
# HLG KET Working Document

## Thematic area: Nanotechnology

# Nanotechnology: a sustainable basis for competitiveness and growth in Europe

*Preamble*

*This report describes the current situation for nanotechnologies in Europe and gives an outlook on policy areas which need to be addressed to support the industrial deployment of this key enabling technology in and from Europe.*

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## Executive summary

Nanotechnology is a very diverse, naturally multidisciplinary cross-cutting concept that covers a wide range of developments from novel approaches for the development of new materials to structures with tailor-made unique properties. The emergence of nanotechnology has potential implications for the creation or refinement of a wide range materials and devices with applications across society from medicine and electronics to materials and energy related topics (storage, efficiency and transportation). Many of these applications allowing improvements of products and processes may be ready for market trials and deployment within the next 5-10 years.

*Opportunities*

As an "enabling technology", nanotechnology is key in the value chains, being used to realise smaller, quicker, more powerful, or more "intelligent" intermediates and systems components for products with significantly improved or even completely new functions.

Significant opportunities will arise if Europe is able to bring together value chains from different industry sectors to interact with each other in a meaningful way to create new products and applications at the interface of their traditional domains and if this is supported by complementary cross-border and cross-institutional public policies.

An undisputed fact is the great potential for nanotechnology to provide employment and societal solutions. Deployment of nanotechnology is a major driver for the trend to improve existing products by creating smaller components and better (functional and environmental) performance materials. In this segment nano-companies will grow rapidly (especially building on Europe's strength of having a well functioning network of small, medium and large sized companies) and thus ensure continued high employment in areas where EU industries are traditionally world leaders (i.e. materials, consumer, automotive and ICT). The minute scale of the system components alone enables the realisation of novel functionalities and properties for improving existing products and applications or developing new, perhaps market disruptive, innovations.

The value and impact of nanotechnology today and in the future is the subject of much research and produces a wide variety of economic figures. According to some studies nanotechnology impacted US$254 billion worth of products in 2009. This impact is forecast to grow to perhaps US$2.5 trillion by 2015.

Nanotechnology offers a large potential to impact on employment and to provide solutions for major societal challenges. It is important in this context that nanotechnology is a major contributor to keep employment figures at high level in sectors, in which the EU is among global leaders. It is estimated that by 2015 about 2 million nanotechnology workers will be needed worldwide of which 0.8-0.9 million would be in the United States and 0.3-0.4 million in Europe.

Building on Europe's strength in having a well-balanced and well-functioning network of small, medium and large sized companies can allow optimised value chain interactions. This is especially important due to the potential impact of nanotechnology on established industries and markets by introducing technological innovations to economically important sectors with an orientation towards "value-added" value chains .

Europe should not always look to Asia where the current technology solution is being produced, but look for areas where technology deployment is characteristically complex. Solving such complex challenges is a strength with a European 'mindset' for implementation of technology.

*Challenges & potential solutions*

**The main challenge is that there is no single nanotechnology industry and hence the continuum from successful quality research to useful products needs not only to encompass the significant "research" gap from academia to industry, but requires wide scale cooperation in and along many different value chains and between various industrial sectors before this KET can fulfil its potential usefulness for society.**

Currently, there are clear risks associated with the successful deployment of nanotechnologies and nanomaterials because of the uncertain regulatory environment and consequent investment and trade implications. As a major step in the safety debate a new approach is currently being discussed between Member States and the EC for targeted safety research. This involves a public fund to finance the research that is needed for practical decision making. This would complement basic research that in many cases creates more questions than answers.

The benefit-risk discussion in specific application areas should guide future policy including funding and governance. The new EC strategy to link societal challenges with technology and have a parallel safety discussion on specific uses via a techno-socio-economic innovation ecosystem should be a step forward to enable the timely delivery of the smart and sustainable growth objectives of the 2020 agenda.

It is key that the private and public sectors can develop common risk- benefit messages targeted for specific applications of nanotechnology towards societal challenges. This should form the basis for the urgently needed broad dialogue with the public about the benefits of nanotechnology in everyday life (including the economic risk of not exploiting the technology for Europe) as well as the discussion around safety concerns.

A pragmatic proposal is that new nanomaterials should be evaluated along specific value chains in their respective appropriate use categories and the level of protection required assessed using regulations that are already in place. A too rigid precautionary regulation approach runs the danger of significantly reducing the adoption of nanotechnology in Europe, while not avoiding any risk coming from its market adoption via products from other less controlled areas of the world.

Manufacturing for new nanomaterials and their introduction into the value chain as the basis for the technology is a challenge. Countless new nanomaterials have been synthesised in laboratories worldwide, opening up the potential for a wide variety of new applications. However, new exciting materials often remain at the laboratory stage, because the road from fundamental science to end-systems production is very complex.

The deployment of nanotechnology is key for Europe to strengthen its manufacturing capacities while addressing societal challenges, through a rejuvenation of manufacturing technologies, processes and products as well as through creation of new business. Development of new applications and materials will require new unit operations as well as the clever combination of new and existing processes. Up-scaling is critical in the development of any new process. In order to achieve mass production of nanomaterials, new multipurpose plants will have to be developed.

Europe has strong basic research and a well developed science landscape, significant interest from the next generation and a good industrial base for exploitation of nanotechnology. The “back-bone “ of this deployment is the excellent symbiotic network of smaller, medium and large companies as well as the presence of major full value chains in Europe within a smaller area than, for example, the Asia-pacific region, enabling significant cooperation for deployment. Difficulties for deployment include issues around utilisation of this technology, difficulties for establishing start up companies, information deficits in commercialisation of research, and fragmentation both in the research and innovation landscape across Europe.

Nanotechnology is by definition a technology that requires integrated approaches involving a variety of scientific, technical and engineering disciplines. Furthermore the development of resource efficient processes requires efficient interlinking of natural sciences and engineering. For the development of converging technologies interdisciplinary skills will be critical. There is the need to provide future engineers and scientists with a multidisciplinary and broad skill set and educate them in sufficient numbers to deploy not only nanotechnology itself, but also to enable the integration of this technology into other areas. Information, education and training of market players are key parameters for the integration of new materials and technologies in the different value chains.

Nanotechnology needs to cross traditional boundaries such as cross border funding. This is especially needed for smaller Member States, who have to achieve a critical mass through such cooperation. Cross border funding should be made available to support projects which bring together development and/or prototyping ventures with multiple companies from various sectors along the value chain in the same way that current FP programmes bring together various partners for research activities.

Smaller enterprises need to be able to easily understand the precise allocation of responsibilities at EU and country level. Existing support structures are, in general, too complex despite efforts to simplify and make them SME-friendly.

The basis for the successful deployment of nanotechnology in the US and Germany is the excellent cooperation and synergy between various national ministries and public bodies. This is key to get added value through innovation and sustainable solutions from invested public and private funds.

A true market push initiative can only be successful in markets where Europe is traditionally strong (for example automotive, aerospace and consumer) as there will be no distinct “nano-industry” sector that is able to achieve critical mass and a unique end-market. Thus for the successful deployment of nanotechnology it is crucial that EU Innovation Policy is complemented and integrated with EU Industrial Policy to ensure Europe can fulfil its potential for leadership at global level. Hybrid public – private financing models can be a way to fill the current investment short fall in Europe.

Due to the character of nanotechnology, it is essential to put industry first in order to create a demand pull, instead of trying to induce a science push.

Nanotechnology can contribute to many societal benefits. Therefore a target-oriented procurement market that can describe concrete impact for products and processes without being over prescriptive is required. The countries that are currently the most successful in the exploitation of nanotechnology (like US and Germany) are those which have established a “super customer”.

There is the need for a consistent and coherent EU strategy for the deployment of nanotechnology across all Member States and along the various value chains. The target should be to create a favourable framework for technology development, innovation and related policies.

## 1. Introduction

Instead of "ever higher, ever wider" as for traditional technological solutions, the motto of nanotechnology can be described as "ever smaller, ever faster".

Obtaining a precise definition of the scope of nanotechnology is a non trivial task. It is commonly described as "the study of the controlling of matter on the nano scale. Generally nanotechnology deals with structures sized between approximately 1 and 100 nanometre ($10^{-9}$ metres) in at least one dimension, and involves developing materials, structures or devices within that size."[1]

However, nanotechnology is a very diverse, naturally multidisciplinary cross-cutting concept covering a wide range of developments from novel approaches for the development of new materials and structures with tailor-made unique properties and the direct shaping of biological matter on the atomic scale to semiconductor fabrication and emerging techniques for molecular-self assembly amongst many others developments.

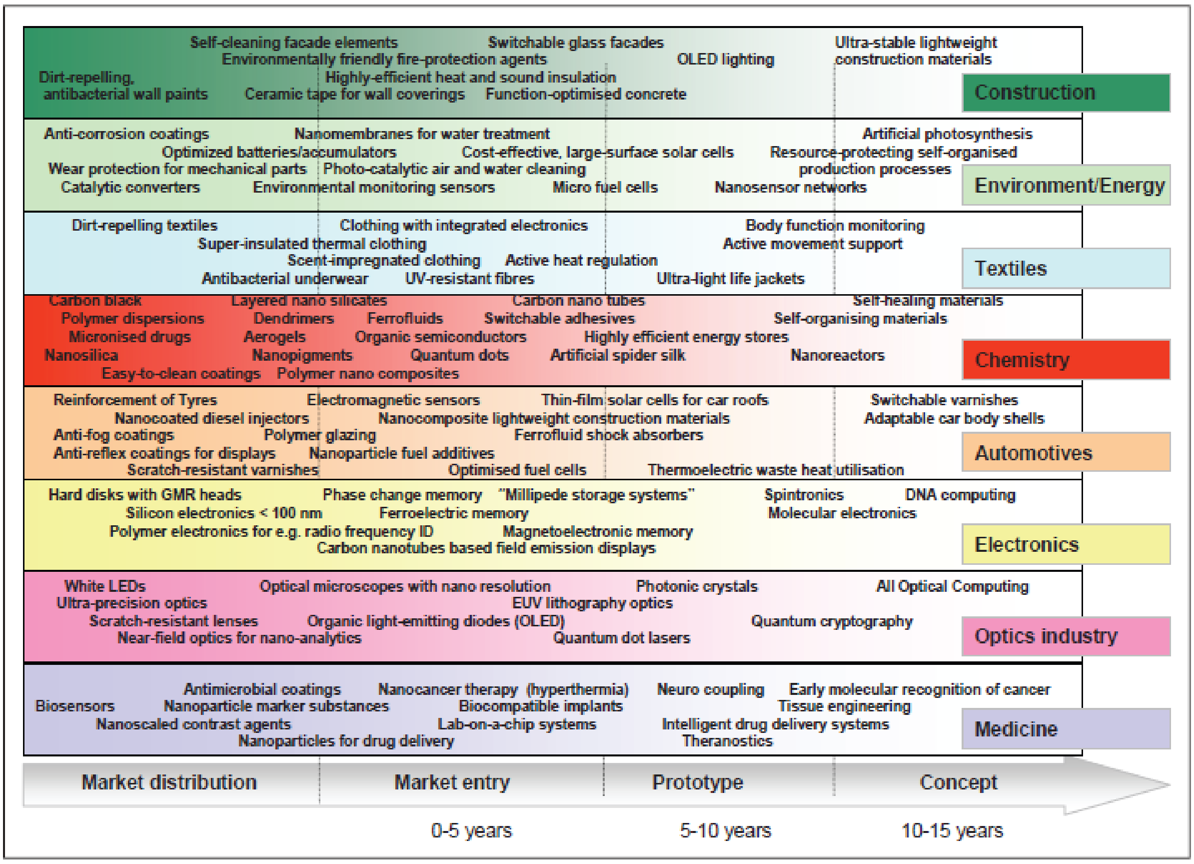
The emergence of nanotechnology has potential implications for the creation or refinement of a wide range materials and devices with applications across society from medicine and electronics to materials and energy related topics (storage, efficiency and transportation).

