ObservatoryNANO Factsheets
March 2011

Introduction to Factsheets

This second set of ObservatoryNANO 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:

- Challenge;
- Nano-enable solution;
- Technology Readiness Level (TRL);
- Barriers to commercialisation;
- Measure of impact;
- The competitive position of the EU;
- EHS, ELSA and 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.

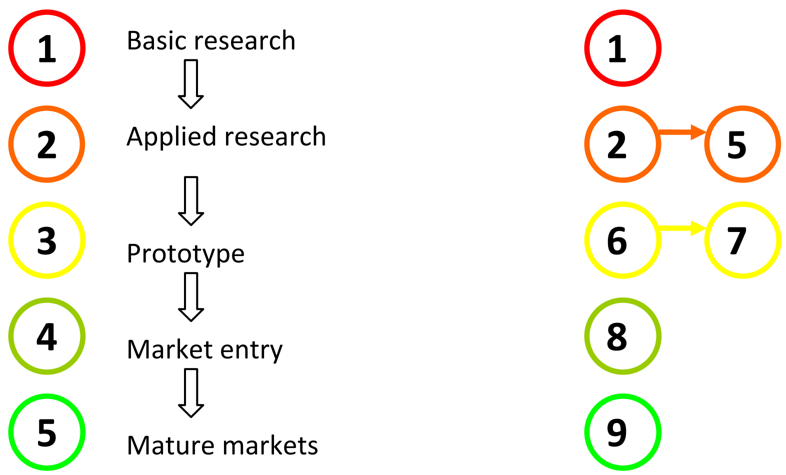

Figure 1: ObservatoryNANO TRL scheme (left) corresponding to the defence standard nine-point scheme (right).

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 during 2010; 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

In this sector the all-important challenge is that of CO_2 emission reduction, which leads to several key derivative challenges that can be summarized by weight reduction, drive train efficiency gain and electric car battery economics (both in terms of weight and monetary cost per KWh stored).

Challenge	**Nano-enabled solution**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
Need for low-cost, lightweight vehicles	Nanocomposites	**2-5** depending on the specific nano-particles or nano-fibres involved	• 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 (PNC) 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.	**EHS:** Potential for release and subsequent exposure of manufacturers and users of nanomaterials during machining and manipulation should be given consideration. ***Other:*** Work on thermoplastic composites in particular is gaining importance and can bring cost effective breakthroughs as well as real recyclability (very hard with existing thermoset composites).
	Nanostructured metals	**4-5** for small parts (e.g. screws) **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 aircraft 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.	***Regulations:*** Especially in the aeronautics sector, lengthy certification processes slow down adoption of new materials.
Need for low-cost, low-mass electric energy storage	Nano-structured anode and cathode materials Nano-separator films	**2-5** depending on specific materials used (some are already mass-marketed whereas others are not beyond lab scale trials)	• Stability of the nanostructure • Lack of clarity with regard to 'winning' material limits available funding for upscaling	• Current impact is limited • Future impact both in terms of cost reduction and reduced dependence on scarce elements may be substantial	Several large industry as well as university spin-off ventures have strongly developed their IPR position; however, China and USA remain leaders with more upscaling experience	***Other:*** Many global automotive players see main automotive market growth in Asia, but expect fastest growth for some types of 100% e-vehicles to take place in Europe (e.g. delivery vans).

Need for internal combustion and jet engines and their drive trains that are more energy-efficient with lower emissions	Nano-coatings, and lubricants	**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.	***EHS:*** The potential for release of nanomaterials and subsequent exposure of those using the coatings should be considered. ***Other:*** Incremental nature of innovations in this area has been eclipsed by the e-car 'hype'; however, very substantial CO2 reductions can be obtained with these technologies and is widely adopted.
	Nano fuel additives Nano-enabled low-rolling resistant tyres	**4-6** depending on additive	• Fuel additives often fail to reach significant fuel savings • Incumbent fuel suppliers perceive risks of longer term issues either with engine wear or with health issues through emissions	• Fuel additives are being used already also by mainstream oil companies. Nano character not always highlighted. • Low resistance tyres can bring 3-5% fuel efficiency gains for any vehicle on rubber tyres at a marginal added cost	Strong both in fuel additives as well as in tyre additives. Some of the EU headquartered tyre companies are perceived as innovation leaders in their sector, especially Michelin and Pirelli.	***EHS:*** It is correct to hold concern that fuel additives could eventually be released into the environment. On that basis, there is a need to investigate toxicity of and potential for exposure to any NMs used. Cerium Oxide, one NM which has been suggested as a fuel additive, has been indicated as harmful in toxicity studies to date.

Agrifood

Drivers in nanotechnology for the Agrifood sector revolve around health (nutraceutical delivery) and safety through advance antimicrobials and pathogenic food-borne bacteria detection

Challenge	Nano-enabled solution	TRL	Barriers to commercialisation	Measure of Impact	EU's competitive position	EHS, ELSA & other issues
Antibacterial and antimycotic packaging to reduce risk of pathogenic food borne bacteria whilst inhibiting migration of antimicrobial into the food.	Two solutions have emerged: Antimicrobial functionalised nanoclay-platelets fixed into a polymer matrix (minimal to no migration of antimicrobial) Natural and edible antimicrobial nanofilms	**4-5**: In Europe scale up of composites production sites with functionalised nanoclays means they are available for use. **3-4**: Field of edible nanofilms is maturing with nanocomposite films (with natural antimicrobials such as chitosan) are available.	• Conservative food packaging industry (although easier now food contact material legislation is becoming clearer) • Limited production capacity for edible nanocomposite films	• Predicted rapid growth in this area over the next 2-3 years • Antimicrobial properties with no negative effect from migration or ingesting antimicrobial • Improved performance • Job creation	Strong position due to acquisition of venture capital for scale out.	***EHS***: Potential workers exposure for manufacturers, exposure for professional users who package food and consumers depending on level of fixation in matrix; on disposal, there is environmental exposure. Hazard and risk assessment to be completed on a case-by case basis. ***ELSA:*** Citizens should be well-informed about the state of the art of nanotechnology in food packaging. They are more concerned with good information than with avoiding risks. ***Regulation***: New measures on food contact materials comes into force in May 2011 stating clearly that plastics using nanomaterials should be assessed on a case-by-case basis.
Increased bioavailability of lipophilic components (such as fatty acids, vitamins, antioxidants, carotenoids, and phytosterols)	Nano-laminated coatings using food-grade (GRAS) ingredients to improve the bioavailability of lipids within the gastrointestinal tract	**1- 3**: In Europe is at R&D and prototype stage. There is more exploration of tailoring the manufacturing process for different delivery systems rather than exploitation of current knowledge	• Large scale production facilities not in place (though information on this is difficult to obtain from large nutraceutical developers)	• A real driver for such an innovation is that the nutrients delivered through the gut are thought to have an effect on various cancers, heart disease, hypertension, obesity, and diabetes.	Excellent position in R&D in both nutraceuticals and in multi-layered nano-emulsions (which is necessary for this technique)	***EHS***: potential workers exposure for manufacturers, exposure for consumers; on disposal, potential exposure of surface water, soil after excretion out of the human body. Hazard and risk assessment to be done on a case-by case basis. ***ELSA:*** citizens should be well-informed about the state of the art of nanotechnology in food. They are more concerned with good information than with avoiding risks.

Rapid detection of pathogenic food borne bacteria in food processing industry	Nano-enabled immunoassays	**1-3**: One (of many) examples is the Nucleic acid lateral flow immunoassay to detect pathogenic Listeria (which usually takes several days).	• For such devices it is a matter of acquiring venture capital for up valuing these assays developed in University labs and Research Centres. • Lack of visibility of this technology in the food processing industries is seen as the major bottleneck of this technology	The ability to detect pathogenic food borne bacteria and to locate the source in the food value chain, keeping with the example, reducing the risk of listeriosis.	A strong position in R&D in this field. Limited up-valuing opportunities post demonstration.	***EHS:*** Significant direct environmental exposure is unlikely but, in the waste stage, environmental exposure and effects may occur. It is hard to predict what kind of materials may enter waste streams, thus hampering the assessment of any (potential) risk. Regarding human safety, applications will be in vitro, and nanomaterials will be embedded in the devices, both implying there is likely to be little significant human exposure during use. There could, however, be potential worker exposure during product manufacturing and environmental exposure resulting from the process.

Chemistry & Materials

Chemistry & Materials is a fundamental subject and represents the basis for applications of nanotechnology as covered by the other nine more application oriented technology sectors. With respect to the more fundamental character of this technology sector, the table below describes the most relevant nano-materials instead of applications.

