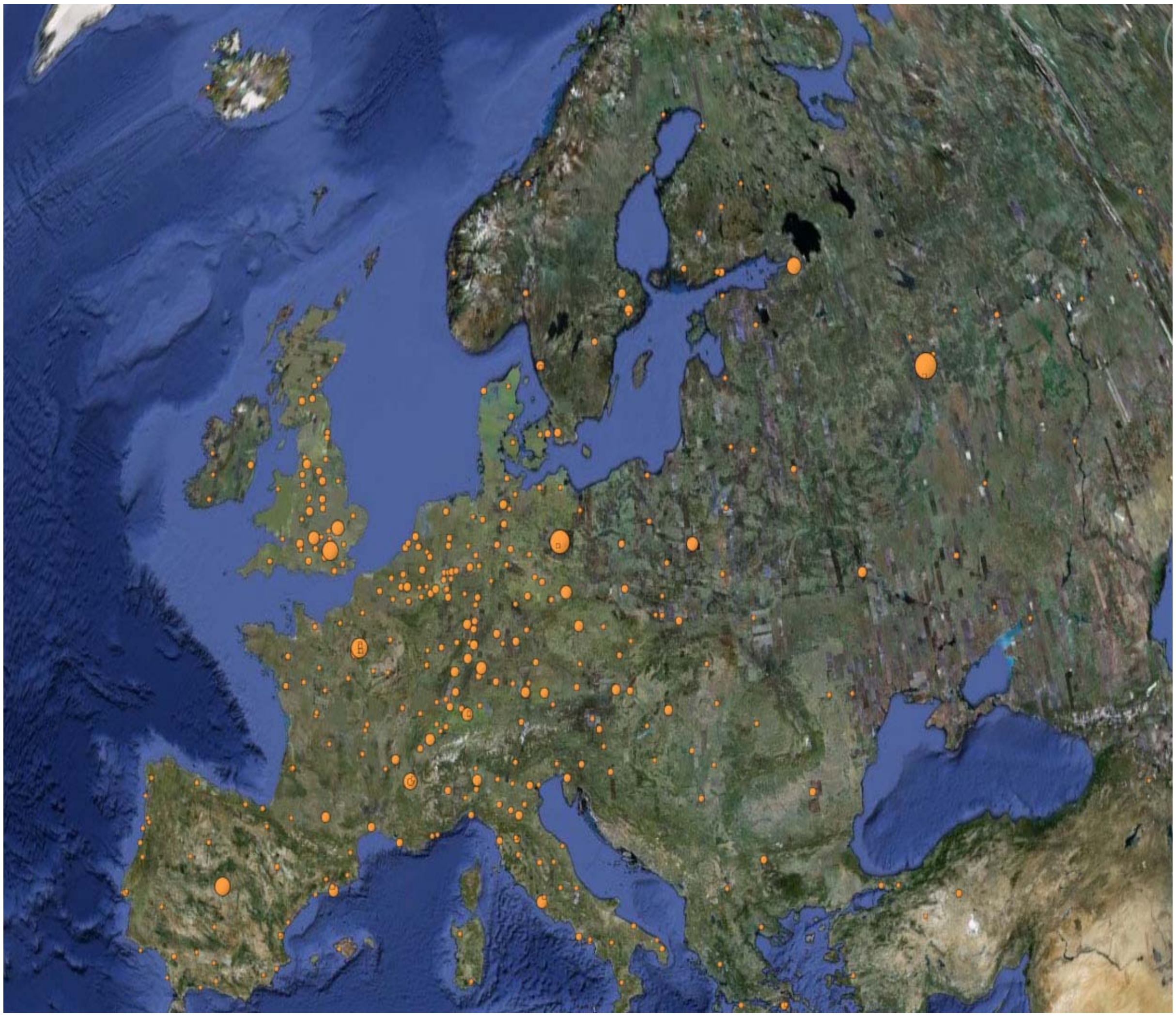
Figure 6: East Asia



Top cities in this region include:

1. Beijing 2. Tokyo 3. Ibaraki 4. Shanghai 5. Seoul	6. Osaka 7. Kanagawa 8. Singapore 9. Teajon 10. Taipei	11. Hsinchu 12. Nanjing 13. Hong Kong 14. Kyoto 15. Aichi