The minute scale of nanotechnology system components alone enables the realisation of novel functionalities and properties for improving existing products and applications or developing new, potentially disruptive ones.

Within the context of the discussion on Key Enabling Technologies (KETs) the nanotechnology theme has a unique position as it is, *de facto, a* cross cutting KET for the other five defined KET themes: micro and nanoelectronics; photonics; advanced materials; biotechnology and advanced manufacturing systems.

**As an "enabling technology", nanotechnology is applied early on and a key element in the value chain, being used to realise smaller, quicker, more powerful, or more "intelligent" intermediates and systems components for products with significantly improved or even completely new functions[2].**

[1] Nano.DE report, Status Quo of Nanotechnology in Germany BMBF, 2009
http://www.bmbf.de/pub/nanode_report_2009_en.pdf
[2] http://www.bmbf.de/pub/nano_initiative_action_plan_2010.pdf




*Examples of application opportunities and degree of maturity of nanotechnological developments in different sectors (VDI TZ GmbH)*

*Figure 1 : Examples of application opportunities*[3]

## 2. THE VISION. CONTRIBUTION OF NANOTECHNOLOGIES IN ADDRESSING SOCIETAL CHALLENGES

**Why nanotechnology?**

Europe faces a set of unique societal challenges. These include ageing, employment, security, climate change, security of energy supply, feedstock and water supplies, and mobility issues amongst others, all of which will require sustainable solutions within the next decade.

Nanotechnology, as a key cross-sectorial enabling technology, will be essential to achieve solutions to these challenges by providing new solutions for quality of life, environmental protection, information society and medicine (see Figure 1 in previous section).

***What could nanotechnology deliver to meet our major societal challenges***

***Sustainable Energy Supply and Consumption***

*Current renewable energy technologies like hydro-electricity, wind, solar, tidal, geothermal and biomass may not fulfil future energy demand. Nanotechnology could make a profound impact through:*

- *Thermo-electrics – electricity from (waste) heat*
- *Nanostructured solar cells using nano – based transparent and flexible conductive layers*

[3] http://www.bmbf.de/pub/nano_initiative_action_plan_2010.pdf ***p. 16***

- *Efficient energy storage with new nanostructured battery materials*
- *Electricity from controlled electrochemical reactions – fuel cells*
- *Direct generation of hydrogen with sunlight or photolysis*
- *More efficient wind turbines based on nano-enabled materials for rotor blades*

***Nanotechnology and the Environment***
*The environmental sector currently benefits from a wave of new ideas based on nanotechnology such as:*

- *Soil and groundwater remediation using, for example, zero valent iron particles*
- *Water treatment via nanofiltration, nanoadsorbants or nanocatalysts*
- *Air purification with photocatalytic nanomaterials*
- *Pollution detection and sensing using novel, cheap and high resolution nanosensors*
- *More efficient resource and energy utilisation through substitution of conventional materials and processes (e.g. nanofoams for insulation of buildings, light weight materials for mobility, resource efficient processes )*

***Healthcare and nanomedicine***
*Many approaches to nanomedicine are being pursued today and many are close to new medical diagnostics or clinical therapeutics:*

- *Optimised formulation and delivery of drugs. Smart systems for drug delivery (targeted drug delivery and controlled release)*
- *In vivo imaging with improved resolution and performance as well as early detection of biological markers of diseases by means of nanobiosensors and lab on chip systems*
- *Regenerative medicine including bio-reabsorbable scaffolds for tissue regeneration Advanced therapies related to regenerative medicine include the use of stem cells (embryonic, IPS, and/or mesenchymal)*

Examples of the potential impact of nanotechnology are numerous. They include small scale, highly efficient solar panels through nano-photovoltaics, highly efficient filters for sewage treatment, manufacturing processes that are highly resource efficient with significantly less environmental impact, and novel computer memory devices with dramatically increased storage capacity (see Appendix 1).

Currently energy and resource efficiency are two of the key application sectors for nanomaterials, with a variety of applications in healthcare a close second.

Energy (including energy conversion, efficiency, storage and transportation) is a field in which nanotechnology will lead to breakthroughs in the efficiencies of solar cells, the realisation of high efficiency fuel cells, improved battery lifetimes and new energy storage solutions such as super capacitors[4].

For example Organic Light Emitting Diodes (OLED) for lighting use 30% less energy than fluorescent lamps[5], while organic photovoltaic (OPV) cells have the potential to produce solar electrical power at 20% of the cost of silicon based technologies and with a thickness of only 0.1% of a comparative silicon cell[6]. OPV technology is also more resource efficient.

[4] http://www.suschem.org/upl/3/default/doc/Suschem_SRA_final.pdf
[5] http://www.bmbf.de/de/7045.php
[6] http://www.gsk.de/fileadmin/gsk.de/assets/Veranstaltungen/PDF/Pr%C3%A4sentation_Herr_Deibel.pdf

Nanotechnology applied to medical applications – nanomedicine (see case study in appendix 2) – is a key enabling technology in itself that will enable earlier diagnosis, better targeted therapies and improved therapy monitoring[7]. The nano scale is the ideal scale for interacting with biomolecules and can therefore contribute to a new and innovative approach to medicine. Sensing, interacting, destroying, monitoring and tracking biomolecules involved in pathological processes is of paramount importance for diagnosing, curing and monitoring most human illnesses that mostly originate at the molecular level ( Appendix 3).

## 3. Current situation. Opportunities and challenges for the deployment of nanotechnologies

Nanotechnology faces both the greatest challenges and the greatest opportunities of all the defined KETs in making an effective long-term impact. And as an enabler for other technologies, its effective implementation and deployment will impact significantly on their ultimate success.

**The main challenges is that there is no single nanotechnology industry and hence the continuum from successful quality research to useful products needs not only to encompass the significant "research" gap from academia to industry, but requires wide scale cooperation in and along many different value chains and between various industrial sectors before this KET can fully fulfil its potential usefulness for society.**

However, an additional significant opportunity will arise if Europe is able to bring together value chains from different industry sectors to interact with each other in a meaningful way to create new products and applications at the interface of their traditional domains.

Many of these applications providing clear improvements of products and processes will be ready for market trials and penetration in the next 5-10 years (KET Open Day on Nanotechnologies, Brussels, 27 October 2010).

### 3.1. Strengths & Opportunities

- **Economic benefits**

It is undisputed that nanotechnology has a big potential to boost employment and societal solutions. Nanotechnology is a major driver for the trend to improve existing products by creating smaller components and better performance materials. In this segment nano-companies will grow rapidly (especially building on Europe's strength in having a well functioning network of small, medium and large sized companies) and thus ensure continued high employment in areas where EU industries are traditionally world leaders (i.e. materials, consumer, automotive and ICT). Nanotechnology is especially important due to its impact on established industries and markets through introducing technological innovations to economically important sectors with an orientation towards value added value chains (P. Wolff, BMBF, KET Open Day on Nanotechnologies, 27 October 2010). Nanotechnology is not an "industry" or a "market" per se, in the same sense that biotechnology is, for example.

Breakthrough solutions from nanotechnology are still in the development phase via a bottom up approach, where functional devices and entire fabrication systems are built at the nano-scale. There is a significant challenge to put specific detailed robust market figures to these solutions at this early stage. These market segments are therefore rarely covered in nanotechnology market size reports. However the potential to

[7] http://www.etp-nanomedicine.eu/public/press-documents/publications/etpn-publications/091022_ETPN_Report_2009.pdf

achieve improved and new solutions for societal challenges by exploiting the potential of this technology is huge in all areas of application.

The value and impact of nanotechnology today and in the future is the subject of much research and produced a wide variety of figures. According to studies[8]nanotechnology impacted US$254 billion worth of products in 2009. This impact is forecast to grow to perhaps US$2.5 trillion by 2015.

An estimate for total worldwide sales revenues for nanotechnology in 2009 is just under US$ 11.7 billion. This is expected to increase to more than US$ 26 billion in 2015 [10]: a compound annual growth rate (CAGR) of 11.1 %.

Research for the National Science Foundation in the United States looked at a range of scenarios for the potential world market for nanotechnology in 2015 with totals from US$ 500 billion to US$ 2 trillion (see Figure 2).

The largest nanotechnology segment in 2009 was nanomaterials. The market for all nanomaterials is estimated to increase from US$ 10 billion now to almost US$ 19.6 billion in 2015, representing an annual growth rate of 14.7 %. Sales of nanotools will also experience high growth of around 3.3% CAGR[9] to reach $ 6.8 billion in 2015.

Analysis of the exact impact varies due to differences in the methodologies and assumptions made, including different definitions of the scope of the nanotechnology market. For example analyses may include existing, long-established “nanoparticle” technologies such as production of carbon-black, rubber reinforcements and photographic silver. Alternatively, they may be based on the market value of nanotechnology “component” input alone, as opposed to the total value of products produced at the end of the value chain that include nanotechnology or are enabled through this KET.