Challenge	**Nano-enabled solution**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
Providing efficient and cost effective fillers for rubber, tyres, pigments etc.	Carbon Black	**5**	• Industrial scale production and commercialisation already achieved.	• Utilisation in mass markets (tyres, toners etc.)	EU among the leaders in Carbon Black production	***Regulations:*** As described within the REACH regulations, potential risks in the manufacture and use of all chemicals must be considered. Implications of NMs within the REACH guidance are currently under review.
Enabling new electronics (beyond silicon), new displays, new PV-cells, strong and conductive composite materials	Graphene	**1-2**	• Remains at research stage. • Numerous scientific and technological questions remain open.	• Promising perspectives, but no impact as yet	Numerous research institutions involved in Europe, problems with research-to-application transition.	***Regulations:*** As described within the REACH regulations, potential risks in the manufacture and use of all chemicals must be considered. Implications of NMs within the REACH guidance are currently under review.
Providing water resistant, light weight, highly porous and conductive materials, suitable as electrode materials or thermal insulation	Carbon Aerogels / Organic Aerogels	**4-5:** electrode materials and energy storage **4**: thermal insulation and light weight applications	• Reliable volume production at a reasonable price remains an issue.	• Niche markets at present, but rapidly growing	Numerous research institutions involved in Europe, problems with research-to-application transition.	***Regulations:*** As described within the REACH regulations, potential risks in the manufacture and use of all chemicals must be considered. Implications of NMs within the REACH guidance are currently under review.
Thermal and acoustic insulation, lightweight construction, catalysts, filtration, particle sensors,	Inorganic Aerogels	**4-5**: for thermal insulation **2**: acoustic insulation **3**: catalytic	• High brittleness • Demand for aerogels that are mechanically stable and more water resistant. • Reliable, cheap volume		Research activities mainly focused in the US; Europe playing only a minor role	***EHS:*** High dust production during material installation leading to high potential for worker's exposure. ***Regulations:*** As described within the REACH regulations, potential risks in the manufacture and use of

shock absorbers		applications **3**: other applications	production remains an issue. • SiO_2 aerogels have to be protected against humidity, which is costly.			all chemicals must be considered. Implications of NMs within the REACH guidance are currently under review.
Multi-purpose wear-resistant coatings	Non-oxide nano-ceramic films	**2**: overall (e.g. boron nitride (BN)) **4**: tungsten carbide (W_2C)	• Lack of controllable, reliable, and reproducible production methods for most non-oxide nano-ceramics	• W_2C rapidly gaining application interest		***Regulations:*** As described within the REACH regulations, potential risks in the manufacture and use of all chemicals must be considered. Implications of NMs within the REACH guidance are currently under review.

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.

Challenge	**Nano-enabled solution**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
Developing environmentally -friendly cement production processes	Cement-based materials: use of nano additives (e.g. fly ash, limestone, pozzolan, etc) to both replace clinker and to recycle construction material By reducing calcinations/decarbonations, kiln temperatures, and the amount of fossil fuels used, CO_2 emissions would be reduced	**4**	• **Cost:** Nano-enhanced cement remains too expensive to become a construction standard. Since most benefits are environmental, legislation would likely play an important role in increasing penetration of these new cement products.	• In Europe a number of construction companies include nano-enhanced cement or nano additives for cement/concrete among their product range.	Worldwide cement industry is lead by a few cement and building materials groups. These six international groups are rooted in Europe.	***ELSA:*** The concrete and cement industry is one of the most polluting industries in the world in terms of CO_2 emissions totaling 5% of the world's CO_2 emissions. Production of 1 ton cement releases 0.8 ton CO_2 into the atmosphere from the processing of limestone into clinker. Benefits to society would largely come from CO_2 reduction
Reducing energy consumption through improved insulation material	Reducing total insulation layer thickness High thermal resistance and extremely low thermal conductivity of nanoporous solids or nanoparticular powders.	**3-4** Vacuum Insulation Panel (Pyrogenic Silica) **4-5** SiO2-Aerogels **1-3** Hybrid Aerogels **1-3** Organic Aerogels	• **Costs:** Aerogels and VIPs are more expensive than traditional insulation material. • **Disadvantage of SiO2-Aerogels**: very brittle and moisture sensitive	• Low impact and very low market penetration at present.	Weak compared to the US, who are in a leading position. All major companies are based in the US (Aerogel Composite, Cabot Corporation, Aspen Aerogels, MarkeTech International, Taasi Aerogel Technologies, Nanopore)	***EHS***: Potential for exposure of workers at the manufacturing stage and users of the finished product must be considered. In addition, the brittleness of aerogels could lead to increased likelihood of exposure of humans and the environment throughout its lifetime of use and at disposal. Life cycle assessment of the nano-solutions compared to other options is needed to determine the best option for the environment and society as a whole.
Improving the	Control of rheological	**2-5** Fumed	• **PCC:** Cost compared to	• Global market of	**Fumed Silica**: EU	***EHS:*** Potential for exposure of

durability and weatherability of adhesives & sealants	properties using nanoscale filler materials. Smart curing and switchable adhesion (‘disbond-on-command) to allow for improved recyclability using, for example, superparamagnetic nanoparticles and external electro-magnetic fields.	Silica and Precipitated calcium carbonate (PCC) **1-2** Smart Curing **1-2** Switchable adhesion	ground calcium carbonate. Poorer dispersion ability of fine and ultra-fine grades (especially non-coated). • **Smart curing and switchable adhesion**: proper dispersion of nanoparticles	fumed silica around 300000 t/a (2009). • Global market of PCC around 13 Mill. t/a (2007). • Largest consumer of PCC is the paper industry • Low impact for smart curing and switchable adhesion.	position is strong compared to Asia and comparable to the US. Key players are Cabot Corporation, US; Evonik Industries, Germany, Wacker Germany and Rhodia, France **PCC**: US is leading in production capacity (Specialty Minerals Inc., US). A major producer in the EU is Solvay in Belgium. Asia, esp. China has strongest growth.	workers at the manufacturing stage and users of the finished product must be considered. Life cycle assessment of the nano-solutions compared to other options is needed to determine the best option for the environment and society as a whole.
Production of construction products that have enhanced qualities while also being energy-efficient and environmentally -friendly	Self-Cleaning window panes (TiO2); photocatalytic coatings to reduce pollution (TiO_2); low emissivity coatings (Low-E); smart glazing;). Electrochromatic window developments that are: energy-saving; insulating; easy-to-clean; UV controlling; photovoltaic; fire-resistant.	**5** for self cleaning windows **4** for photocatalytic coatings **5** for low E-coatings. **4** for electrochromatic windows	• Cost: 30-80% higher than traditional glass. • Cost is also the main barrier of dynamic or switchable glazings. • Privacy glass is also high cost about €1700 per m^2.	• In general there is a slow increase in market penetration. • Photocatalytic coatings are in use; mainly for small-scale high-profile projects such as churches or bridges. • The market for electrochromatic glass is expected to reach $218.3 million in 2013.	European companies lead the field in the development and production of nano-enabled glazing products.	***ELSA:*** Consumer resistance due to societal concerns regarding the toxicity of nanomaterials.

Energy

Nanotechnologies have the ability to improve the performances of energy generating systems. Batteries and supercapacitors provide storage solutions, especially for energy harvesting devices, and high societal impact applications such as electric vehicles. Thermoelectric devices would allow the harvesting of existing environmental heat, which is a totally free energy source. They would be dedicated to specific applications.

Challenge	Nano-enabled solution	TRL	Barriers to commercialisation	Measure of Impact	EU's competitive position	Other issues
Increase yield of thermoelectric materials and devices. Reduce energy loss due to heat leak, especially in vehicles.	Give structure at the nanoscale to thermoelectric materials in order to decrease thermal diffusion	1-2	• Thermoelectric conversion efficiency of thermoelectric materials is quite low, and has to be improved. • Cost of processes for nanomaterials	• Enabling the reuse of free thermal losses is a key point. Energy harvesting by thermoelectric devices could help save electricity in electric vehicles and increase their efficiency. • Heat emitted by human body could be saved providing energy supply for mobile devices such as sensors.	About hundred European research labs work on thermoelectric materials, less than in Asia (>150) but more than in North America. Few economic actors are present in Europe. Industrial actors are mainly established in Asia, especially in China.	***EHS/Regulations:*** A part of the materials displaying the best performance are either toxic or rare on the earth, and may possibly raise regulation and supply issues.
Increase the power and life time of batteries Enable electric vehicles and new mobile solutions.	Si Nanowires to replace graphite in lithium batteries negative electrodes	1-2	Scientific and technological issues: • fundamental understanding incomplete • material mastery • large scale production process	• Improving power range of storage solution would help new products to reach market including electric cars and new mobile solutions.	Some European research labs display promising results, especially in France, with both academic and applied labs. International competition is very strong, mainly in the USA, who devote enormous budgets, and also in Asia.	***EHS:*** End of life and recycling stages would need specific processes to harvest Si nanowires
Increase capacity of supercapacitors. Enable high power storage solutions for several uses.	Metallic or metal oxide nanowires to increase geometric surface of supercapacitors' electrodes.	1-2	Scientific and technological issues: • material mastery • electrode synthesis • low lifetime through cycling	• Supercapacitors are used as a solution to harvest and provide high power, in addition to batteries, for power train of public transport vehicles etc. Increased capacity would increase power of such devices and therefore allow for development of electric vehicles	Some European research labs display promising results, especially in France, with both academic and applied labs. International competition is very strong, mainly in the USA, who devote enormous budgets, and also in Asia.	***EHS:*** End of life and recycling stages would need specific processes to harvest Si nanowires. Replacement of Ruthenium (used in electrodes, but toxic for health and environment) by other metals is still hugely disadvantageous in terms of performance and life time.