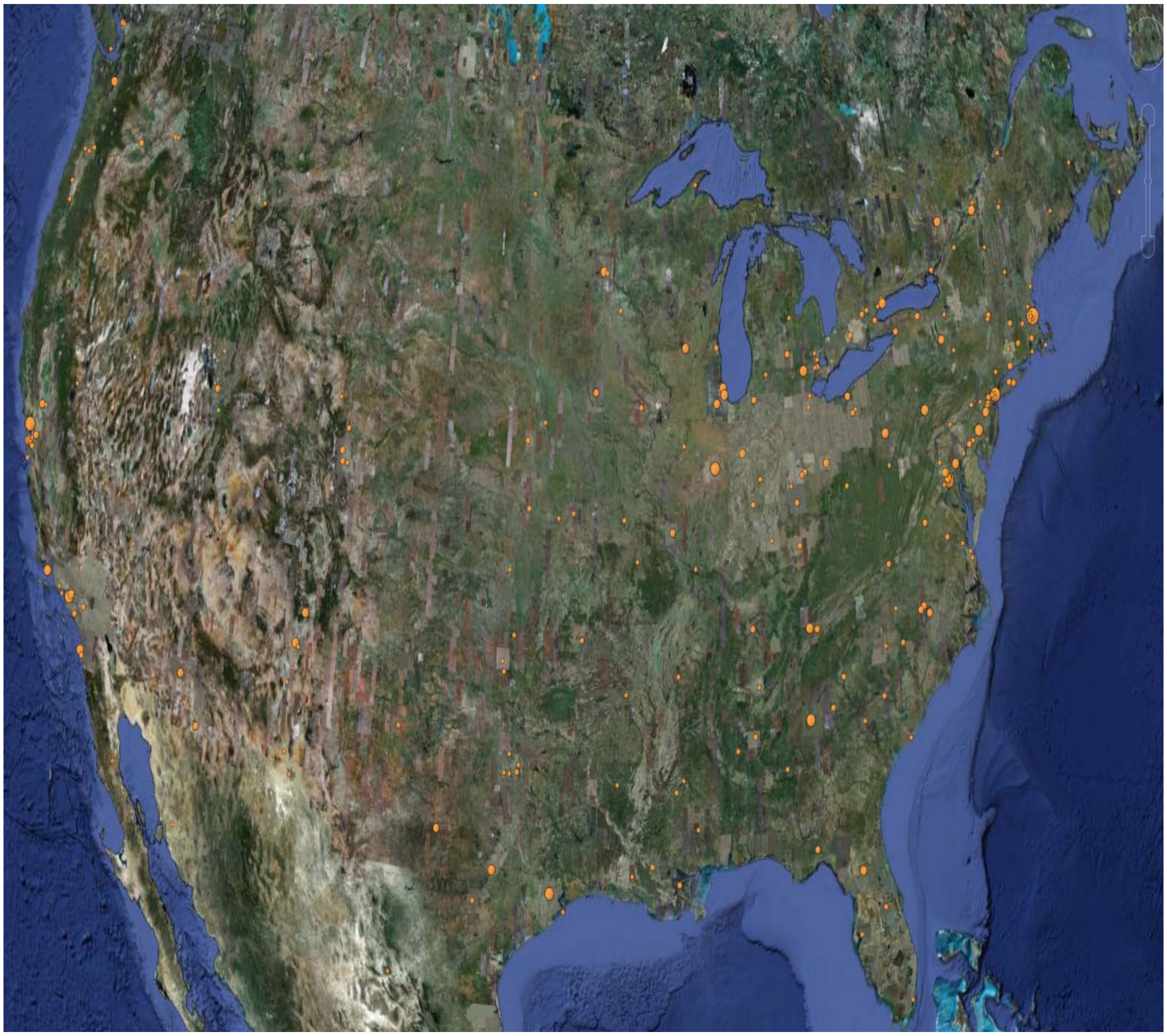
Figure 7: Europe



Top cities in this region include:

1. Moscow 2. Berlin 3. Paris 4. London 5. Madrid	6. Grenoble 7. Cambridge 8. Oxford 9. Dresden 10. Warsaw	11. St. Petersburg 12. Stuttgart 13. Zurich 14. Rome 15. Milan

Figure 8: North America



Top cities in this region include:

1. Cambridge, MA 2. Berkeley, CA 3. Urbana, IL 4. Atlanta, GA 5. New York, NY	6. Princeton, NJ 7. Houston, TX 8. Ann Arbor, MI 9. Los Angeles, CA 10. Washington, DC	11. Stanford, CA 12. Santa Barbara, CA 13. La Jolla, CA 14. Austin, TX 15. Philadelphia, PA

Figure 9 to 12 presents more detailed information on publication distributions in Europe.

Figure 9: EU Nano-publications (1998)

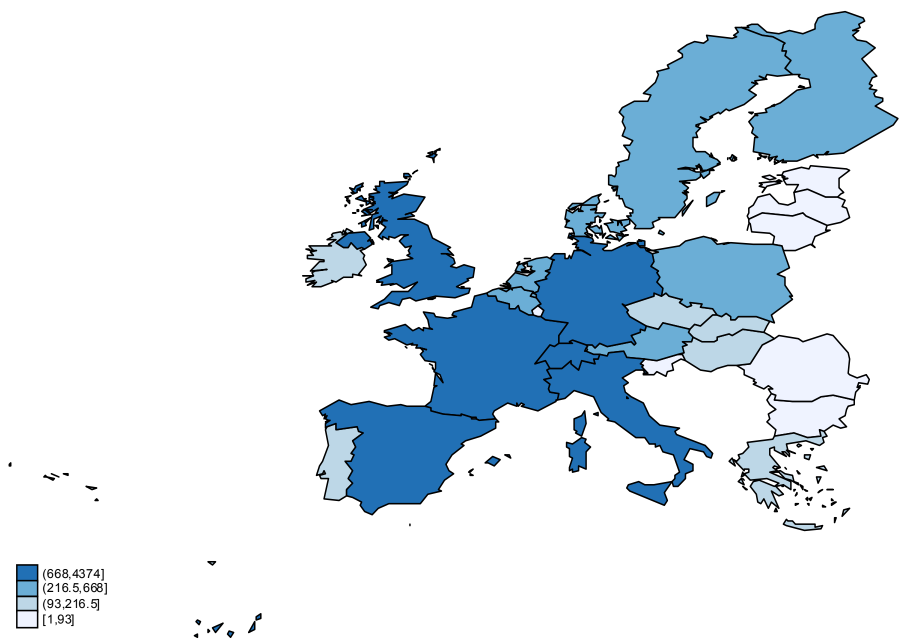


Figure 10: EU Nano-publications (2007)

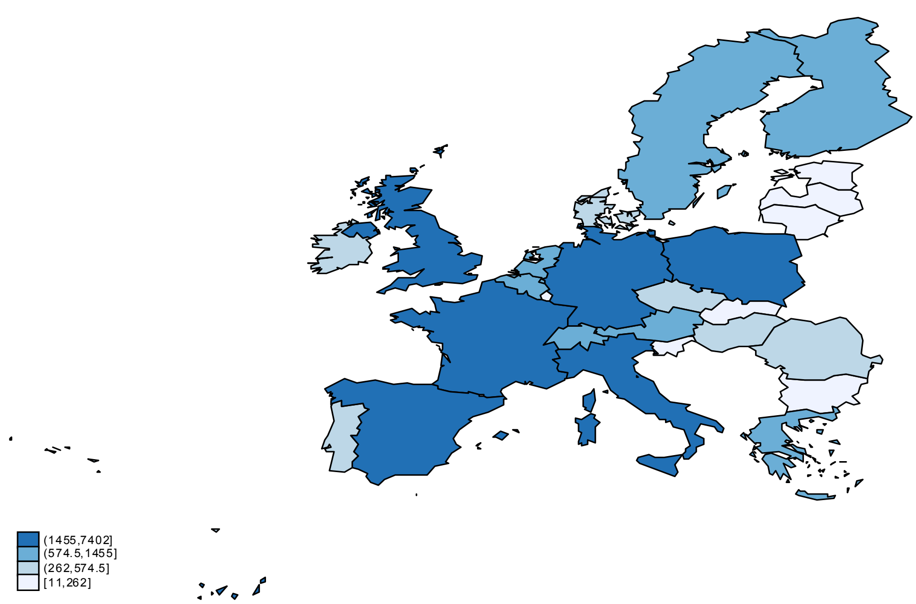


Figure 11: EU Nano-publication density (1998)