Experience in other technologies, for example plastics and biotechnology, tells us that the full time span from initial basic research to market deployment for technologies is around 20 years. Nanotechnology research only really started in the late 1980s. Thus effective deployment and implementation of the technology can be expected to start now (Forfas[9], 2010).

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[8] Ireland’s Nanotechnology Commercialisation Framework 2010 – 2014, Forfas (Aug.2010) http://www.forfas.ie/media/forfas310810-nanotech_commercialisation_framework_2010-2014.pdf, page 6

[9] bcc research 2010 ‘Nanotechnololgy: A Realistic Market Assessment’ http://www.bccresearch.com/report/NAN031D.html

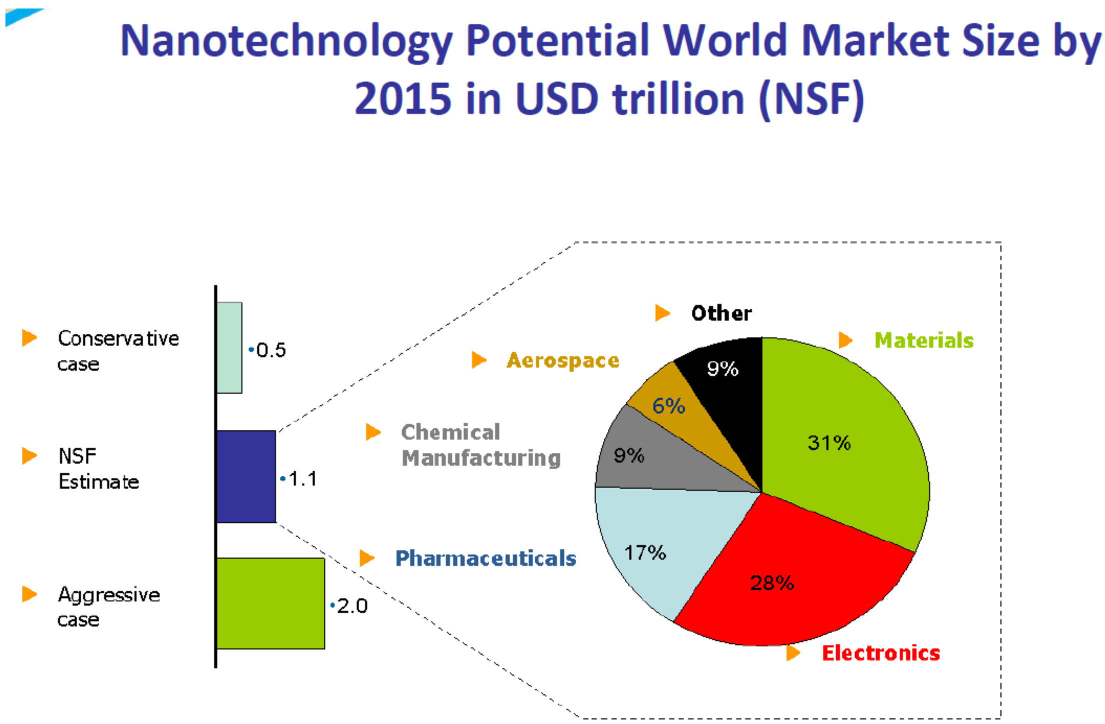


*Figure 2. Potential world market size by 2015* [10]

In the past nanotechnology has been, to a certain extent, a victim of its own hype: no real-world technology could be expected to live up to the claims made for it in some of the early excitement about the field. Several "over-the-top" safety discussions are a consequence of this hype, in which areas of both benefits as well as risks were described that are still in the "visionary or precautionary phase" rather than of "real life" relevance.

- **Employment**

Nanotechnology offers great potential to impact on employment and to provide solutions for major societal challenges. It is important in this context that nanotechnology is a major contributor to maintaining employment figures at high level in sectors (for example process and manufacturing, automotive, ICT, medical), in which the EU is among global leaders, through improving products by providing new functionalities, using less resources, and being cheaper ( KET Open Day on Nanotechnologies, Brussels, 27 October 2010). Without deployment of this KET it is likely that these sectors would become non-competitive. In addition new applications through this technology alone or through the convergence between various KETs (i.e. bio – nano) will create new high value added jobs (KET Open Day on Nanotechnologies, Brussels, 27 October 2010).

It is estimated [12] that by 2015 about 2 million nanotechnology workers will be needed worldwide, of which 0.8-0.9 million would be in the United States, 0.3-0.4 million in Europe (see Figure 3).

[10] C. Tokamanis, KET Open Day on Nanotechnologies, 27 Oct.2010

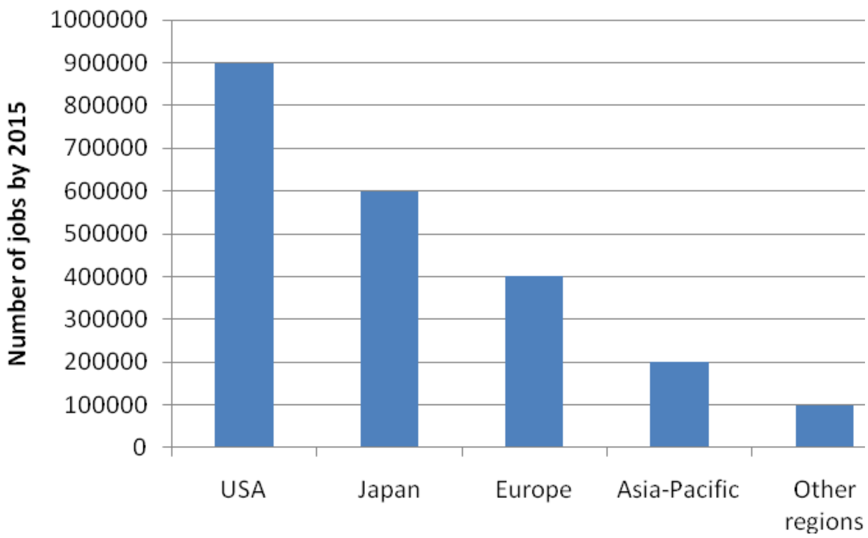


*Figure 3. Number of Nanotechnology Jobs by 2015 globally* [11]

So far the majority of these new jobs arise from the penetration of nanotechnology into industries, such as processing, manufacturing, ICT and consumer-facing sectors, in which Europe is among the world market leaders.[12]. This will enable the stability of employment numbers in industries needing the deployment of nanotechnology for their competitiveness, as well as create new jobs in emerging businesses.

- **Research (incl. safety research)**

There is no doubt that in nanotechnology research the EU has a primary position, not only with respect to levels of public funding, but also in terms of its technological position. Investment is still at the level of 2007-2008, but Europe is under investing with respect to the commercial output of nanotechnology results.

Regarding research on the safety aspects of nanotechnology, a new approach is currently being discussed between Member States and the EC. This involves a public fund to finance research that is needed for practical decision making on safety to complement fundamental research - research that in many cases creates more questions than answers. Currently research funding schemes have a bias towards finding effects (which then require further research for validation and quantification of risk) rather than creating practical scientific knowledge for public decision making (i.e. is this application safe or not?). Industry has a role to participate in this process to accelerate knowledge acquisition, help protect its own workforce and customers, and establish good governance.

More research funding on the question "what is normal, what is the baseline variation of health parameters" is required to establish the abundance and risk contribution of the natural and existing nanoparticles/ nanomaterial spectrum in the environment, the modes of action/ interaction with biological and eco-systems and assessment of how human and other biological systems currently cope with, or are affected by, the presence of such materials in the environment (J. Epprecht, KET Open Day on Nanotechnologies, 27 October 2010).

[11] http://www.oecd.org/dataoecd/59/9/43179651.pdf p.26: OECD, 'Nanotechnology: an overview based on indicators and statistics' (2009), based on Roco, MC and WS Bainbridge, *Societal Implications of Nanoscience and Nanotechnology. Kluwer Academic Publ*, (2001)

[12] Chemical Engineering News, Vol. 88, No. 29, p10-16

- **Playing to our strengths : diversity of small and large companies**

Nanotechnology is a major driver to improve products and processes by creating smaller components and better performing materials. In this market segment nano-companies will grow rapidly and can ensure continued high employment, in particular, in areas where EU industries already have a traditional leading position such as materials, consumer, automotive and ICT.

Deployment of nanotechnology can also build on Europe's strength in having a well-balanced and well-functioning network of small, medium and large sized companies that can allow optimised value chain interactions. This is especially important due to the potential impact of nanotechnology on established industries and markets by introducing technological innovations to economically important sectors with an orientation towards "value-added" value chains (P. Wolff, BMBF, HLG KET Open Day on Nanotechnologies, Brussels, 27 October 2010). It should be remembered that nanotechnology is not an "industry" or a "market" *per se*, in the same sense that biotechnology is, it is more pervasive. The nanotechnology commercialisation value chain is described in Figure 4.

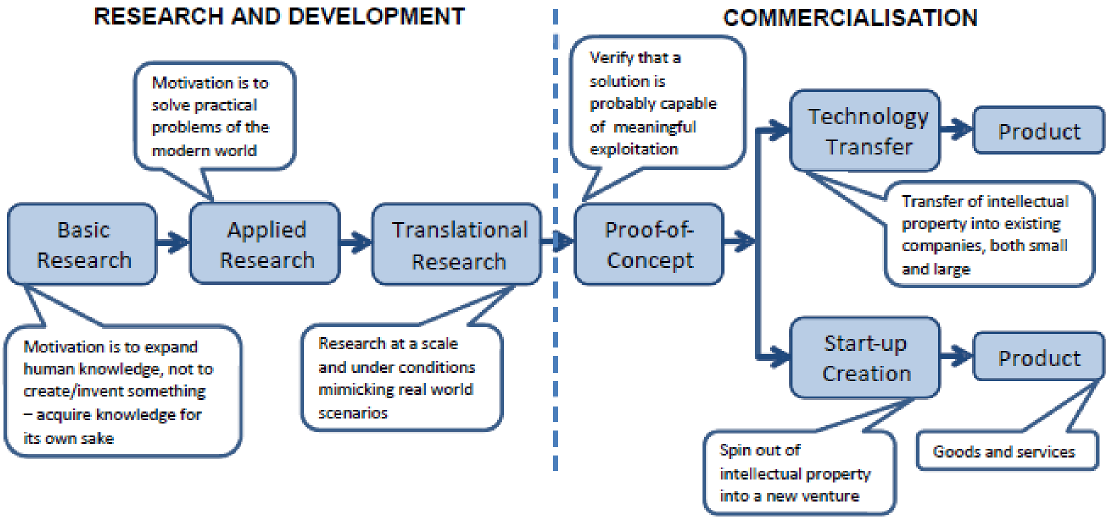


*Figure 4. The Nanotechnology Commercialisation Value Chain*[13]

Many opportunities will arise if Europe is able to bring together different industry sectors to interact with each other in a meaningful way in creating new products at the interface of their traditional domains. Many applications will be ready for market trials over the next 5-10 years[14].