Environment

The Technology sector "Environment" summarises the applications of nanomaterials for environmental remediation and the treatment of contaminated air, water and soil.

Challenge	**Nano-enabled solution**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
Remediation of soil/groundwater (main target compounds: chlorinated solvents)	Application of free Nano Zero Valent Iron particles (NZVI) in suspension	**4-5**: In the U.S. 10% of all remediation projects involve NZVI; in Europe only a few full-scale projects thus far	• Scepticism by some governments (fear of public backlash). • Lack of knowledge on possible negative impacts on environment. • Lack of experience with the technology in the EU and technology transfer.	• Possibly cheaper because of shorter treatment period and less above ground infrastructure • Improved performance • Most probably less impact on environment • Job creation	The US has greater wealth of experience with this technology. No projects in Asia are known of.	***Regulations:*** No regulations for the application of NZVI so far; project authorisations are the responsibility of local/state authorities. ***EHS:*** Long-term effects on environment are not known. ***ELSA:*** The unknown risks raise societal concerns.
Drinking water production; waste water treatment; remove hardness; desalination of sea water	Nanostructured membranes	**5**: drinking water production, desalination , removal of hardness (depending on the definition nanostructured membranes have been in use for many years) **4**: industrial and public wastewater treatment.	• Problems with membrane fouling • Membrane selectivity • No need to replace existing/conventional water treatment systems at this time (e.g. active carbon, ozone) • Installation (and energy) costs	• Positive impact on public health and environment	EU is in a relatively strong position (research and production); market leader in membrane production is Japan; installations in developed countries only (maintenance of plant requires expertise)	***Regulations:*** Regulations on minimal water quality will influence the development and spread of the technology.
Drinking water production; waste water treatment; CO_2 capture and storage (CCS); removal of contaminants from surfaces and air	Nano-enhanced membranes/surfaces	**4-5**: products with photocatalytic nano-TiO2 (such as cement, air filters, water purification systems) **1-3**: CCS, waste water treatment	Technical challenges; lack of knowledge on chemical reactions (toxic intermediates?); potential release of free NP.	Possibly positive impact on public health and environment (nano-TiO2 in cement/ concrete may reduce air pollutants)	Many more applications and products in Asia due to cultural differences in public hygiene	***Regulations:*** Technology adoption driven by regulation – particularly air and water quality standards.

Healthcare

The Technology sector Healthcare" summarises the applications of nanomaterials and nanotechnology to medical products and to products supporting healthcare.

Challenge	**Nano-enabled solutions**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
The routine sequencing of the personal genome using 3rd generation ('next generation sequencing' (NGS)) particularly in the broader context of developing personalised treatments based on the genetic background of the patient.	Nanopore gates formed of protein that are inserted into a membrane or that are made by nanofabrication into a silicon-based chip; magnetic nanobeads that regulate the flow of DNA strands through multiple nanopores to allow base pairs to be read very accurately; zero-mode waveguides (ZMW); quantum dots attached to proprietary DNA polymerase molecules as the core sequencing engine; FRET- (fluorescence resonance energy transfer)-based approaches	**3-4** for 3rd generation sequencing methods (**5** for 2nd generation)	• Reducing costs in order to achieve the "$1000" human genome target not yet achieved. • Overcoming IP issues	If low cost personal genomic sequencing achieved as expected then high societal impact potential to reduce healthcare and societal costs due to better diagnosis of predisposition towards certain diseases and, subsequently: • the adaptation of treatments or lifestyles • the customisation of therapies towards specific pathologies • the reduction in doses of highly toxic drugs used and their side effects • increasing the effectiveness of novel (and possibly costly) targeted drugs	The US is the market leader but Europe is beginning to achieve a strong competitive position	***ELSA:*** Careful communication required to allay public fears related to societal and ethical concerns over potential misuse of personal genomic information ***EHS:*** Significant direct environmental exposure is unlikely but, in the waste stage, environmental exposure and effects may occur. It is hard to predict what kind of materials may enter waste streams, thus hampering the assessment of any (potential) risk. Regarding human safety, applications will be in vitro, and nanomaterials will be embedded in the devices, both implying there is likely to be little significant human exposure during use. There could, however, be potential worker exposure during product manufacturing and environmental exposure resulting from the process.
Therapeutic delivery using nanotechnologies to: - maintain therapeutic drug	A wide variety of nanomaterials and nanostructures for use as carriers or delivery systems	**1-5** (NOTE. There are products at all stages of	• Funding issues for smaller companies to develop solutions to, for example, proof of concept stage and through the long safety	• Positive impact on public health and environment due to better targeting of smaller quantities of drugs to their site of	EU is in a strong research and commercial position	***ELSA:*** Demographically-ageing populations with increased incidence of related diseases and reduced healthcare budgets present an important macroeconomic backdrop

ranges for longer -effectively target drugs to their sites of action - personalised patient drug dosage - reduce the level of drug needed - decrease drug toxicity and side effects - increase commercial drug lifetimes through new formulations		developme nt, from basic research through to products approved onto the market)	testing/regulatory approval stage • Large pharmaceutical company business models are often based on a "blockbuster" model not suited to specialist applications • Decreasing healthcare spending budgets • Limited drug patent lifetimes combined with long regulatory approval times • Uncertainty over risk issues.	action • Potentially reduced costs to healthcare systems through better selection and use of drugs • Increased value in medicine and to the patient by better performance and reduced side-effects • Potential to meet unmet medical needs, e.g. delivery of otherwise difficult-to-deliver drugs or delivery across biological barriers, e.g. blood-brain barrier		***EHS:*** Potential worker exposure during product manufacturing. Intended use is to administer to patients, thus exposure potential of patients is high. Careful risk benefit analysis as required by regulation therefore warranted. Low exposure potential for users (clinicians, pharmacists) and for the environment.
Applying nanotechnology to treat a wide range of diseases that results from malfunctioning, damaged, or failing tissues by helping the body to regenerate **(regenerative medicine)**	A variety of nanostructured or nanoscale materials and surfaces that provide a suitable environment for the growth and differentiation of cells	Mainly **1-3**: very few products have reached or are nearing **4**.	• Lack of access to capital • Stringent safety and regulatory hurdles • Dearth of clinical evidence on (cost) effectiveness leading to problems with utilisation and reimbursement. • Unsupportive culture in some healthcare systems in utilising innovative products thus does not provide an attractive environment for the commercialisation. • Need for conceptual shift in the working practices of clinicians.	• Ultimately expected to have a strong impact on healthcare in the longer term due to treatments resulting from the body being assisted to regenerate its own damaged or lost tissues thereby replacing more traditional therapies and treatments, e.g. orthopaedic implants. • Is expected to have high level of acceptance from patients but will require conceptual changes in clinical approach.	EU position is very strong in terms of research but currently less so in terms of product development.	***EHS:*** Potential worker exposure during product manufacturing. Intended use is to administer to patients, thus exposure potential of patients is high. Careful risk benefit analysis as required by regulation therefore warranted. Low exposure potential for users (clinicians, pharmacists) and for the environment. ***Other:*** Extensive training and education will probably need to be provided by the "manufacturer" as the technology is "disruptive" to current technologies and clinical practices.

Information & Communication Technology

The impact of nanotechnology in electronics is significant, from novel materials and processes to extend the life of Moore's law to novel approaches to displays, memory, and networking. The primary challenge is for these technologies to scale to reliable, cost-competitive mass production.