(publication records per 1000 persons)

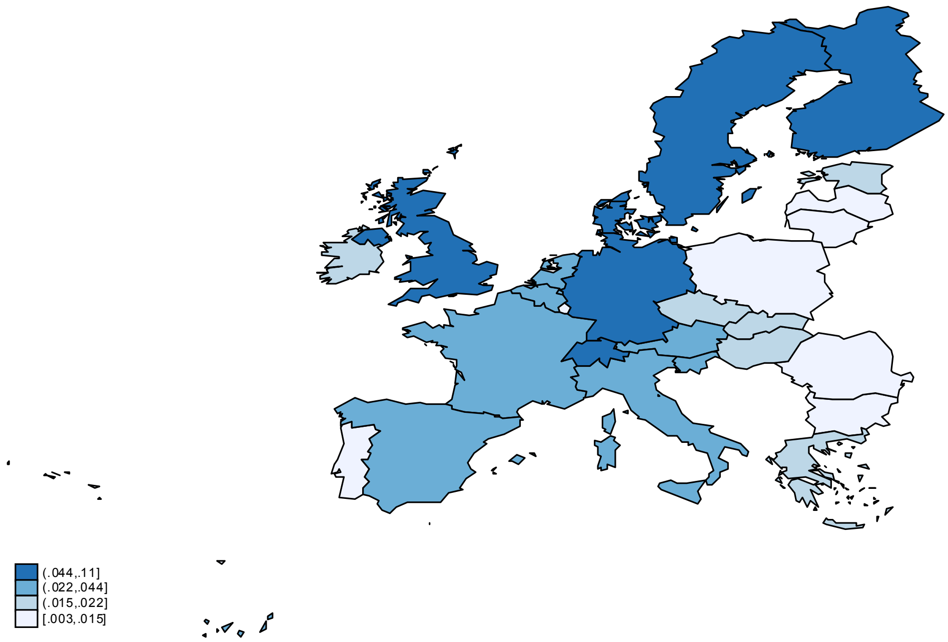


Figure 12: EU Nano-publication density (2007)

(publication records per 1000 persons)

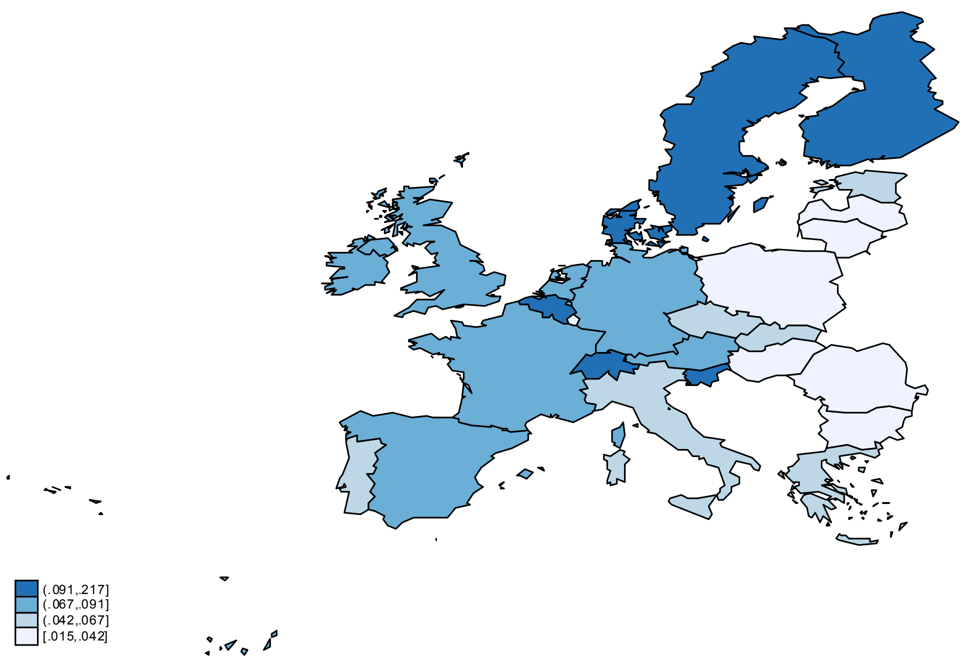
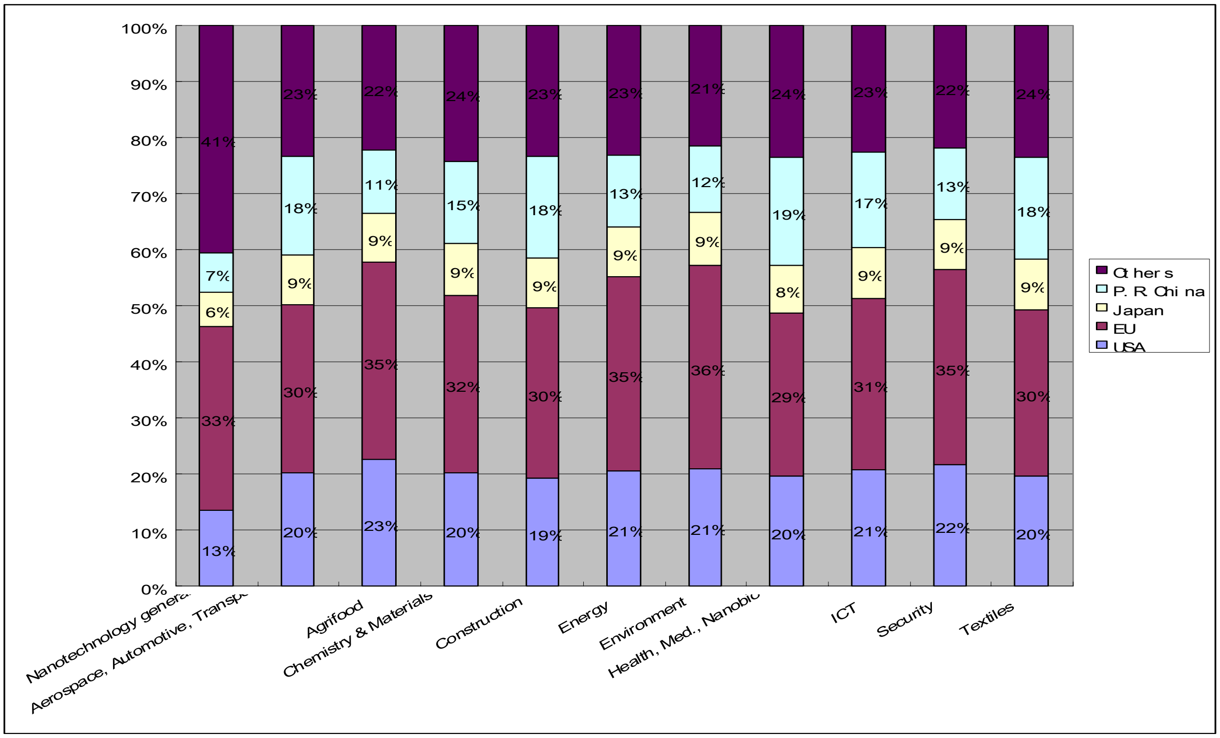