An example of this would be the interface between the semiconductor industry and the medical device industry (see appendix 2), with the latter having the ability to mass produce miniature devices and the former having the knowledge of how such technology could be used in useful products. The KET recommendations should consider policies which would encourage these cross industry alliances or partnerships. This could be achieved by launching programmes which encourage industries to explore new collaborative domains via multi-sectorial approaches to speed up innovation along the value chain.

[13] http://www.forfas.ie/media/forfas310810-nanotech_commercialisation_framework_2010-2014.pdf, p.39
[14] KET Open Day Nanotechnology sessions e.g. bio-medicine, nano-magnetic digital systems

- **Europe – a cultural competitive advantage**

Europe should not always look to Asia, where many of the current technology solutions are being produced, but look for areas where technology deployment is characteristically complex. Solving such complex challenges is a strength that plays to a European 'mindset' on implementation of technology.

Understanding high-end demand and the quality of your materials is key; working with incredible complexity to build integrated structures is still an ultimate strength of European enterprises: no one else in the world can do this as well as Europe.

Europe is educated in complexity – which is not so true for our significant global competitors. However there is also the danger that Europe can be caught as a victim of this diversity, as institutions at EU, member state and regional level push individual competition too far with detrimental effects on overall EU success.

The basic societal values of the EU can form the basis for an ultimate competitive advantage and are positive indicators for KET success in EU because of their inherent complexity. Therefore Europe has a strategic or technical advantage already AND is socially adapted to cope and work with complex systems. This places the EU exactly where commercial investment should be for competitiveness and growth: not just to retain current markets but possibly to regain lost markets.

Practical examples range from multi-national aerospace collaborations such as Airbus[15] to the CNT-Innovation Alliance[16]. This is a partner programme involving over 80 industrial entities (based in Germany) to develop technologies and applications for new value chains for a number of industry sectors using carbon nanotubes (CNTs).

This ability to integrate technologies and bring complex products back into the market has helped to attract considerable inward investment that is almost entirely directed into technology companies. Significant subsidiary investments in research and development have been made in Europe by major players from North America and Japan.

## 3.2. Weaknesses & Challenges

### 3.2.1. Fragmentation

- **Cooperation and funding policies**

The basis for the successful deployment of nanotechnology in the US and Germany is the excellent cooperation and synergy between various national ministries and public bodies. This is key to get added value from invested funds through innovation and sustainable solutions [9].

Global spending on nanotechnology R&D from governments, corporations and venture capitalists totalled US$ 18.2 billion in 2008 (Forfas report [9], p. 71). Of this total funding government spending constitutes around half largely dedicated to overcome early technological barriers via promotion of fundamental research (P. Wolff, BMBF, HLG KET . on Nanotechnologies, Brussels, 27 October 2010). On a regional basis Asian nations lead overall spending both in government and private investments.

Increasingly venture capitalists are getting engaged with most of their funding going to the energy and environment sectors. Public funding via entities such as the European Investment Bank (EIB) can go hand in

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[15] http://www.airbus.com
[16] http://www.inno-cnt.de

hand with venture capital private funds (H.Gruber, M.Beckmann, HLG KET Open Day on Nanotechnologies, Brussels, 27 October 2010,). However for venture capital funding, the usual requirement of a relatively short exit horizon (say three years) from their investment is often too short. This means that hybrid public – private financing models are needed to fill a potential investment shortfall.

- **Cooperation across border**:

Nanotechnology needs to overcome traditional boundaries such as cross border funding. This is especially required for smaller Member States, in order to achieve a vital critical mass for cooperative research and innovation. Cross border funding should be made available to support projects which bring together development and prototyping ventures, with multiple companies from various sectors along the value chain, in the same way that the current EU FP programmes bring together various partners for research initiatives.

A significant barrier for a common European approach in this area is fragmentation of activities. This is seen both for funding as well as on in terms of safety discussions. An example is given below. *Occupational safety*: In France an important initiative has been launched to improve the safe handling of nanomaterials in the workplace (nanoSafe[17] - J.F. Clerc, KET Open Day on Nanotechnologies, 27 October 2010). The next step must be to rollout this type of initiative across all Member States to capitalise on this project.

The establishment of multidisciplinary and multisectorial EU Centres for nanotechnology based processing industries should be evaluated, in order to support demonstration activities, thus improving deployment efficiency.

### 3.2.2. Regulatory Framework Conditions

There is the need for a consistent and coherent EU strategy for the deployment of nanotechnology across all Member States and along the various value chains. The target should be to create a favourable framework for technology, innovation, regulation and governance that facilitates knowledge transfer and utilisation by removing barriers that hinder collaboration between research and industry.

In addition Europe must establish its leadership in responsible nanotechnology innovation, which promotes innovation while safeguarding health, safety and the environment (HSE) and also engages the public in an open dialogue on benefits and risks.

Currently, there are clear financial risks associated with deployment of nanotechnologies and nanomaterials because of the uncertain regulatory environment and trade implications. This impedes private investment. A regulatory framework across national and international jurisdictions needs to be introduced that fosters a common understanding of this complex field. Member State specific regulatory approaches can develop into significant barriers for deployment of this KET.

The EU should recognise the work undertaken by ISO and the OECD, in particular on nomenclature, and agree on a Europe-wide definition of “nanomaterials” as soon as possible. Any regulation of nanomaterials in the internal market needs to be based on a scientific risk assessment and methodology such as the approach adopted for the Registration, Evaluation and Authorisation of Chemicals (REACH) initiative.

The use of standardised test methodology for characterisation of nanostructured products (for example OECD standard testing methods) is essential. Access to testing methodology should be easy – if testing can only be carried out by a handful of highly specialised laboratories in Europe then this will slow practical implementation of new technologies. For the future it is essential that risk assessment using different safety standards does not become a barrier to global trade replacing fiscal tariffs.

[17] http://www.nanosafe.org

There is an urgent need for a harmonised European approach to nanotechnology risk assessments and management (J.F. Clerc, KET Open Day on Nanotechnologies, 27 October 2010).

Today global trade is characterised by decreasing tariff barriers, however regional regulation is becoming a significant trade issue. Countries that have no regulation on nanotechnology are able to export their products, whilst emerging economies like China, Singapore, India, Thailand and Vietnam are not engaged in public dialogue about safety and responsible use of nanotechnologies (SciDev Net, January 2010).

Costs of REACH-style registration for novel materials are uncertain and could be substantial. This could effectively eliminate continuing innovative contributions from SMEs without intervention from public funds specifically to enable registration. High regulatory costs can lead to acquisition of smaller innovative enterprise by larger companies with access to the necessary funds (S.Sepeur – KET Open Day on Nanotechnologies, 27 October 2010).

The basis for a successful deployment of nanotechnology in the US and Germany is the excellent cooperation and synergy between various national ministries and public bodies [9]. This cooperative attitude is not universally evident on a pan-European basis. Indeed there have been calls from some sections of the European Parliament for a moratorium on the further development of nanotechnology (KET Open Day on Nanotechnologies, 27 October 2010).

In order to stimulate innovation and make full use of the enabling potential of nanomaterials, the EU regulatory environment needs to be robust, for example, with regard to the protection of intellectual property, at the same time facilitating operational flexibility, promoting innovation and enhancing the EU's ability to compete in the global marketplace.

Despite, or in the absence of, global harmonised governance policies, more private corporations will adopt their own explicit nanotechnology safety policies to gain competitive advantage and these will diffuse along value chains. Increased costs, fragmented market requirements and new trade barriers can be expected to arise from this.

- **Risk-benefits as basis for responsible deployment**

To a large extent nanotechnology has been a victim of its own hype: no real-world technology could be expected to live up to the claims made for it during its initial publicity. A consequence is that this hype produces "over the top" discussions on potential health and environment dangers that are often based on the "visionary phase" rather than what can be expected in reality to be induced by the technology.

A recent EC public online consultation on nanotechnology[18] and its application showed that both experts and the general public see many benefits in nanotechnologies, as well as recognising potential risks. In the survey more than 80% of respondents had either high or reasonable expectations of nanotechnologies in general (see Figure 5).

[18] http://ec.europa.eu/research/consultations/snap/report_en.pdf

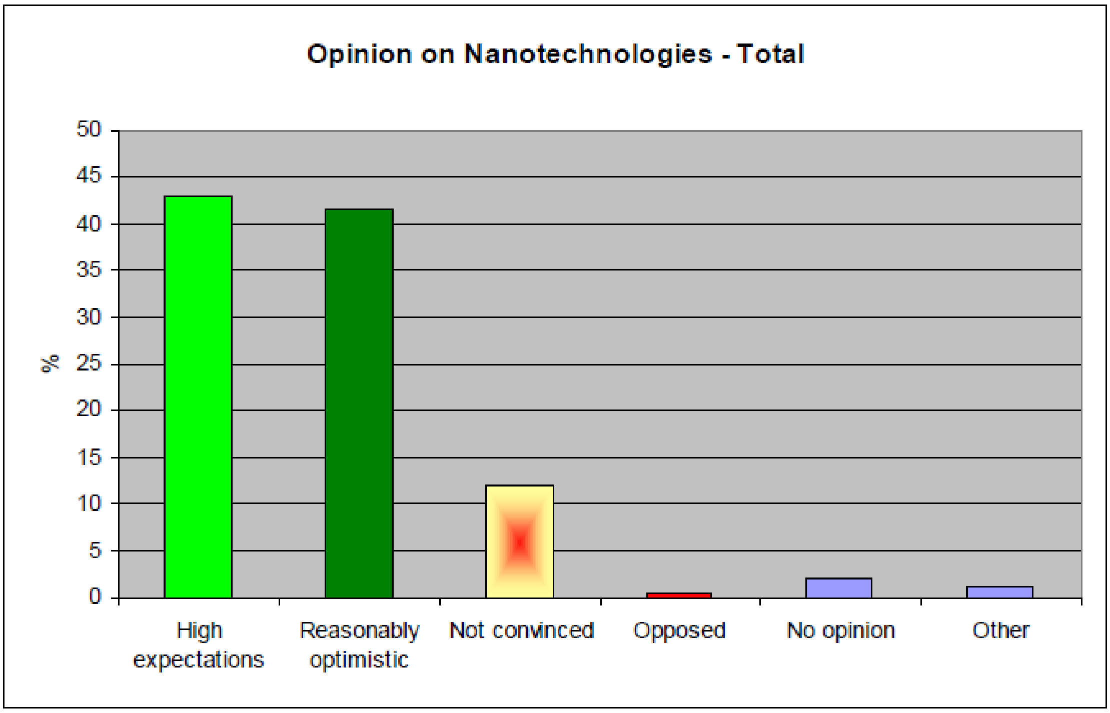


*Figure 5. Opinion on Nanotechnologies*[19]

The result of this public consultation demonstrates that benefits and risks are recognised differently in specific applications. For example application is energy, ICT, construction and aerospace are perceived as high benefit/low risk; while applications in food and agriculture are seen as low benefit/high risk by public authorities, NGOs and industry.