Challenge	Nano-enabled solution	TRL	Barriers to commercialisation	Measure of Impact	EU's competitive position	EHS, ELSA & other issues
Improving networking and computing performance	Nanophotonic technologies and structures may be used to build high performance optical communication devices.	**4**: III-V quantum wells and high index contrast structures **1-2** for on chip interconnects	• 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.	***EHS:*** Unknown EHS impacts especially during manufacturing stage and end of life of the products
Universal memory enabling new computing applications	A 'unified memory' combining high speed, high density and non-volatility.	**4-5** for PCRAM, MRAM, FeRAM **3** for Resistive RAM, Q-dot RAM	• Low volumes fail to achieve cost-competitiveness. • Further technology developments required.	• Enabling new ICT applications, from embedded devices to cloud computing.	Extensive research in EU, but current memory markets dominated by Asian and US companies.	***EHS:*** Adapted disposal/recycling procedures should be anticipated in order to limit potential environmental release of NM.
Improving integrated circuit performance	***Beyond CMOS:*** Fundamentally new electronic design paradigms ***More Moore:*** Improved materials understanding, new tools	**5** for Atomic Layer Deposition **2** for novel Substrates **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.	***EHS:*** Adapted disposal/recycling procedures should be anticipated in order to limit potential environmental release of nanomaterials
Displays for information sharing	Use of various nanomaterials, such as quantum dots and carbon nanotubes (CNTs) to improve LCD and LED performance.	**3-4** for CNT as ITO replacement **3** for Q-dot LEDs and CNT backlighting	• Manufacturing readiness • Cost • Dominance of existing LCD • technology	Economic opportunities for company and employment expansion, as new approaches require new expertise	Display manufacturing traditionally performed in Asia, though EU has strong research capabilities, particularly in organic electronics	***EHS:*** Unknown EHS impacts especially during manufacturing stage and end of life of the products

Security

The scope of the Security sector reaches beyond technologies to counteract terrorist activities and assist in homeland security. For example protecting industry and the consumer from counterfeiting and ensuring communication security are also being addressed by novel nano-enabled solutions.

Challenge	**Nano-enabled solution**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
Reducing tax and business revenue losses associated with counterfeiting activities. Improving citizens' safety and quality of life.	Novel technologies for anti-counterfeiting applications including functionalised nanocomposites, nanotech holograms, nanotech RFID, and nanobarcodes,	**1-4**	• Extra costs and requirement to adopt new technologies throughout the supply chain and customs. • The accessible market for new technologies likely to be limited initially to higher cost items.	• Strengthening the position of Europe's pharmaceutical, food and manufacturing companies; • Reduction in financial costs associated with purchase and use of counterfeited goods. • Fewer job losses due to unfair competition caused by counterfeiting. • Significant rise in customer goodwill and confidence in products and services.	North America (mainly USA) leads the process of IPR and brand protection closely followed by EU countries.	***ELSA:*** Low public awareness of the risks of illegal goods and the availability of advanced anti-counterfeiting technologies. RFID tags on consumer goods have already given rise to privacy concerns. In addition, the mainstreaming use of RFID tags consumer goods may compromise recycling efforts. ***EHS:*** If widespread use, disposal/recycling procedures to be anticipated in order to limit potential environmental release of NM.
Providing citizens, organisations and businesses with a tool to enable secure communications and prevent leaks of sensitive information and espionage attempts.	Quantum cryptography devices (QCD) for secure communications	**2-3**	Key technological limitations include; • Number of links involved in the secure communication process • Maximum distance between the links	• Reducing costs of secure communications for businesses and governments.	Europe is at the leading edge of quantum information processing worldwide. Until now, European publication output and quality has been on a par, even superior to the US.	***ELSA:*** There is tension between the fundamental rights of freedom and security. More secure communication may influence the current balance in unforeseen ways. Ethical reflection is needed in parallel to technology development. ***Other:*** To retain Europe's leading position in research and to capitalise on the already significant investments in quantum information systems, EU investment must remain competitive with the US and other countries.

Providing improved security in public places and services including airports, train stations, customs control, post depots, etc.	Forensic and homeland security applications of Raman spectroscopy; surface enhanced Raman scattering (SERS), resonance enhanced Raman scattering (RERS) and Spatially offset Raman spectroscopy (SORS))	**2-3** for SERS **3-4** for other modes (conventional, RERS and SORS)	• Cost and size of the systems. • The mechanisms underpinning SERS are not fully understood.	• SERS and RERS are most adaptable spectroscopy technique for stand-off and non-contact analysis of hazards. • SORS proved to be very valuable for non-invasive chemical analysis of hazards concealed within non-transparent containers and packaging.	Europe is on a par with other regions in developing tools for security applications based on Raman spectroscopy.	Further research directed towards quantitative aspects of SERS is considered desirable. Adoption of adapted safety procedures for handling /disposal of nanomaterial-based solutions

Textiles

Nano-enabled textiles offer improved levels of protection together with lower weight, higher comfort, and multi-functionality. They can also provide specific advanced features, which can be of value in both the medical and sport/outdoor sectors to enhance comfort, protection, and performance.

Challenge	**Nano-enabled solution**	**TRL**	**Barriers to commercialisation**	**Measure of Impact**	**EU's competitive position**	**EHS, ELSA & other issues**
Providing protection against biological and chemical hazards, impact, and infection for those working in high risk professions or environments.	Protection from: - *chemical toxins, toxic agents, poisonous gases* (nanoparticles of magnesium oxide, dendrimers, or gold); - *microbes and bacteria* (silver, copper and titanium dioxide nanoparticles); - *impact* (inorganic fullerenes, multi- walled carbon nanotubes); - *heat and fire* (titanium dioxide, silicon dioxide, clays, layered double hydroxide, and aerogels)	**4**: Impact and fire resistance, water repellency and stain resistance, UV radiation **1-2**: Protection against nuclear/radiation/ biological/chemical toxic agents	• High cost of manufacturing and products. • Competition from alternative technologies. • Difficulty to enforce intellectual property protection • Poor marketing capabilities on the high tech side; • Public procurement with slow adoption of the most innovative solutions	• The EU market for protective textiles has been estimated to be €9.5-10 billion and provides around 200000 jobs in production and related industries, including 35-40000 in services. • Nano-enabled textiles may take advantage of the expected growth of European PPE exports (7.6% between 2012 and 2016).	When compared to Asia and the USA, Europe has a strong competitive position in the field of protective textiles in terms of research capabilities and private enterprises, and the pull of a market driven by safety regulations. However, the USA is at the forefront due to its large defence market offering US based competitors a favorable launch path for costly advanced technologies. Nevertheless the EU is considered competitive for critical mass size and diversity.	***Regulations:*** Existing regulation is considered sufficient to deal with nanotechnology-related products. ***EHS:*** At the current time the potential for NM release from some clothing products with respect to the wearer or the environment (particularly at disposal) is unknown. Research is ongoing to establish further knowledge on this, and results should be taken into account.
Innovative solutions for medical and sports textiles to reduce costs and infections (in healthcare environment), enhance comfort and performance.	- Antimicrobial and antibacterial properties (e.g silver or titanium oxide (TiO_2) nanoparticles); - Healing, drug or fragrance release (chitin nanofibrils or nanocapsules which release active agents); - Abrasion/chemical resistance, enhanced	**4**: Stain resistance; Water repellence; Antibacterial activity; Water/ Moisture management; UV	• Lack of interdisciplinary competences. • Insufficient scientific knowledge. • Reduced reproducibility of the results. • Difficulties in	• Nanotechnology enabled products are at moment a tiny 1-1.5% of the global market for medical/sports textiles; however, forecasts predict a steady increase. • Prices should fall,	The USA is also the world leader in nano-enabled medical and sports textiles; however, Europe holds strong position in these sectors, where the competitors include Japan, Canada, South Korea and a rising China.	***Regulations:*** Existing regulation is considered sufficient to deal with nanotechnology-related products. ***EHS:*** At the current time the potential for NM release from

	tensile strength, electrical conductivity (carbon nanotubes, metal oxides nanoparticles); - Stain resistance, water repellence/moisture control (TiO_2, plasma nanocoatings) - Smart textiles to monitor or control physiological parameters (integration of fabrics with electronic devices).	Protection; Healing wound dressing; Active agents releasing textiles. **3**: Tear/wear resistance; improved insulation; antistatic, and conductivity properties. **1-2**: Wearable smart textiles.	process scalability. • High costs. • Limited durability of nano-enabled functionality under repeated washing. • Difficult integration of the innovative solutions with current production processes. • Competition from alternative solutions. • Public procurement tendency to resist innovation.	but both sectors are ready to accept premium prices for high performance products. • Job creation is limited due to the small quantities needed and the offshore production.	Global sports textiles leaders based in Europe including Adidas, Puma, Decathlon and various Scandinavian niche brands design in the EU but produce in China. Several small high-tech firms based in Europe (Belgium, UK) have succeeded in getting their technologies applied by these world leaders. Fashion design is still strongly based in Europe; this leadership position could perhaps be leveraged more than is being done today by connecting fashion designers with high tech suppliers.	some clothing products with respect to the wearer or the environment (particularly at disposal) is still largely unknown. Research is ongoing to establish further knowledge on this, and results should be taken into account to regulate this matter.

Statistical Analysis of Publications in Nanotechnology

During 2010 the publication analysis of the ObservatoryNANO focused on sector specific publications and a snapshot of these results are described here. For the purposes of an initial context Figure 1 indicates the total worldwide nanotechnology publications for the period (1998-2009) before the number of publications per year and per country are illustrated in Figures 2a-2j.