Figure 13: comparison of publications applicants in individual technology sectors between EU-27 and major competitors (all shares in %)



Statistical Analysis of Patent Applications in Nanotechnology

All data is based on the free online patent service "esp@cenet" and on the "Worldwide Patent Statistical database" (PATSTAT) of the European Patent Office (EPO))

Figure 14: development of worldwide nanotechnology patent applications (1987 - 2007)

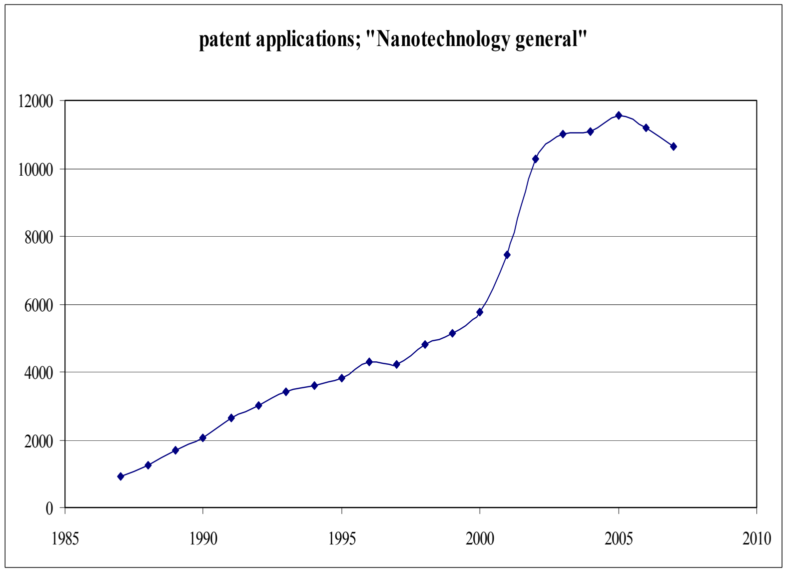


Figure 15: assignment of nanotechnology patent applications to countries according to first priority application

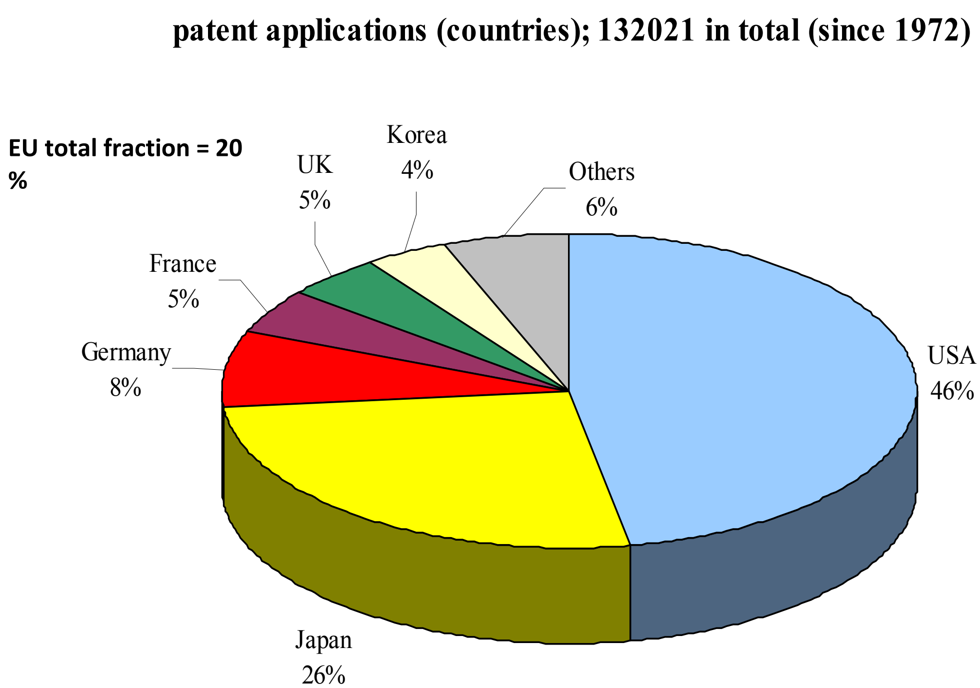


Figure 16: assignment of nanotechnology patent applications to technology sectors