The benefit-risk discussion in specific application areas should guide future policy including funding and governance. This also requires that good governance has to differentiate between nanomaterials that are already on the market (using existing regulations), products that are near market (on market in the next five years) and potential future solutions that may be available on the market in a time horizon over five years.

In recognising the need for consistent, scientific, evidence based regulatory governance, the discussion has also to recognise the principle: "no market – no regulation needed". The new EC strategy to link societal challenges with technology and have a parallel safety discussion on specific uses as a techno-socio-economic innovation ecosystem should be a step forward to the timely delivery of the smart and sustainable growth objectives of the 2020 agenda (C. Tokamanis, KET Open Day on Nanotechnologies, 27 October 2010).

In particular, new nanomaterials should be evaluated along specific value chains in their respective different use categories and the level of protection required assessed using regulations that are already in place, in particular with regard to protection of the workforce. A too rigid precautionary regulation approach runs the danger of significantly reducing the adoption of this technology in Europe, while not avoiding the risk coming from its adoption via imported products from other less controlled areas of the world.

It is key that the private and public sectors have to develop detailed and accepted risk- benefit messages targeted for specific applications of nanotechnology towards societal challenges. These have to differentiate between shorter term, real market opportunities and longer term promises ("visions") for benefits. There may also be value in discussing specific uses of nanomaterials in certain critical areas, for example human

[19] http://ec.europa.eu/research/consultations/snap/report_en.pdf

behaviour modification, that will be controversial. The time for such a broad EU dialogue with citizens is now (L. Frewer, KET Open Day on Nanotechnologies, 27 Oct. 2010).

Learning from business sectors such as the insurance sector on how to establish dialogue with the public on risk, especially on incremental change versus innovation potential, can be a way to unlock the ongoing nanotoxicology/ nanosafety debate, where increasing data can create greater uncertainty through complexity. Public dialogue will also require a focussed definition for nanotechnology, as too broad a definition will corral many products (which clearly provide no current risk) into the "nanosafety discussions". However producing a widely accepted definition might, in itself, prove a significant challenge and obstacle.

A "pure" risk discussion should be substituted by an approach, which asks "what additional risk" does nanotechnology bring in comparison with existing solutions (J.Epprecht, KET Open Day on Nanotechnologies, 27 October 2010).The change in risk profile and adequate information about precautionary measures being taken is key to this approach.

Many aspects of the nanomaterials debate should be integrated into the wider debate on innovation, not just as a distinct problem area in itself. Several areas of debate, such as precautionary principle and uncertainty arising from new products and processes, are not limited to nanomaterials only.

The promotion of nanotechnology requires a broad dialogue with the public about benefits in everyday life (including the economic risk of not exploiting the technology for Europe) as well as around safety concerns. It is key to include in this debate the fact that the public has the right for safe products as well as the right to access the benefits that the use of this technology can bring to improve their quality of life.

- **Standardisation**

Standardisation and normative rules are key factors in accessing markets and important tools for accelerating the transfer of technology between science and industry. This is key for the manufacturing sector, as elaborated in the report of the Advanced Manufacturing Systems KET; i.e. nanostructures are analysed by very sophisticated instruments, which can be applied industrially only for low volume, high value production. Currently there are no applicable standards to reliably measure nanotechnology on-line during volume production. Therefore there is a danger that every value chain, or chain segment, will develop their own heterogeneous standards based on secondary properties.[20]

- **Intellectual Property Rights**

The successful exploitation of nanotechnologies requires cooperation along the value chain and the formation of consortia from very different sectors. Therefore a pragmatic approach, including the publication of best practice, has to be broadly available to avoid long delays in consortia discussions around intellectual property rights (IPR) requirements including foreground and background knowledge (see EC project Nano2Market[21]).

The timely introduction of a more streamlined, cost effective and efficient European patent system is a key requirement for the essential protection of IPR that is a prerequisite for commercial implementation of innovation.

[20] Leppänen, KET Open Day Nano 27 October 2010
[21] http://www.nano2market.eu/

### 3.2.3. Advanced Manufacturing

Manufacturing for new nanomaterials as the basis for this technology is a challenge. Countless new nanomaterials have been synthesised in laboratories worldwide, opening up the potential for a wide variety of new applications. However, new exciting materials often remain at the laboratory stage, because the road from fundamental science to end-systems production is very complex.

The deployment of nanotechnology is key for Europe to strengthen its manufacturing capacities while addressing societal challenges. This will be achieved through a rejuvenation of manufacturing technologies, processes and products as well as through creation of entirely new business.

The increasing demands from society, while natural resources dwindle combined with increasing prices, decreasing availability of fresh water as well as adverse climate change underline the necessity to improve the overall efficiency of resource consumption for industrial production in the future. Continuous enhancement of the resource efficiency of processes via product as well as process technology innovations will become a key factor for success. Solutions can be provided by the development of integrated resource efficiency strategies within production units; i.e. optimising products and processes so that all input materials (including raw materials, renewable feedstock, energy, water, solvents, catalysts, packaging etc.), all processes, output materials (including products, side products, waste streams etc.), adaptation to environment, and all recycle options are optimised. Standardised, modular multipurpose plant concepts for rapidly adjustable production and corresponding supply chain concepts should also be optimised to reach sustainability objectives. Occupational safety has to be considered in the design of any process.

To create high-value nano-based products, academia, materials producers and final system integrators need to work together in close collaboration among the sectors and along the value chains. The much stressed European paradox of being better in science than in reaping the economic benefits of this research can only be overcome if this type of collaboration becomes the standard procedure in Europe.

Currently manufacturing processes for nanomaterials are relatively crude and dependent on processes not specifically developed for nanomaterials, but adapted to this purpose. Corresponding approaches to manufacturing processes often involve unit operations. Nanostructured and nano-containing materials or intermediates, however, offer the possibility to combine or integrate multi-operational systems into fewer or single steps. In both cases nanomaterials provide new challenges for manufacturing processes including online monitoring . **Development of new nanomaterials will require new unit operations as well as the clever combination of new and existing processes**.

**Up-scaling is critical in the development of any new process. In order to achieve mass production of nanomaterials , multipurpose plants will have to be developed.**

**Nanomaterials, like any innovative material can have high impact on the processing and manufacturing technologies of downstream industries.** Heavy investments with long pay-back times, which are required for the uptake of nanotechnologies are barriers to the deployment of nanotechnologies. This is especially important as the uptake of new materials along the value chain is hindered by the “conservative” nature of manufacturing processes and equipments down along the value chain (KET Open Day on Nanotechnologies, 27 October 2010). Critical areas are the need for new machines and a skilled workforce, the division of labour, multi-purpose equipment and areas such as quality insurance with high investment costs.

### 3.2.4. Network of SMEs and large companies needs strengthening

For the deployment of nanotechnology Europe has strong basic research and an elaborate business landscape, significant interest from the new generation of citizens and a good industrial base for exploitation. The "back-bone " of this deployment is the excellent symbiotic network of smaller, medium and large companies as well as the presence of significant complete value chains in Europe within relatively smaller areas than, for example, in the Asia-Pacific region, enabling better, closer cooperation for deployment. Difficulties still are in utilisation of the technologies, difficulties for start up enterprises, information deficits in commercialisation of research and fragmentation in both the research and innovation landscape across Europe (Nano-initiative action plan 2010, BMBF p. 14).

In order to effectively contribute, smaller enterprises need to be able to easily understand the precise allocation of responsibilities at EU and country level. Existing technology support structures are, in general, still too complex despite efforts to simplify and make them SME-friendly.

Many essential pre-regulatory processes, such as the appropriate definition of nanomaterials, is already taking too long. This creates uncertainty along the value chain and therefore adversely affects potential investment. In addition stronger support is needed to transform developments from research into commercial applications. Support for marketing and provision of expert consulting to SMEs, as well as ongoing simplification to rules for participation in multinational programmes is required (M. Jung, S. Sepeur, KET on Nano , 27 October 2010). It is also important to bring industrial and business policies nearer to current business models and to ensure that they are accessible and understandable (provided in local language etc.) across Europe.

A successful nanotechnology commercialisation strategy needs:

- A sharp, multidisciplinary focus covering a small number of strategic areas, with a collaborative multidisciplinary approach
- The efficient use of funds that avoid duplication of staff, instrumentation and facilities, but creates a functioning network of centres of excellence
- Fewer commercial obstacles to infrastructure, funding and technology transfer. For example, both France and Ireland have created hubs for nano-design with several centres (J.F Clerc, M. Cronin, KET Open Day on Nanotechnologies, 27 October 2010). The role of "smart specialisation" by Member States is crucial for the successful deployment of nanotechnology
- Prototyping and testing facilities open to all. The commercialisation challenge needs support for proof of concept and demonstration projects, advanced new materials, risk taking in investment and funding, technical maturity, and faster approval time downstream
- High quality and environmental standards that are common across the single market (and beyond) and are widely accessible
- A skilled workforce available to all parts of the value chain

**Information, education and training of markets players** are key parameters for the integration of new materials and technologies in the different value chains. This is relevant for acquisition of appropriate skills in the workforce of a variety of different sectors, technology education, and training for new specific equipment to manufacture and process this technology.

One of the major strength of the European economy is the network of small and large companies. In order to effectively contribute smaller enterprises need to be able to easily understand the precise allocation of responsibilities at EU and country level. Existing support structures are, in general, too complex despite efforts to simplify and make them SME-friendly.