From Figure 1 it is clear that the number of nanotechnology publications continues to grow and Figures 2a-2j indicate that Germany is a clear leader in terms of publication numbers in each of the technology sectors. France, the UK, Spain and Italy are also leading contributors.

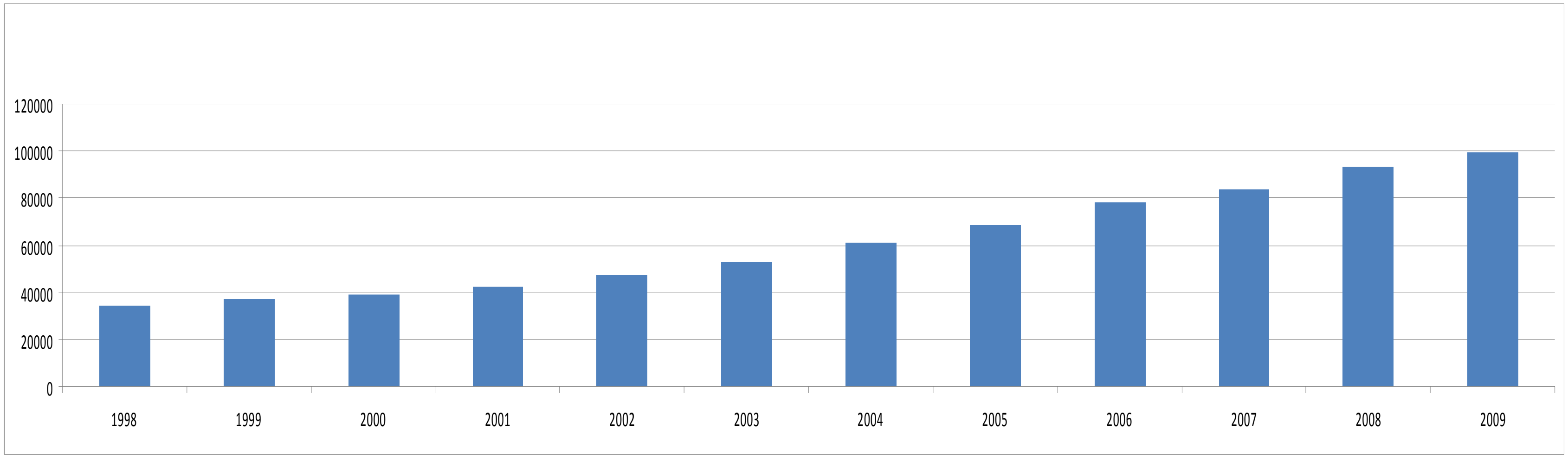

***Figure 1**: Total worldwide nanotechnology publications for 1998-2009*

Sectorial publications analysis

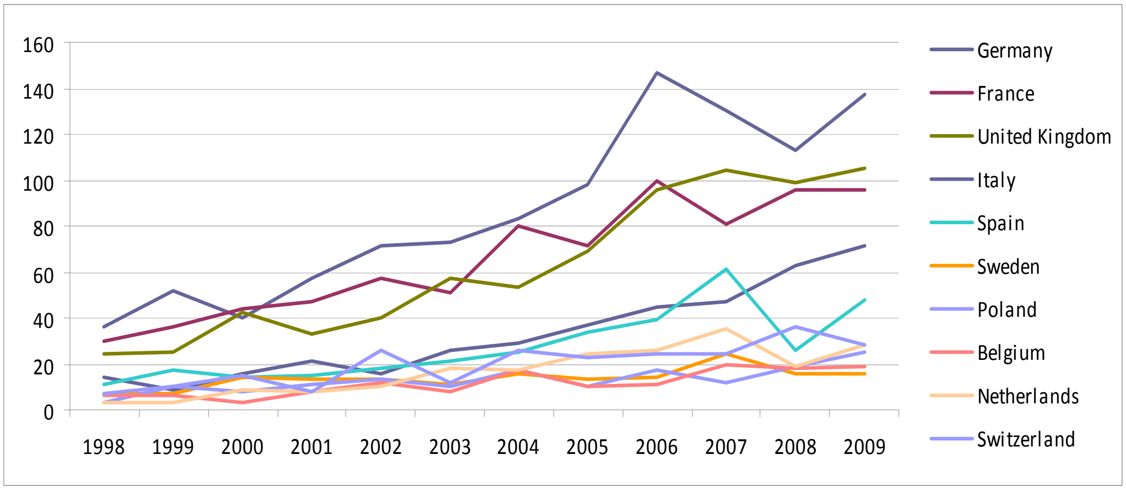

Figure 2a: *Number of publications per country per year (1998-2009) for AEROSPACE, AUTOMOTIVE & TRANSPORT sector.*

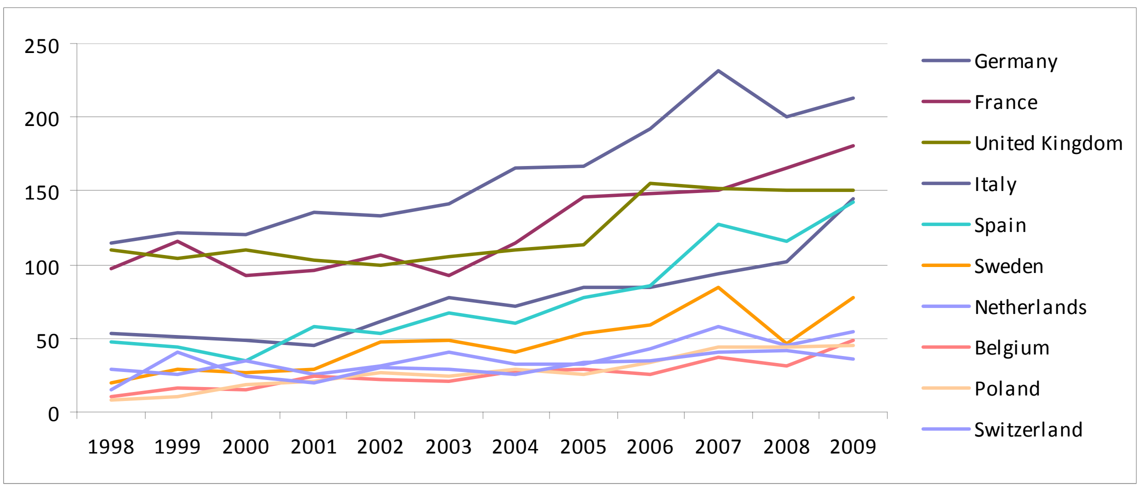

Figure 2b: *Number of publications per country per year (1998-2009) for AGRIFOOD sector.*

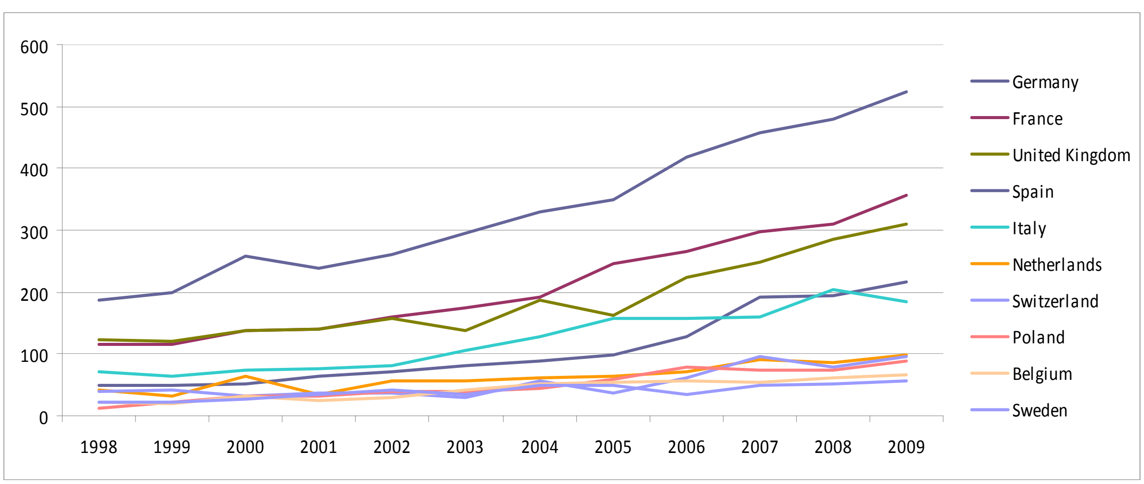

Figure 2c: *Number of publications per country per year (1998-2009) for CHEMISTRY & MATERIALS sector.*