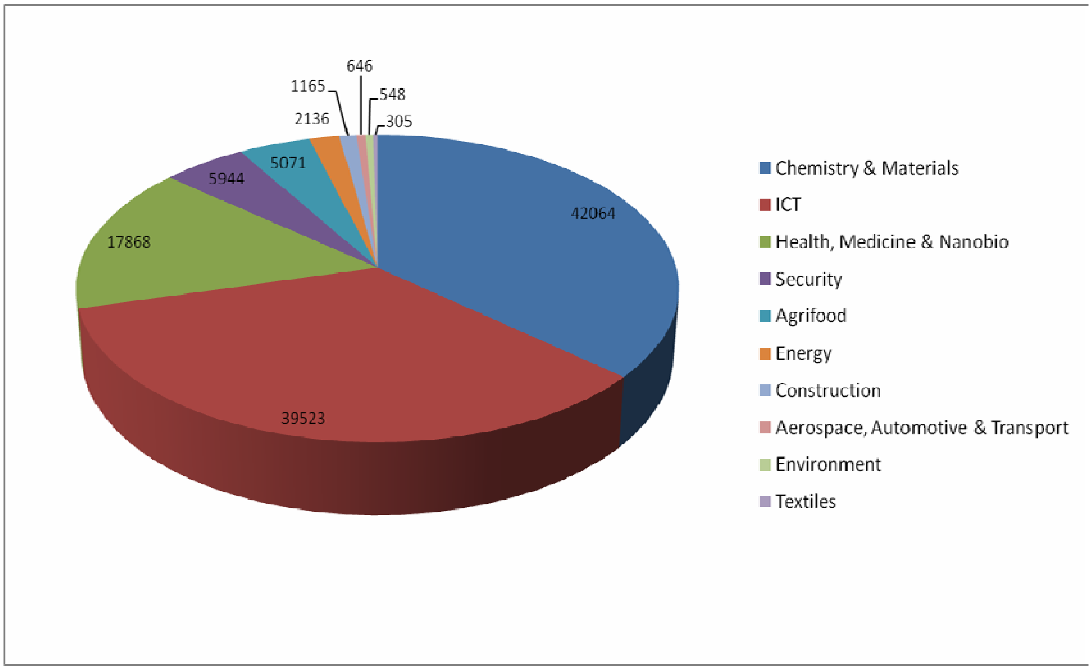


Figure 17: comparison of patent applications in individual technology sectors between EU27 and major competitors (all shares in %)

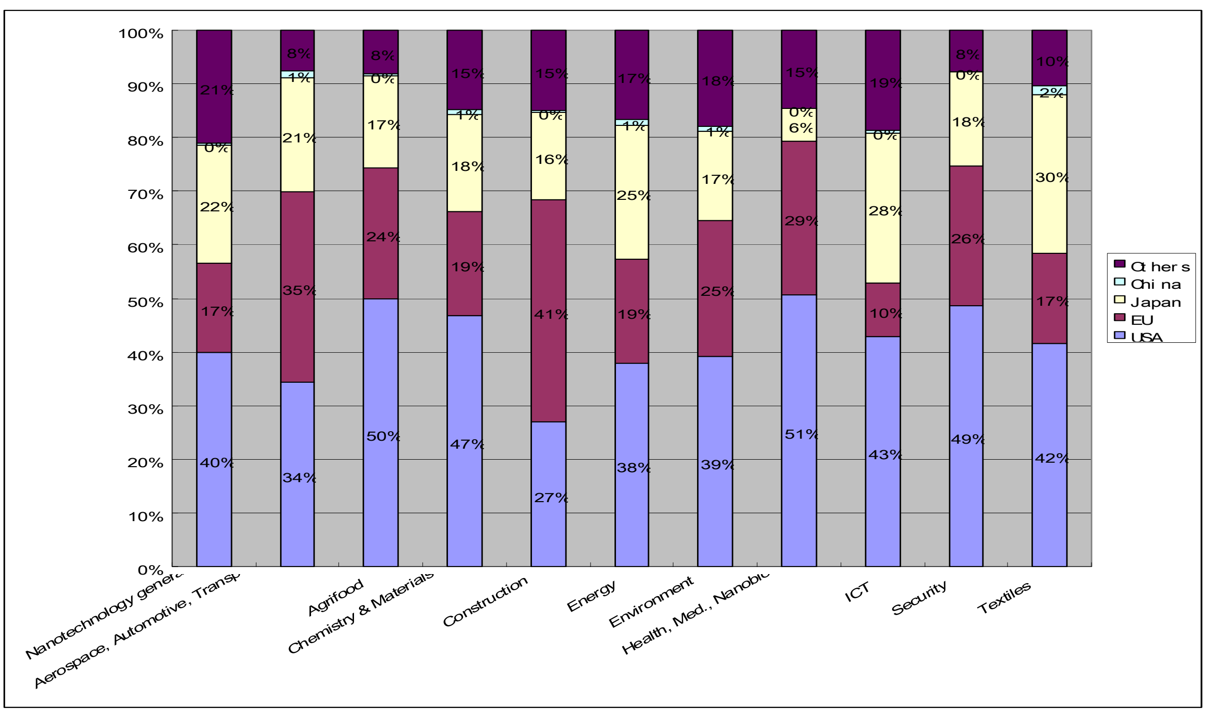


Figure 18: EU Nano-patent applications (1998)

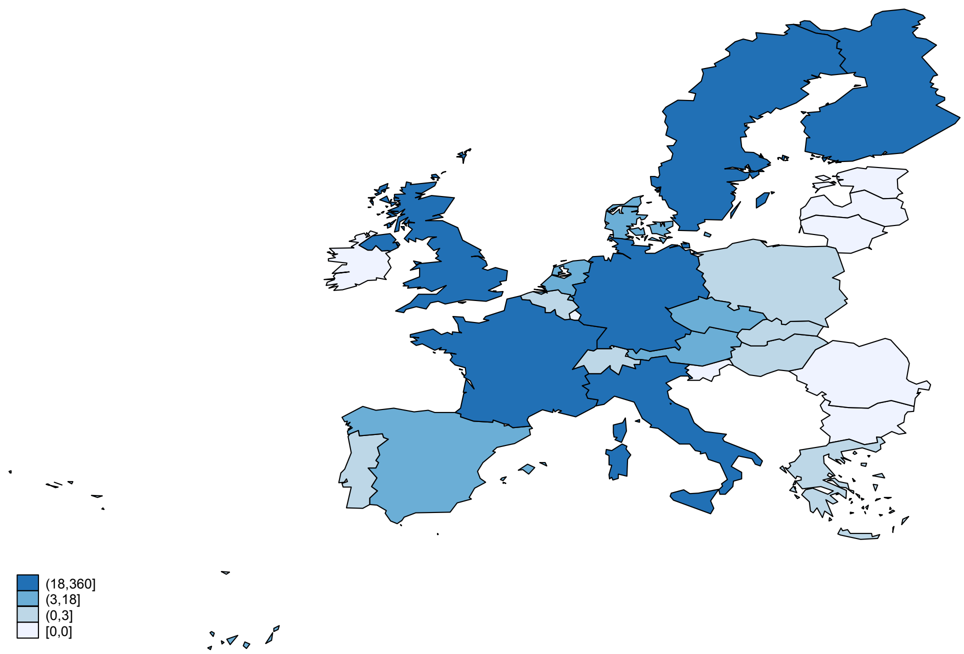


Figure 19: EU Nano-patent applications (2007)