An issue, apart from an uncoordinated, and sometimes "diffuse" political discussion on regulations between stakeholders and institutions, is the information deficiency in the industry itself.

For example a leading retailer of a wide range of consumer goods had to approach a chemical company to learn about nanomaterials that might be present in its textiles, furniture, sports and electronic equipment, because none of its direct suppliers could give the retailer an adequate answer[22]. Clearly fostering knowledge transfer on the opportunities available from nanotechnology and best practice and adequate risk management throughout the value chain, including all SME partners, is of primary importance (KET Open Day on Nanotechnologies, 27 October 2010).

### 3.2.5. Skills needs

Nanotechnology is by definition a technology that requires integrated approaches involving a variety of scientific, technical and engineering disciplines. Furthermore the development of resource efficient processes requires an efficient linkage between natural sciences and engineering. For the development of converging technologies, such as nano-bio or nano-electronics, multidisciplinary skills will be critical. There is the need to provide future engineers and scientists with a multidisciplinary and broad skill set and educate them in sufficient numbers to deploy not only nanotechnology, but also the integration of this technology into other areas.

Specific courses providing a broad introduction to nanotechnology for both business and technical students are not widely available at University level in Europe. Courses on nanotechnologies are still largely missing from most normal engineering school curricula. Furthermore, skills required for exploitation and cooperation along the value chains will be essential for the deployment of nanotechnologies. The objective should not be limited to the education of world class scientists, but also to have enough high skilled engineers to manufacture and handle nanomaterials and technologies at industrial scale. These specific skills also have to be included in the re-training of the workforce under life long learning programmes.

At a higher level for the business leaders of the future MBA students need to learn about emerging technologies such as nanotechnology, in addition to the modules on biotechnology and electronics that are currently taught.

## SWOT analysis from working group on nanotechnology in Europe

Europe has a very strong fundamental research base in nanotechnology and an elaborate multi-faceted research landscape involving significant public and private stakeholders. There is significant interest in the technology from the new generation of citizens, and a good industrial base for exploitation.

Difficulties still remain in utilisation and deployment of the technology. There are considerable barriers to easy establishment of start-up companies, there are information deficits in the commercialisation of research along the value chain, and fragmentation both in the research and innovation geography of Europe. See the SWOT in Figure 6.

[22] Several presentations at KET Open day Nano, 27 Oct. 2010

| **Strengths** | **Opportunities** |
|---|---|
| • High potential for employment and societal solutions<br>• Strong basic research<br>• Elaborate research landscape<br>• EU population is open-minded towards nanotechnology<br>• Interest from the new generation<br>• Good industrial base (SME and large company network)<br>• Skilled workforce to deal with complexity<br>• World leading value chains in Europe within EU region | • Responsibility to speed up deployment<br>• Diverse, more efficient materials<br>• New diversity of application<br>• Broad risk-benefit discussion with EU society<br>• Good climate for innovation<br>• Potential for investor interest<br>• Deployment of complex societal solutions<br>• Deployment along value chain into societal benefits |
| **Weaknesses** | **Challenges** |
| • Utilisation shortfall (nanotechnology is cross cutting technology)<br>• Continued uncertainty about economic climate<br>• Limited cross border and inter-institutional cooperation in public and private sector<br>• Risk discussion as priority instead of risk-benefit (no nano-vision)<br>• Difficulties for start-ups: Insufficient provision of risk capital, bureaucratic obstacles<br>• Information deficits in commerce: Potential investors currently lack reliable picture of the opportunities<br>• "mature" world leading industry sectors as primary clients<br>• Demonstration and scale up of process and manufacturing of nanotechnology | • Ensuring the quick conversion of research into products that can be manufactured in Europe (supported by appropriate public-private initiatives)<br>• New cooperative policy approaches as well as need for policy implementation and business models to be nearer to each other<br>• Establish critical mass for deployment (incl. engagement of value chain)<br>• Uncertainty and Harmonised robust scientific risk assessment and i.e. trade impact<br>• Safe, responsible handling of nanotechnology along value chain<br>• Coherent strategy in EU incl. member states and institutions to better use EU strength of dealing with complexity |

| | |
|---|---|
| **lacks long term investments**<br>• **Lack of skilled work force for deployment at larger scale**<br>• **IP and patenting European regulations** | • **Rejuvenation of industry sectors**<br>• **Public-private risk capital fund** |

*Figure 6. Draft SWOT analysis from report*

## 4. HOW TO SUPPORT THE DEPLOYMENT OF NANOTECHNOLOGIES IN AND FROM EUROPE

**Innovation is about speed to market…**

### 4.1. EU policy framework

#### Coordinated policies

- For the successful deployment of nanotechnology it is especially important to actively manage the interface between the EU Innovation Union concept and EU Industrial Policy as it is probable that the main policy challenges will be found at the interface between these policie; that is the transition between research and development and commercialisation (KET Open Day on Nanotechnologies, 27 October 2010).

- It is essential that the EU plays to its strengths. EU Member States must evaluate their priorities in deployment of nanotechnology within their own "smart specialisation" initiatives

- "Use what you have" : European Technology Platforms (ETP) complying with the success criteria set by the ETP expert group in 2009[23], can enable a step change in the cooperation and interaction between authorities at European and national level, industry and academics. Leading European Technology Platforms are already continuing this trend by seeking inter platform collaborations to exploit synergies and interfacial opportunities. Criteria for continuing public support should be the output in terms of concrete actions and results from platforms. Currently many cooperations have just resulted in large discussion forums at EU level, which are in fact too large to be efficient.

- To achieve a European competitive advantage it is essential that national level actions are coordinated within an EU wide approach and that public innovation policies are aligned with private business models (supporting and initiating innovation at various stages of the value chains simultaneously).

- There is a need for a new strategy for governance based on a risk-benefit approach to achieve a consistent and coherent EU strategy as part of a global harmonised approach. The benefit-risk discussion in specific application areas should guide future policy including funding and governance.

[23] ftp://ftp.cordis.europa.eu/pub/technology-platforms/docs/fa-industrialresearch-b5-full-publication-rp_en.pdf

- The new EC strategy to link societal challenges with technology and have a parallel safety discussion on specific uses as a techno-socio-economic innovation ecosystem should be implemented as a major step forward to the timely delivery of the smart and sustainable growth objectives of the 2020 agenda through the responsible deployment of this KET. A dialogue with the general public on the benefits and potential risks from nanotechnology should be started urgently as the public has not only the right for safe production and products but also the right to benefit from the deployment the technology to improve their quality of life and meet societal challenges.

**Closer alignment of policy implementation and business models**

*Stimulate innovation at key stages of the value chains simultaneously*

Nanotechnologies require involvement of different industries before they can become useful for society. Cross-border cooperation along value chains and cross industry partnerships will be necessary to enable the full deployment of nanotechnologies.The ability to act quickly will be determinant, as global competition is putting enormous pressure on process and manufacturing industries. Traditionally, societal challenges were tackled by the public sector by working along the value chain starting from the end user sector, i.e. the providers of the final consumer product who are visible in the market as leaders and innovators. Such a linear approach, although being safe and conventional, has proven not to deliver on its expectations in the past. Therefore, in order to speed up innovation in Europe, it should be complemented by an approach that allows innovation to start at key stages of the value chains simultaneously and involving multiple sectors (such as advanced material producers). This can create real competitive advantage and inspire breakthrough to comprehensive solutions. This approach would bring the implementation of innovation through public policies and "real life" business models[24] much closer to each other.

- **Support adaptation of the value chains for uptake of nanotechnologies**
  Nanomaterials, like any innovative material can have high impact on the processing and manufacturing technologies of downstream industries. Process integration down in the value chains is a challenge, which has to be overcome to ensure the deployment of nanotechnologies. Heavy investments with longer pay-back times which are required for the uptake of nanotechnologies should be supported along the value chains.

- **Support development up to industrial scale**
  Up-scaling is critical in the development of any new process In order to achieve mass production of nanomaterials , multipurpose plants will have to be developed. Demonstration at industrial scale should therefore be supported in order to promote the deployment of nanotechnologies. First industrial units are subsidized in some non-European countries (for example China and the US).

- **Potential demonstration and market replication actions at EU level to facilitated deployment**
  Demonstrator projects are essential to replicate market introduction conditions, however there is the question of how far can innovation be funded by public money. Demonstrator projects represent the top level for technology development.

## Supporting cross- border and cross- sectoral collaboration

*Coordination of national policies, added value of cross border collaborations to be identified*
*Encourage different sectors to work together*
*Support cross-industry and cross-border alliances.*

[24] KET Open day on Nanotechnologies conclusion, 27 October 2010

- Nanotech is a KET that requires cooperation between EU institutions and between Member States to deploy this technology along the various different value chains.

- Nanotechnology needs to traverse all traditional boundaries including cross-border funding. This is especially needed for smaller Member States, in order for them to access a critical mass for cooperative actions. Cross border funding should be made available to support projects which bring together development and/or prototyping ventures involving multiple companies from various sectors along the value chain in the same way that current Research Framework Programmes bring together a wide variety of partners for research projects, thus adding a truly European spirit to the programmes.

- There needs to be an improved focus for EU funding for cross-over technologies at the interface between disciplines for example nano-advanced materials, bio –nano, nano-photovoltaics and nano-ICT.

- Innovation and industrial policies, like existing research policies, must encourage cross- industry and cross-border alliances/partnerships including support for the launch of programmes that encourage industries to explore these new collaborative domains.

- Cross border funding should be made available to support projects that bring together development or prototyping ventures with multiple companies from various sectors along the value chain in the same way that Research Framework Programmes (FPn) bring together a variety of partners in research initiatives.

## Efficient instrument for innovation

- Innovation requires impact based programmes for societal challenges supported by flexible funding instruments, which should support faster proof of concept/ technical maturity and finance larger scale demonstration projects. This could lead to the use of a significant part of the remaining budget in the current Framework Programme (FP7) for collaborative development and innovation initiatives to bridge the "death valley" (or innovation gap) between research and the realisation of societal value. This shift of funding should be accompanied by an evaluation by the EC to determine the innovation output of the various FP instruments, which are currently optimised for research only, to see what additional instruments may be required. This could include better use other funding instruments such as Structural Funds.

  It has already been proposed in some Member States that 30% of the funding of research programmes should be "earmarked" for these innovation areas (see Irish national funding proposals : Forfas report [9] p. 59-62,).