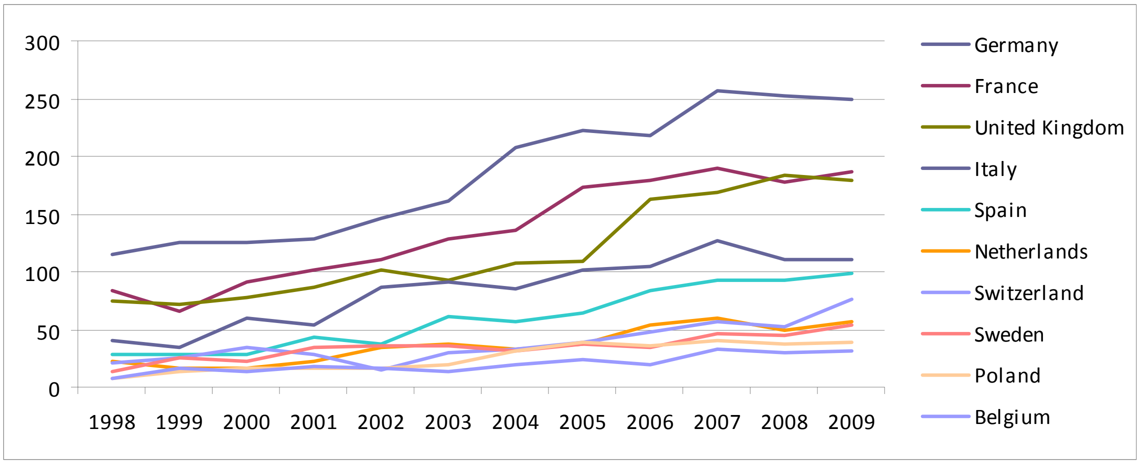

Figure 2d: *Number of publications per country per year (1998-2009) for CONSTRUCTION sector.*

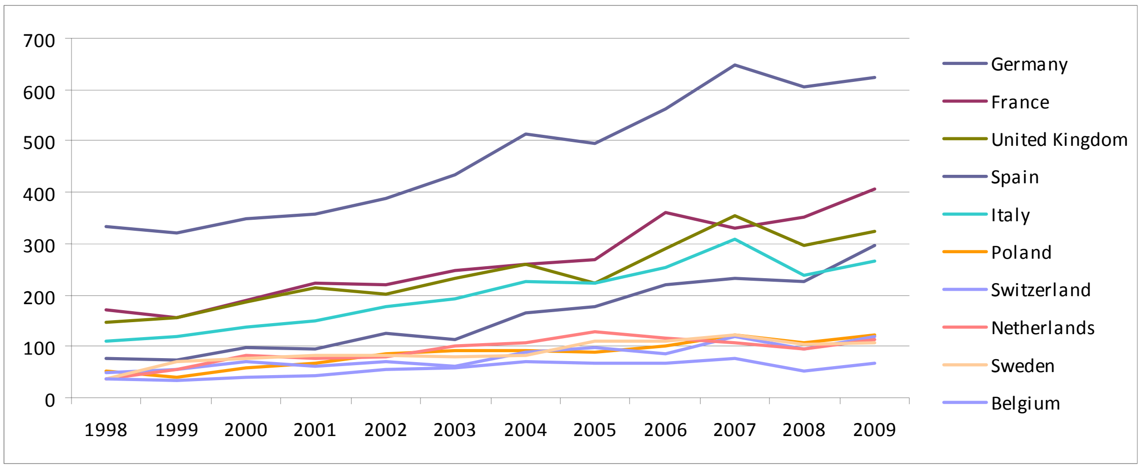

Figure 2e: *Number of publications per country per year (1998-2009) for ENERGY sector.*

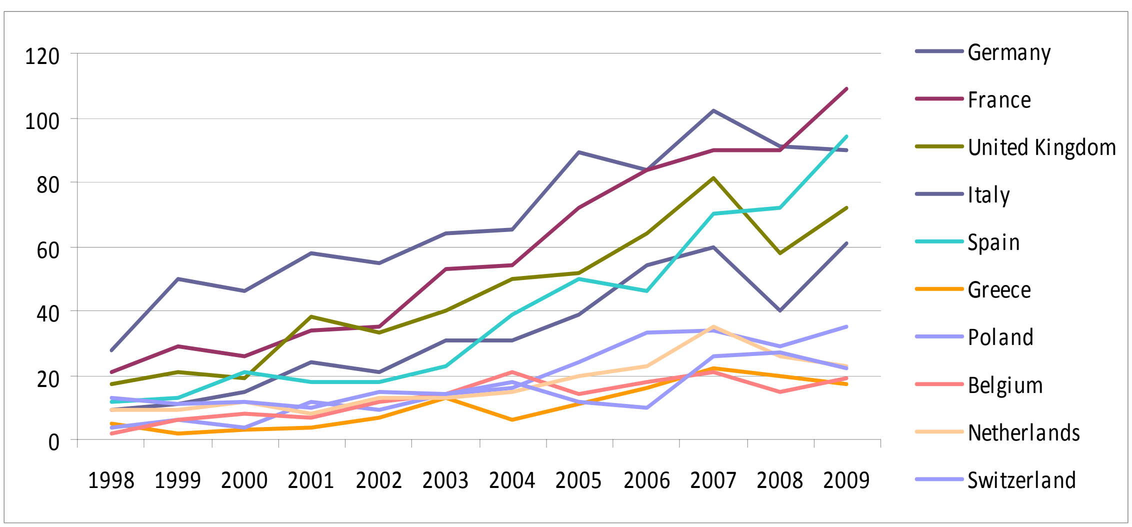

Figure 2f: *Number of publications per country per year (1998-2009) for ENVIRONMENT sector.*

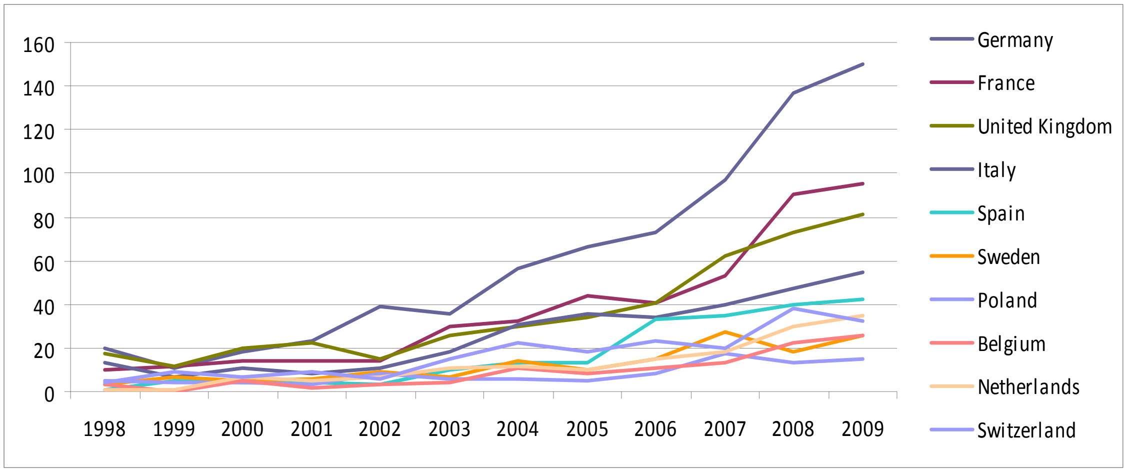

***Figure 2g**: Number of publications per country per year (1998-2009) for HEALTH, MEDICINE & NANOBIO sector.*

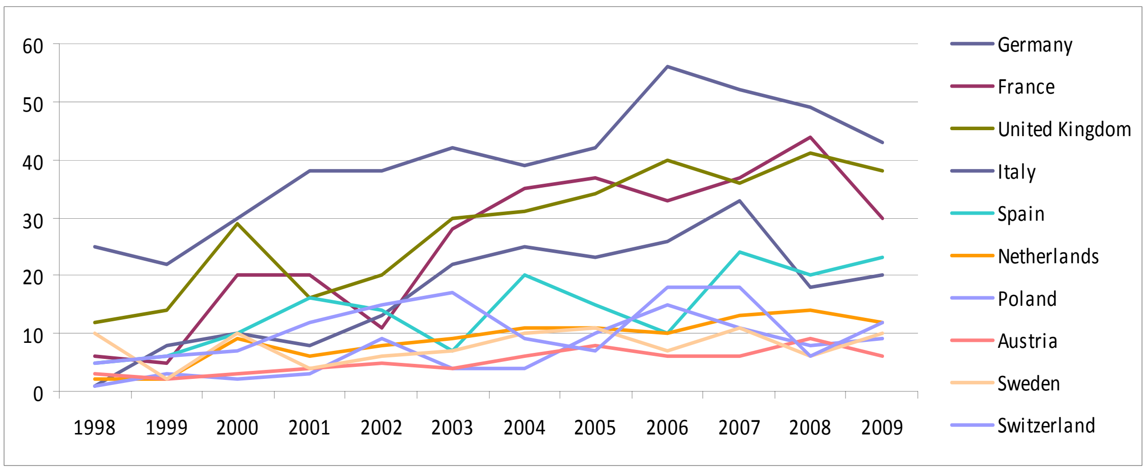

***Figure 2h**: Number of publications per country per year (1998-2009) for INFORMATION & COMMUNICATION TECHNOLOGY sector.*