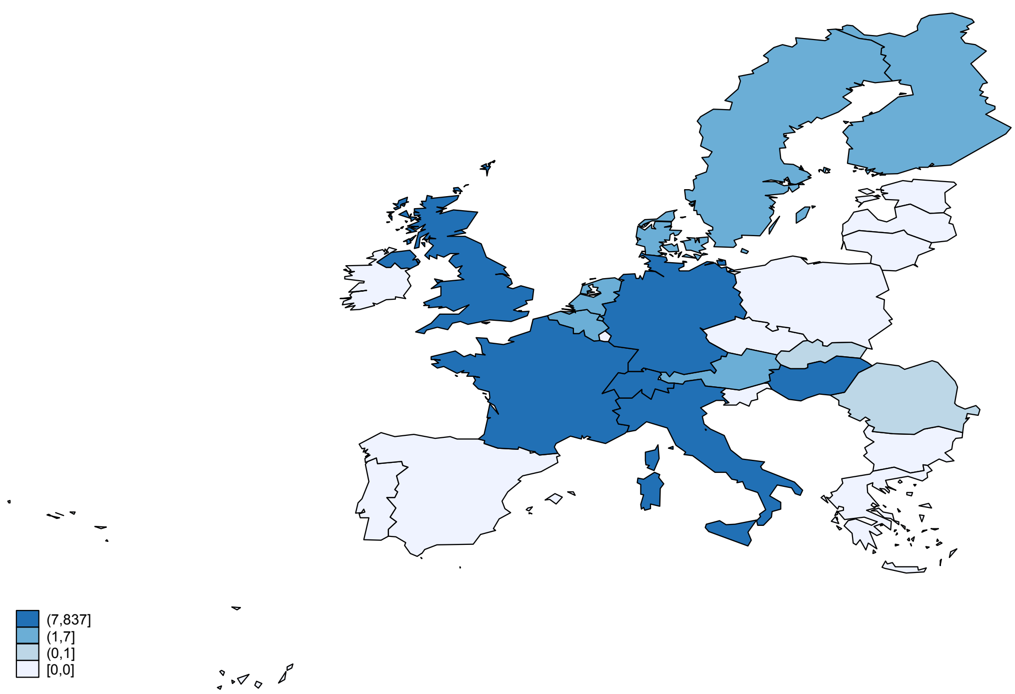


Figure 20: EU Nano-patent application density 1998

(patent application numbers per 1000 persons)

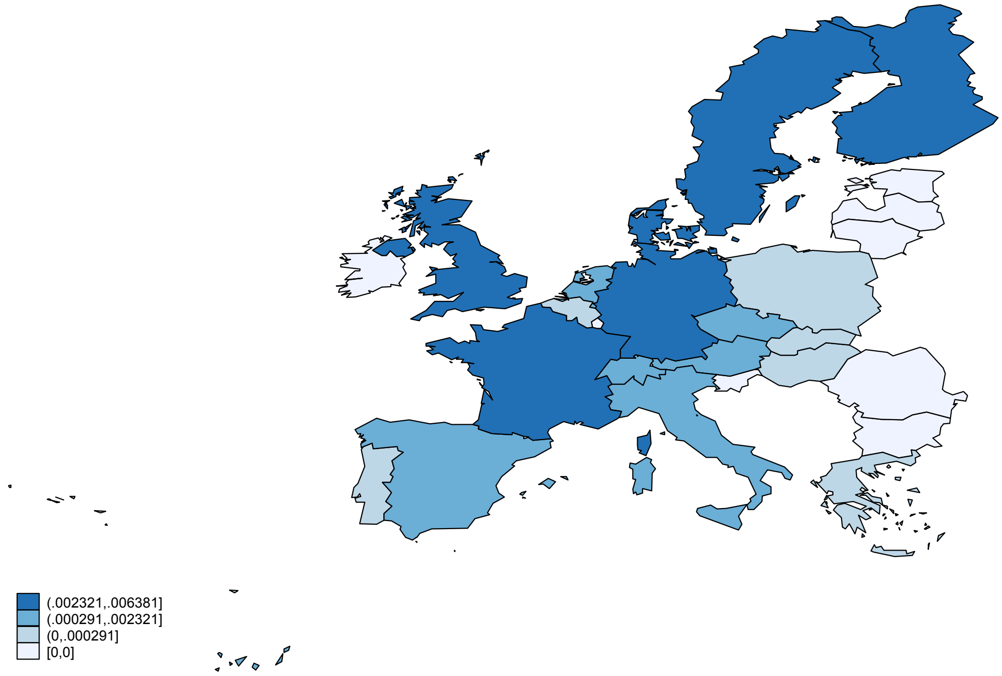
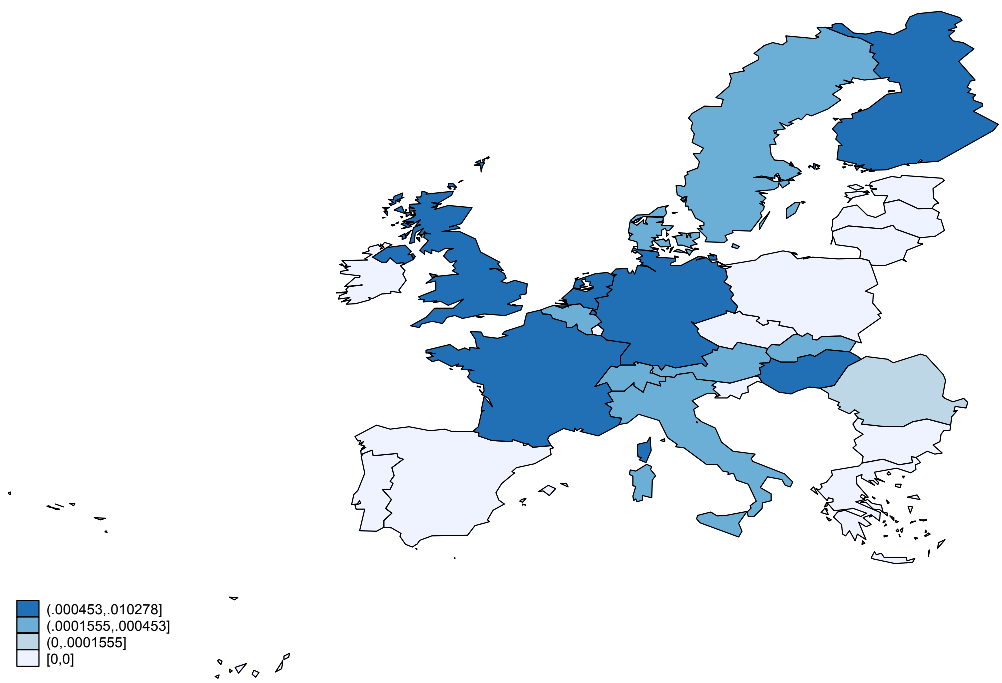