- **Criteria for success of funding for innovation**
  Research programmes need clearly defined success metrics and rigorous periodic evaluation. Quality criteria for research programme evaluation could include the number of patents created, spin-off companies established, the number of PhD and qualified scientist/ engineers trained as well as public outreach initiatives (Forfas report [9], 2010).

## 4.2. Supporting measures for innovation

### Market push

Within European private manufacturing funding is currently aligned with four key priorities:

- Production of large quantities of highly purity nano-scale particles
- Processing nano-scale components within matrix materials
- Coating surfaces with nanoscale materials
- Online analysis during production and processing

A true market push initiative can only be successful in markets where Europe is traditionally strong (for example automotive, aerospace and consumer) as there will be no distinct “nano-industry” sector as such that is able to achieve critical mass (Forfas report [9], 2010) and a unique end-market. Thus for the successful deployment of nanotechnology it is crucial that EU Innovation Policy is complemented and integrated with EU Industrial Policy to ensure Europe can fulfil its potential for leadership at global level.

Due to the character of nanotechnology, it is essential to put industry first to create a demand pull, instead of trying to induce a science push (Forfas report [9], 2010). This will require enhanced communication and collaboration both along and between different value chains in Europe and globally.

Broad and coherent innovation policy as developed by the Business Panel on Future EU Innovation policy (final report[25] ) is key for nanotechnology deployment (see details in Annex 5).

### Market pull

- **Super customer**
  Nanotechnology can contribute towards many societal benefits. Therefore a target-oriented procurement market that can describe concrete targets for products and processes without being over prescriptive is required. For example a requirement to improve general energy efficiency in the public sector in a technology neutral way but with a clear timeline for implementation.

  The countries that are currently the most successful in the exploitation of nanotechnology are those which have a “super customer”. This is an organisation or group of organisations that can significantly contribute to the commercialisation of nanotechnology research through funding leverage and application focus.

  In the United States such a “super customer” might be the Department of Defence or Department of Energy, or the small and medium size enterprise sector (SME) in Germany (Forfas report [9], 2010).

  The US military has tremendous market-pull potential. For example the Institute for Soldier Nanotechnologies[26] was established at MIT to research military applications and the US Army and Air Force have made exclusive contracts with suppliers for certain classes of nanotextile clothing and wound dressings.

[25] http://ec.europa.eu/enterprise/policies/innovation/files/panel_report_en.pdf
[26] http://web.mit.edu/isn/

In other countries significant international events can provide an opportunity for such a market-pull. For example the Beijing Olympics saw the development of a nanotechnology coating with soiling resistance and fungicidal properties by the Chinese and used on the main Olympic stadium. This helped establish a nanostructured coating industry in the country.

**However, in many EU Member States there is no "super customer" to drive focus and application.** This in turn leads to fragmentation of research, as researchers tend to choose their own areas to work in, and there is no kick-start to commercial application.

- **Access to finance, including risk capital**
  Further development of the European Innovation Fund (via the EIB) should provide more technology driven risk capital investment. There should also be political and financial incentives for Venture Capital to provide early funding for high technology companies. Hybrid public – private financing models can be a way to fill the current investment short fall in Europe.

- **Incentives policy (such as taxation or state aid measures)**
  The UK offers 100%+ tax credit on corporation tax for R&D investment. Such fiscal incentives using the taxation system are the best way to incentivise private research investment (KET Open Day on Nanotechnologies, 27 October 2010).

# APPENDICES

# Appendix 1

| Functionality | Application Examples |
|---|---|
| Optical<br>– Color effects<br>– Selective light conduction<br>– Anti-reflection<br>– IR-reflection/absorption<br>– Light/current conversion (photovoltaics)<br>– Light/heat conversion (solar thermics)<br>– Photochromism | • Transparent, high-effective UV-protecting agents on the basis of ZnO- or $TiO_2$-nanoparticles for sunscreens, textiles or wood surfaces.<br>• Anti-reflection layers on the basis of nanoporous silicon-dioxide layers for solar cells and architectural glass.<br>• Changeable color effects in dependence on the viewing angle based on nano-coated $SiO_2$-platelets for lacquers and cosmetics (interference pigments) or through optical grid structures (interference layers).<br>• Transparent nanoscaled IR-absorbers as heat protection for Plexiglas-roofings and winter gardens.<br>• Transparent nanoscaled silver-IR-reflection layers in heat-absorbing glasses.<br>• Photochrome layers on the basis of tungsten trioxide für tintable windows.<br>• Photonic crystals for selective light conduction in the optical data transmission on the basis of regularly arranged nanoclusters.<br>• More efficient photovoltaics through the optimization of light penetration (photon management) and light conversion through nanostructures (e.g. quantum dots) as well as low-cost materials and processes (thin-layer, dye-sensitized solar and polymer cells).<br>• Nanostructured absorber layers for the maximization of energy application in solar-thermy. |
| Mechanical<br>– Tensile strength<br>– Scratch resistance<br>– Strength<br>– Tear strength<br>– Impact resistance<br>– Gas tightness | • Wear-reduction of highly stressed components and tools through diamond-like or ceramic nanolayers.<br>• Scratch-resistant coatings through incorporation of inorganic nanoparticles into clear lacquers or transparent plasma coatings of plastic optics.<br>• Lightweight construction materials with improved mechanical properties on the basis of nanoparticle/fiber-reinforced composites, nanostructured metal-matrix-composites, organic-inorganic hybrid-materials or ultra-high performance concretes.<br>• Improved tensile strength and breaking strength through the integration of carbon nanotubes in material matrices e.g. for the reinforcement of sports equipment (tennis/golf/ice hockey rackets, bicycle frames).<br>• Gas-tight films for packaging in the food sector through layer-wise nanosilicates in polymer composites. |

| Functionality | Application Examples |
|---|---|
| Electronical/Electrical<br>– Conductivity<br>– Dielectric layers<br>– Superconductivity<br>– Thermoelectricity<br>– Electrochemical energy storage | • Electrically conductive polymers through integration of carbon nanotubes into the polymer matrix for antistatic applications and electromagnetic shielding.<br>• Improved high-temperature superconductivity through nanoscaled substructures for increased ampacity and cost-efficient sol-gel-materials for layer production.<br>• More efficient thermoelectrics for power conversion of heat through nano-structured semiconductor connections.<br>• Nanoporous "low-k"-layers for the reduction of delay in conduction in CMOS-circuits. |
| Chemical<br>– Super-hydrophilicity<br>– Super-hydrophobicity<br>– Corrosion protection<br>– Catalysis<br>– Flame protection<br>– Fire protection<br>– Adsorption power<br>– Adhesion power<br>– Dissolving power | • Antifogging effect through super-hydrophilic titanium dioxide nanocoatings for glasses and exterior mirrors of cars.<br>• Dirt-repellent coatings, inter alia, through nanoparticle-modified fluor-siloxane/silane coating agents for textiles, furnishings and façade surface finishings.<br>• Fire-protection windows on the basis of transparent, nanoparticular fire-protection gels and layers, which, under the impact of heat, form ultra-fine gas bubbles with strongly heat-insulating effect.<br>• Flame-inhibiting effect for plastic casings and cables through integration of catalytic nanoparticles in the polymer matrix, which prevent the spreading of flames by accelerated formation of non-combustible carbonization residues.<br>• Anti-fingerprint layers for stainless steel and metal surfaces on the basis of thin glass coatings.<br>• Efficient adsorbent materials for gas storage or for the removal of contaminants through extended active surfaces and adjustable pore sizes. |
| Thermal<br>– Heat protection<br>– Heat insulation<br>– Heat conduction<br>– Heat storage | • Nanostructured heat-protection layers and alloys for turbine materials to achieve better energy conversion rates at increased working temperatures.<br>• Superinsulating nanofoams (aerogels, polymer foams) for heat insulation in buildings and industrial processes.<br>• Better heat conduction through nanofluids and nanocomposite materials on CNT-basis in industrial processes or in solarthermics.<br>• Efficient heat storage through micro/nanoencapsulated phase change materials to be integrated in the facade components. |
| Magnetic<br>– Magnetically soft materials<br>– Magnetoelectronics<br>– Magnetorheology<br>– Magnetic induction heat | • Nanocrystalline, magnetically soft iron alloys capable of having extraordinary magnetic properties impressed on them, inter alia for high-capacity components in grids (e.g. toroidal tape core, transformers, choke coils).<br>• Magnetic layer stacks with giant magnetoresistance properties for magneto-electronic sensors and data memories.<br>• Dispersions of surface-stabilized nanoscaled iron particles (ferrofluids) with magnetically controllable viscosity for sealings, shock absorbers etc.<br>• Iron oxide nanoparticles for heat generation by means of alternating electro-magnetic fields (e.g. for switchable adhesives or hyperthermal cancer therapy. |
| Biological<br>– Antimicrobial effect<br>– Bioavailability<br>– Biocatalytics<br>– Moleculare recognition<br>– Biocompatibility<br>– Cell permeability | • Antimicrobial equipment of plastics in medical engineering, furniture surfaces, textiles, through silver nanoparticles.<br>• Higher bioavailability of medical agents and dietary supplement substances through liposome encapsulation and nanoemulsions.<br>• Nanoparticles as carriers for the introduction of genetic material into cells (gene vectors) in gene therapy.<br>• Molecular recognition of diseased cells for effective drug delivery through surface functionalized drug-delivery systems.<br>• Nanostructured implant surfaces and nanoparticular bone substitute materials for increased biocompatibility in regenerative medicine.<br>• Nanostructured templates and carrier substances for efficient biocatalysts. |

Examples of possible property optimizations through nanomaterials

***Application and product possibilities of nanotechnology – NanoDE report***[27]

[27] http://www.bmbf.de/pub/nanode_report_2009_en.pdf p. 12-13

# Appendix 2

Convergent technologies such as ICT, nanotechnology and biotechnology can bring about completely new approaches to several of the societal challenges mentioned. As an example :

## Case study 1: Nanomedicine

The nano scale is the ideal scale for interacting with biomolecules and can therefore contribute to a new and innovative approach to medicine. Sensing, interacting, destroying, monitoring and tracking biomolecules involved in pathological processes is of paramount importance for diagnosing, curing and monitoring most human illnesses that mostly start at the molecular level.

Nanotechnology applied to medical applications – nanomedicine – is a key enabling technology which will enable earlier diagnosis, better targeted therapies and improved therapy monitoring[28].