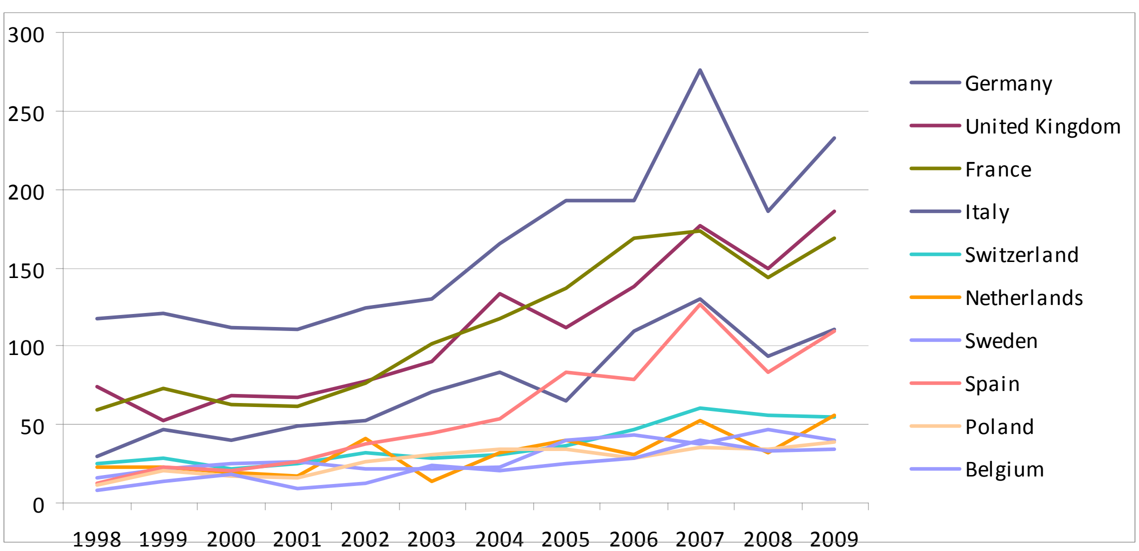

***Figure 2i**: Number of publications per country per year (1998-2009) for SECURITY sector.*

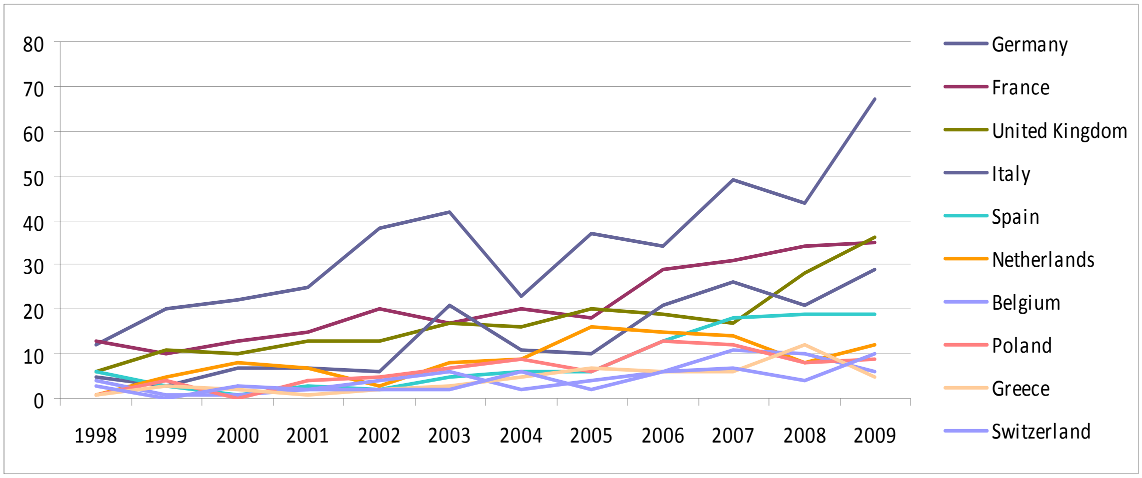

Figure 2j: *Number of publications per country per year (1998-2009) for TEXTILES sector.*

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). The following data is to be seen as supplementary information to the statistical analysis of patent applications that appeared within the 2010 factsheets.

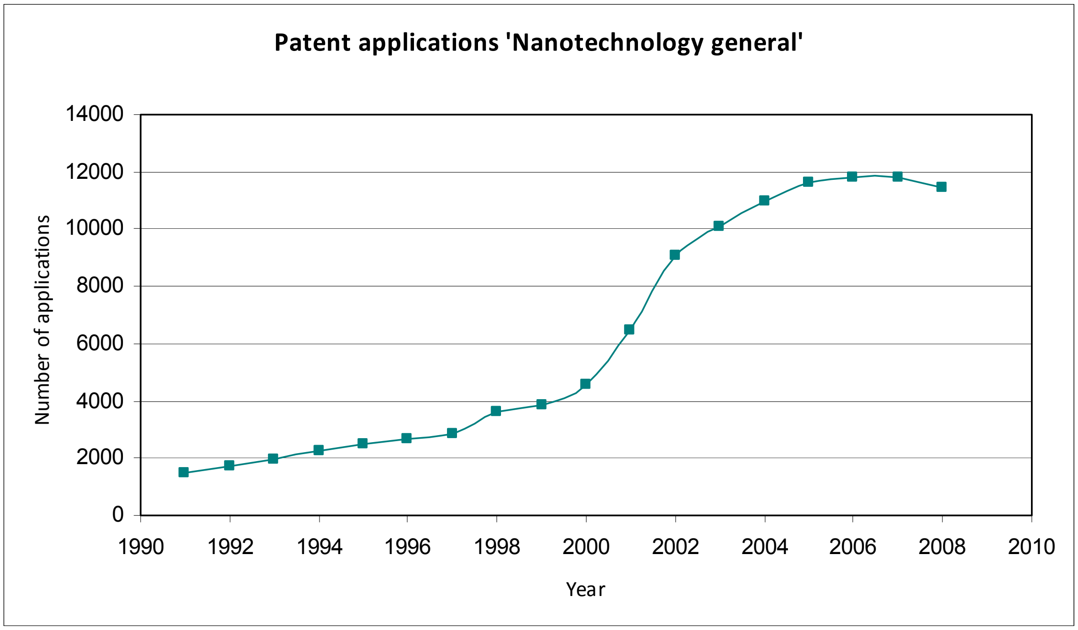

Figure 1: *Development of worldwide nanotechnology patent applications (1991 – 2008)*

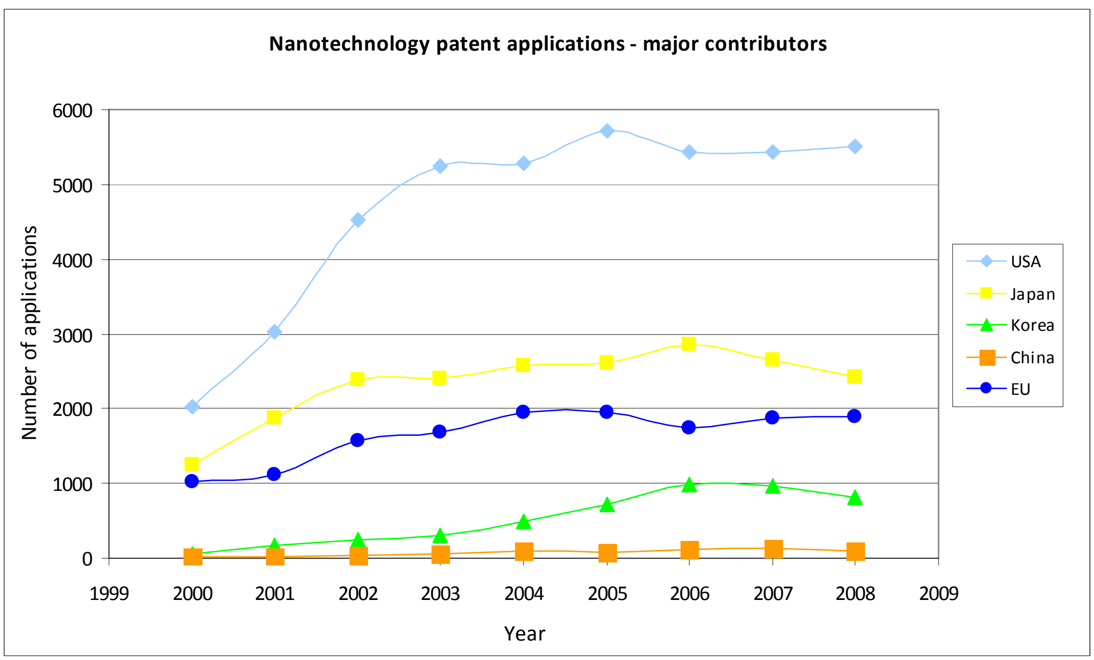

Figure 2a: *Nanotechnology patent applications during the last decade (China and Korea vs. established industrial regions) – linear scale.*