Figure 21: EU Nano-patent application density 2007

(patent application numbers per 1000 persons)



Ratios of Patent Applications to Publications

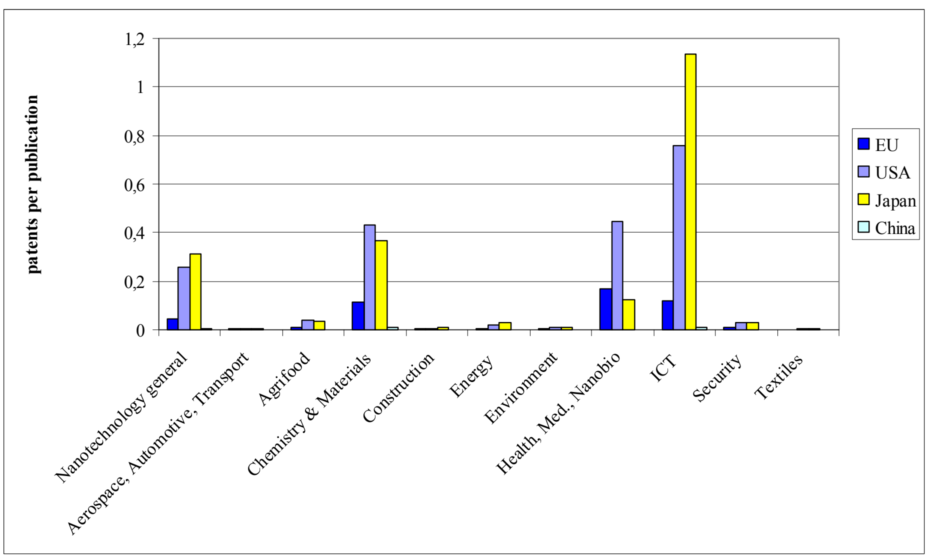
All data is based on "Web of Science", the free online patent service "esp@cenet" and on the "Worldwide Patent Statistical database" (PATSTAT) of the European Patent Office (EPO).

The numbers of publications and patent applications were derived for "nanotechnology in general", the ten technology sectors, and each for EU-27, USA, Japan, and China. From these data the ratio of patents per publication ([number of patent applications] / [number of publications]) was calculated. This ratio may represent an indicator for the "research-to-application efficiency".

Remarks regarding the data analysis:

- China currently has a low contribution due to the, as yet, relatively low number of patent applications. However, the number of Chinese publications has increased considerably in recent years. A delay between front end research and patent applications is generally accepted and as such we can expect an increase in Chinese patent activity in the future.
- In the ICT-sector Japan has a patent-per-publication ratio of more than "1", suggesting that Japan has more patent applications than publications in this sector.
- The calculated patent-per-publication ratio is highest for three technology sectors ("Chemistry & Materials", "Health, Medicine, Nanobio" and "ICT"). The other sectors have considerably lower ratio values. These three sectors may be seen as the most fundamental ones especially for patenting; it more likely that an automotive-electronics patent application will be considered in the ICT-sector instead of the transport sector.
- For "nanotechnology in general" the EU lagging behind Japan and the US in the research-to-application transition.

Figure 22: Ratio of the number of patent applications and the number of publications for "nanotechnology in general" and the ten technology sectors in EU-27, USA, Japan, and China.



Due to the large differences of the values, and the scaling effects of Figure 22, a comparison is difficult. A logarithmic plot points out the weaker sectors in particular (Figure 23). Due to the scaling effect Figure 24 and Figure 25 display the stronger and the weaker sectors separately.

Figure 23: Ratio of the number of patent applications and the number of publications (logarithmic scale) for "nanotechnology in general" and the 10 technology sectors in EU-27, USA, Japan, and China.

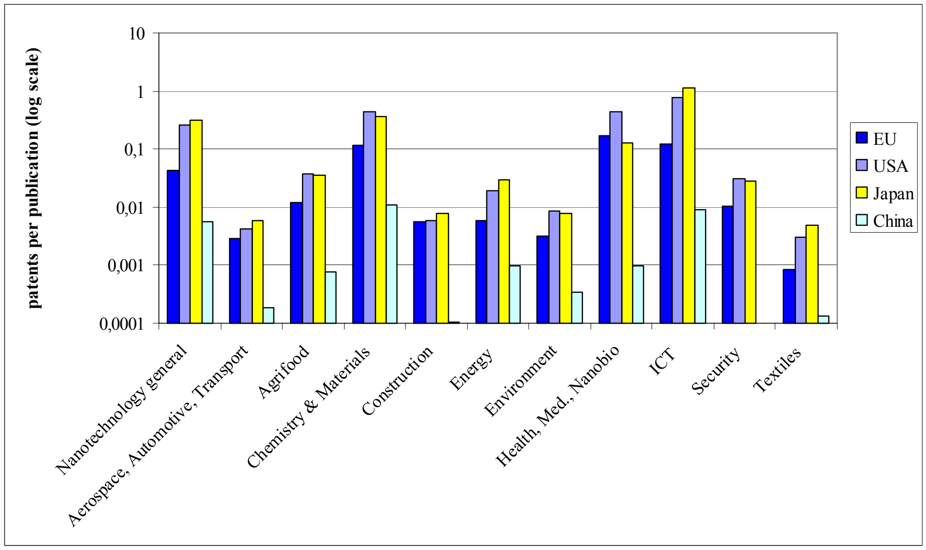


Figure 24: Ratio of the number of patent applications and the number of publications for "nanotechnology in general", "Chemistry & Materials", "Health, Medicine, Nanobio" and "ICT" in EU-27, USA, Japan, and China.