Three main areas are commonly considered in nanomedicine:

- In vitro or in vivo diagnostics
- Drug delivery
- Regenerative medicine[29]

Although nanomedicine is still in its infancy in terms of industrial products, two main industry sectors are contributing to its development:

- The semiconductor industry is investing heavily in the development of sensors and devices, in a top-down approach, by developing smart, more sensitive, less invasive technologies. These are generally at the micro-scale with nano-scale sensing parts. The devices can be operated once implanted, wearable or ex-vivo.
- Independently, the pharmaceutical and biotechnology industries are developing nanomaterials, such as nanoparticles for the targeted delivery of drugs or imaging agents, nanopatterned surfaces for cell sensing and differentiation, and biomaterials for stem cell scaffolds.

**Sensing devices in nanomedicine**

The use of nanotechnology in health-related sensing applications is potentially a massive market in itself covering body-worn sensing, in-vivo sensing and pervasive environmental sensing.

A number of technical challenges confront these technologies. In-vivo sensing devices must be able to scavenge power inside the human body and also provide a reliable communication link to external monitoring devices and feedback to intelligent internal drug delivery systems to ensure appropriate and targeted drug dosage. The limiting step in adoption of such technology will be regulatory concerns.

Pervasive environmental sensing also faces issues of public perception. However, 450 mm silicon manufacturing will enable the production of sensors on a massive and very low cost basis to meet the needs of large sensor deployments in the environment for security and environmental reasons.

Biological construction techniques for such devices might include DNA-based molecular assembly and application of other biological construction techniques for the fabrication of nano sensors. High Performance Silicon and Biological Interfaces will enable a move from macro to cellular based interfaces

[28] http://www.etp-nanomedicine.eu/public/press-documents/publications/etpn-publications/091022_ETPN_Report_2009.pdf

[29] Telemedicine or ambient living using remote sensors is usually not considered as part of nanomedicine

**Value chain considerations**

The nanotechnology value chain in pharmaceuticals is very close to the biotechnology industry, where innovation usually starts in high-tech SMEs that are close to academia until the proof of concept has been reached and pre-clinically proven. Sometimes this SME-led contribution continues until the end of Phase I clinical trials.

The next stage is the acquisition of the innovation / technology by a large pharmaceutical or biotechnology company to bring it through regular clinical trials and regulatory pathways to the market. The main differences with nanoelectronics and other nano-industry sectors is that:

- Medical products are heavily regulated with preclinical and clinical validations requiring long timescales so time-to-market can reach 10 years.
- Use in hospitals is a necessary additional step for product development and validation, which makes the development time longer and requires further interdisciplinary interaction
- The (nano)pharmaceutical industry is currently moving towards an open innovation approach including distributed research and development activities

Currently the most critical phases for the development of nanomaterials for medicine are:

- The need for accurate characterisation and standardisation of materials
- The transfer of technology of the technology to clinical use

Central characterisation laboratories are required in Europe[30] as well as some innovation clusters to provide a continuum from “bench to bedside”[31]

The societal and political support to nanomedicine is usually positive in comparison to other application areas. EU citizens usually accept the use of nanotechnology in medical applications as part of the scientific improvement of medical technologies and healthcare. Furthermore, nanomedical innovations promise to provide improvements for healthy aging and its cost management. However, the intrusion of nanotechnology in the human body raises some new ethical questions, which have to be properly addressed early to ensure a favourable deployment of nanomedicine.

[30] Like the National Characterisation Laboratory supported by the National Cancer Institutes, USA

[31] Like CLINATEC, part of Minatec Campus in Grenoble/France, or the Nanobioanalytik Zentrum (NBZ) in Münster/Germany

# Appendix 2

## Case study 2: Sensors and Nanotechnology in the Healthcare Domain

Nanotechnology Impacts on Future Sensor Development

- Size e.g. implantable and body worn
- Cost e.g. SOC
- Power Reduction
- Potential for Pervasive Sensing
- Lower weight
- Greater sensitivity
- Better specificity e.g. genetic classification of cancers
- Affordable sensor redundancy in systems

- First Generation Sensor Products Emerging into the marketplace e.g. ambulatory ECG, in-home activity monitoring, Fall detection sensors etc. However this market needs to scale to enable the large number of low cost sensor devices that nanotechnology can potentially deliver.
- Sensor technologies and future nanotechnology based sensor will enable a 'shift left' in healthcare i.e. move care from hospital centric to community or home. This is critical to address the societal challenge of a global aging population.
- Focus on usage models not just technology. What usage models can Nanotechnology can enable?

**Future Direction for Nanotechnology in Sensing Applications**

- **Body Worn Sensing**
  - Use case and application specific only
- **In Vivo Sensing**
  - Sensors will need scavenge power in side the human body
  - External communications outside body will be challenge to address in order to get data back out.
  - Intelligent internally drug delivery e.g. dosage modification
  - Regulatory concerns will temper speed of progress
- **Pervasive Environmental Sensing**
  - Issues of perception challenging
  - 450 mm silicon manufacturing will enable to production of sensors on a massive and at very low cost to meet the needs of large sensor deployments in the environment
- **Biological Construction Techniques**
  - DNA-based molecular assembly
  - Application of other biological construction techniques to the fabrication of nano sensors
- **High Performance Silicon and Biological Interfaces**
  - Move from macro to cellular based interfaces

**Healthcare Challenges**

- Excessive focus on pilots of existing technologies, slowing rollout. Need large scale demonstrators to demonstrate usage models, integration into healthcare systems, return on investment and clinical efficacy (Randomised Control Trial - RCT)
- **Healthcare organisational changes** – How will all the sensor data being integrated and acted upon within the healthcare systems
  - Potential for policy impact
- **Personal Health Records**

  - Lack of end to end integration
  - Lack of standards
- **Attitudes and Perception**
  - Design is key!

# Appendix 3

### National Initiatives in Europe Example - Ireland

In 1998 the Irish Government commissioned a major study called Technology Foresight Ireland. The main conclusion was that biotechnology and information and communications technology represented "the engines of future growth in the global economy. A world class research capability in selected niches of these two enabling technologies is an essential foundation for future growth." Science Foundation Ireland was established in 2000 with a budget of €646 million for the first five years. Investment has continued with €162m being allocated as recently as 2010.

Government advisers Forfas sponsored a report - Ireland’s Nanotechnology Commercialisation Framework 2010-2014 - with international consultants Lux Research. The study examined ways to exploit the high level of investment in the sector as a way to help attract more foreign direct investment and encourage indigenous enterprise.

The reports main conclusions were:

There is a need to focus Irish nanotechnology research efforts. To ensure economic impact from public investment, Ireland needs to maintain current funding levels but focus this funding into fewer, more strategic technology-application combinations.

Establish a nanotechnology coordinating group. This coordinating group would comprise multiple stakeholders from government departments, the developmental agencies, industry and academia.

Align funding to focus areas and coordinate funding management. This would define a funding stream for the theme “nanotechnology” in the annual Science Technology and Innovation budget. To fund the recommended focus areas, this nanotechnology commercialisation strategy lead to a total funding requirement of €114 million over the next five years.

Diversify funding sources and increase industrial funding. Introduce structured programmes (aligned to the focus areas) to attract and significantly increase industry involvement, commitment and investment in nanotechnology R&D activities in Ireland.

Establish a self sustaining strategy. The coordinating group should be tasked to develop a self-sustainable plan that secures future required investment with a reduced government contribution.

Infrastructure development to support Ireland's nanotechnology vision. In the near-term the focus should be to leverage and network existing infrastructure, in the medium-term the focus should be to upgrade existing infrastructure, and in the long-term the performance resulting from the above two action lines should be reviewed to identify additional critical infrastructure augmentation.

Develop an entrepreneurial workforce to enable the effective translation of relevant research into commercially interesting opportunities.

Encourage and foster intensive collaboration at a national and international level.

# Appendix 4

**Business Panel on future innovation policy**[32]

The panel noted that innovation has been a central EU priority over the last decade. But the priority has been investing in knowledge rather than utilising it rapidly and powerfully for societal benefit and development. Innovation is global, with increasing competition for best ideas and applications, and Europe must stand out. More technology is not *per se* a solution.

Current (2009) European innovation policy fails to:
- Leverage the power of networks and social innovation
- Implement Community level actions orchestrated around major societal challenges
- Invest ambitiously and strategically in the future
- Open up innovation to the creativity of a broad range of European peoples and ideas
- Anticipate the new institutions and processes that will drive future innovation

The report argued that the European Commission should base its innovation policy on five propositions:

**Broaden the concept of innovation**
Business innovates mainly for return on investment, society must innovate for social return and transformation. Usually these two aspects of rewards of innovation are aligned**.** Europe faces unprecedented challenges. This calls for collaborative, crosscutting responses reaching out to business, public policy communities, researchers, educators, public service providers, financiers and NGOs.

EU action should focus on compelling social challenges, finance social innovation funds, incentivise large scale community level innovations, transform the public sector with a budgetary innovation target and engage both young and old in new types of partnerships.

**Speed and synchronisation:**
Speed and scale are everything in innovation. More is needed to accelerate the uptake of innovative solutions and technologies, especially in the public sector. Funding programmes and innovation support must be synchronised with development of standards, public procurement and regulations.

The EU should set clear innovation targets; launch ambitious European initiatives with synchronised actions around major challenges; ensure EU directives and regulations support innovation; change public procurement to support innovation; and open up government owned data to facilitate a knowledge infrastructure, where European citizens can help transform public services.

**Innovative financing models**
Europe needs a radical new approach to financing innovation with new partnerships to share risk and more intelligent ways to combine funding between instruments. Innovation should be core to financial institutions**,** with the European Investment Bank (EIB) becoming a European Innovation Bank.

A major development of the European Investment Fund (EIF) should create a pan-European Innovation Fund; develop an EU wide market for trading and sharing Intellectual Property; and broker bolder investment readiness initiatives.

**New places for new types of collaborations**

[32]Business Panel on Future Innovation Policy, Sept. 2009 http://ec.europa.eu/enterprise/policies/innovation/future-policy/business-panel/index_en.htm

Innovation feeds on collaboration, the spark and confrontation of different ideas, perspectives and experiences. Information technologies and web 2.0 tools are transforming how people interact. Open innovation is based on the power of networks and access to knowledge across Europe and globally.

Within the EU a network of innovation laboratories should be created; investment made in cultural and creative institutions, organisations and networks; the role of brokers and intermediaries be reinforced; a major prize for innovative localities developed; and universities and public research centres stimulated to be more open and international.