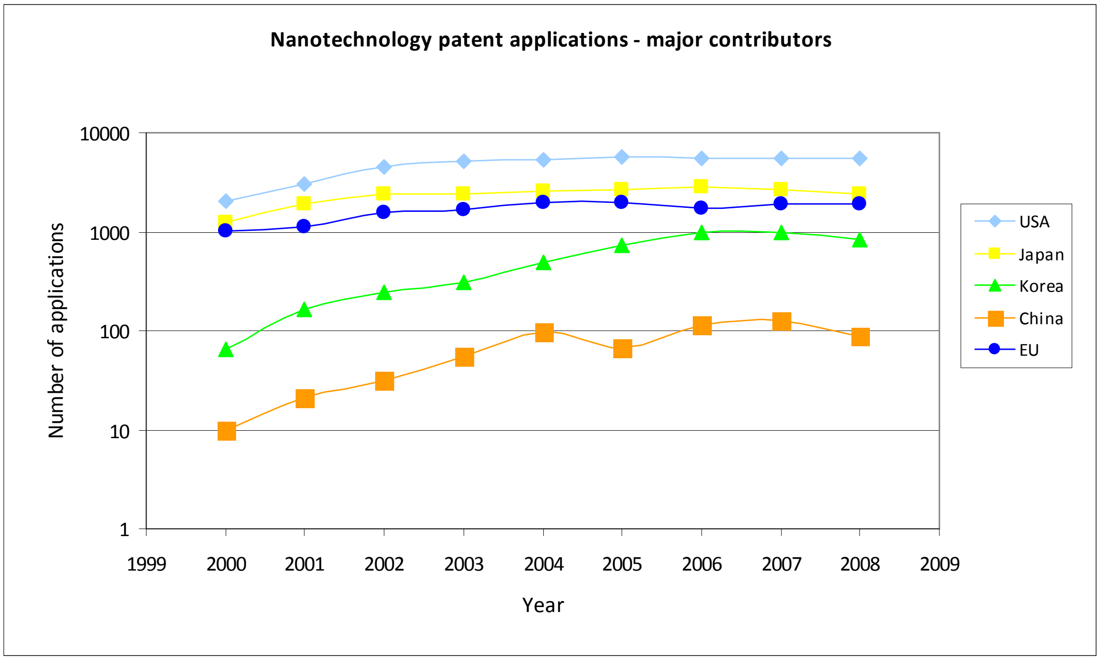

Figure 2b: *Nanotechnology patent applications during the last decade (China and Korea vs. established industrial regions) – log scale.*

Figure 2b indicates a low but rapidly growing patenting activity in emerging countries compared to the established industrialised countries.

Patenting activities of European institutions in Nanotechnology

Long Term Goals:

- Extraction of European institutions that have been engaged in nanotechnology patenting during the past decade
- Identification of key players
- Assignment to European countries

Definition: “Europe” (~40 states)

- EU 27
- Associated countries

Approach: Extraction of patent application families from EPO´s worldwide Database that

- are nanotechnology (indicated by the Y01N classification)
- have at least one institutional (i. e. non person) applicant
- have at least one European, EP or WO priority
- have at least one European institutional applicant
- have been published between 2000 and 2010

Definition: ‘patent family’ (according to EPO):

- all priorities are the same
- selection of the English language representative with the earliest application date

Determination of three institutional types:

- academia (universities)
- public/ semi public research institutions
- companies

First results:

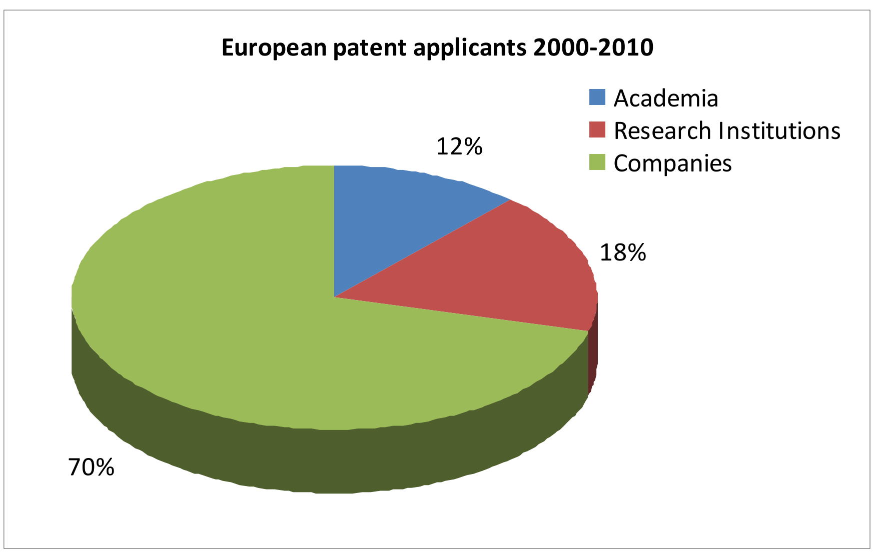

Figure 3: *Nanotechnology patent applications during the last decade (institutional fractions)*

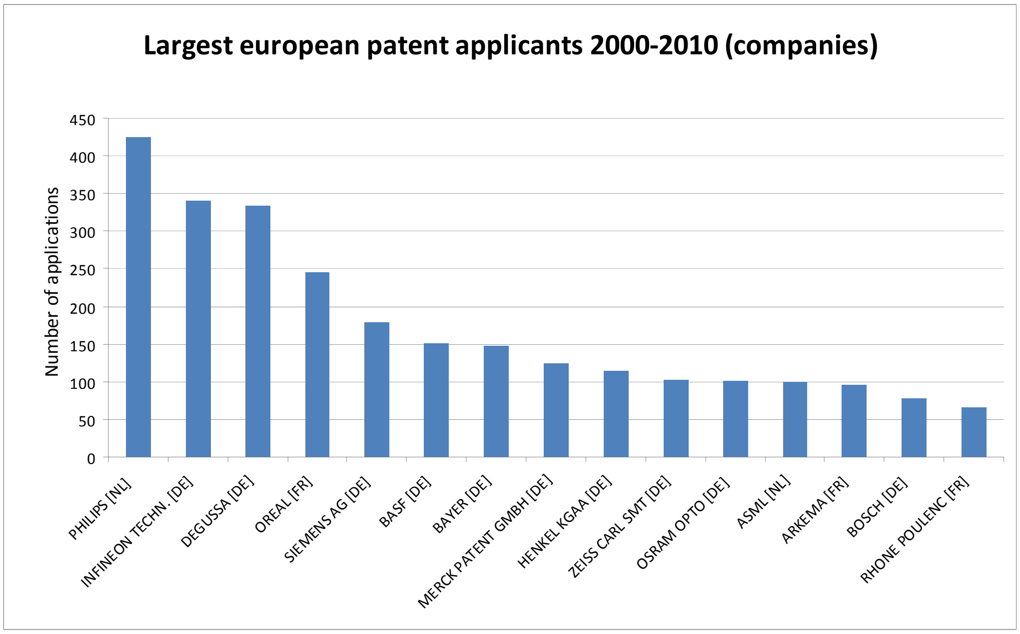

Figure 4: *Largest contributing European companies during the past decade*

Nanoethics and ELSA Issues Overview 2010-2011

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	Sustainability
	Aerospace	Dual use aspects (civilian & defence): security, privacy. Sustainability
	Automotive	Road pricing using chipcard technology: privacy. Sustainability.
Agrifood	General	Risk perception and sensitivity of consumers regarding food ingredients, consumer choice, sustainability, food safety and food security, competition between food and non-food applications and increasing food prices.
Chemistry & Materials	General	Sustainability, precaution, safety.
Construction	General	Sustainability (e.g. zero emission house), 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	Nanobiotechnology	Sensitiveness 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), neuronanoethics, animal testing, general bioethics.
	Drug delivery	Potential biosecurity implications (tricking immune system)
	In vivo Imaging / genomics	Early diagnostics: right (not) to know, possibly increased anxiety, changing definition of health, access to personal genome information.
	Regenerative medicine	Embryonic stem cells; cloning; cell transplantation; stem cell research and therapy. Genetic diagnoses, commercialisation, Medical technology in developing countries, Cord blood banking.
Information and Communications Technology	General	Ambient intelligence debate, privacy, data protection, moral design criteria, concerns about ethical implications of converging ICT and cognitive sciences.
Security	General	Balance security – liberties (EU Charter for Human Rights), privacy, and moral design criteria.
Textiles	General	Some stakeholder criticism of “non-sense” products with unknown environmental risks, such as odourless socks.