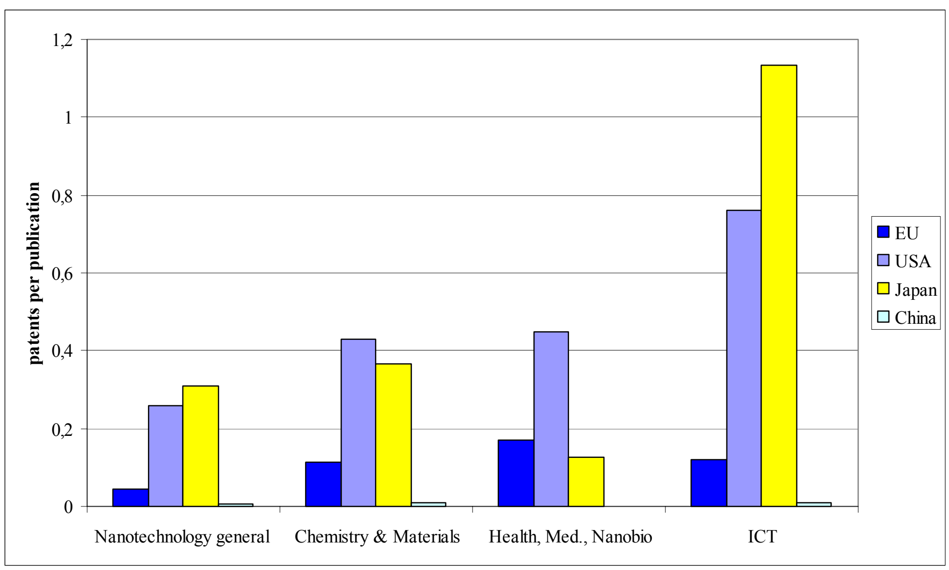
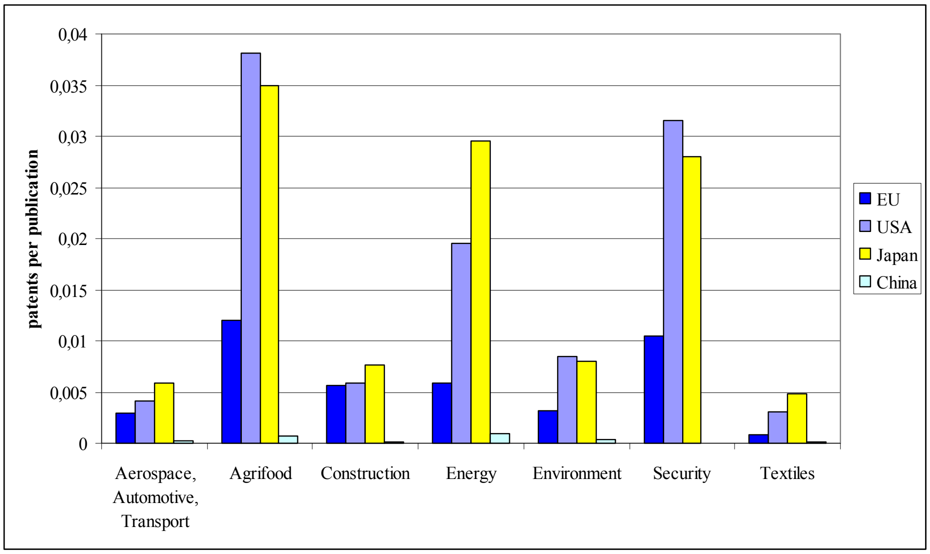


Figure 25: Ratio of the number of patent applications and the number of publications for "Aerospace, Automotive & Transport", “Agrifood”, “Construction”, “Energy”, “Environment”, “Security” and “Textiles” sectors in EU-27, USA, Japan, and China.



Nanoethics and ELSA issues

Nanotechnology is not being developed in a vacuum, but is embedded in a societal context which is continuously changing due to other, non-technological trends. Some of these other societal trends influence the development of nanotechnology in general. These include education and training for researchers and industrial employees, ethics education for natural scientists and engineers and the risk averse culture which is predominant in Europe, but not so much in other parts of the world. The application of nanotechnology in individual technology sectors also gives rise to or is confronted with specific Ethical, legal and societal issues.

Technology sector	**Application**	**Related nanoethics & ELSA issues**
Aerospace, Automotive & Transport	Nanomaterials	Life cycle of nanomaterials. Employees safety.
	Aerospace	Dual use aspects (civilian & defence): security, privacy
	Automotive	Road pricing using chipcard technology: privacy.
Agrifood	General	Risk perception and sensitivity of consumers regarding food ingredients, consumer choice, sustainability, food safety and food security, competition food and non-food applications and increasing food prices.
Chemistry & Materials	General	Sustainability, precaution, consumers and employee safety.
Construction	General	Sustainability (e.g. zero emission houses). Special needs of people in developing countries: low cost, earth quake resistant housing.
Energy	General	Sustainability, competition renewable/non-renewable energy production.
Environment	General	Sustainability
Health, Medicine and Nanobiotechnology	General	Sensitivity of consumers regarding ingredients of cosmetics; the debates on human enhancement and synthetic biology which are not only related to nanotechnology but may also influence acceptance of medical nano and nanobiotech, neuro-nanoethics, animal testing, general bioethics. Social and global justice.
	Drug delivery	Potential biosecurity implications (tricking immune system)
	In vivo Imaging	Early diagnostics: right (not) to know, possibly increased anxiety, changing definition of health.
	Regenerative medicine	Embryonic stem cells; cloning; cell transplantation; stem cell research and therapy. Genetic diagnoses, commercialisation, Medical technology in developing countries, Cord blood banking. Therapeutic or enhancing use of medicine.
Information and Communications Technology	General	Ambient intelligence debate, privacy, moral design criteria. Neural implants and brain-machine interfaces.
Security	General	Balance security – liberties (EU Charter for Human Rights), privacy, moral design criteria.
Textiles	General	Life cycle. Toxicity and ecotoxicity (nanosilver).