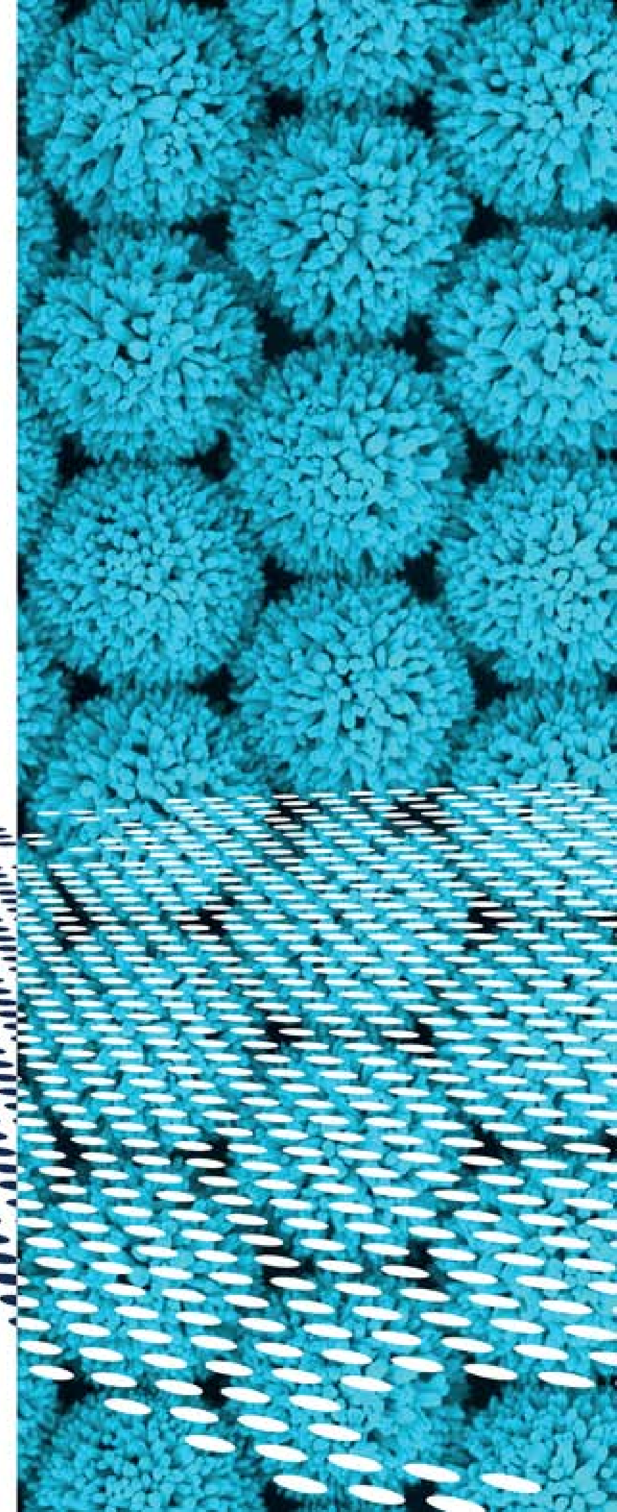
European nanotechnology landscape report



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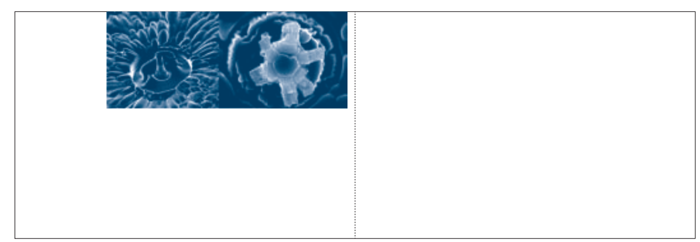

Award-winning image: Many brushes made from carbon nanotubes are formed into a tower 500 nanometres in diameter by using a focused ion beam system. The scanning electron microscope is used to investigate how they behave under the effects of pressure.

«Sea-urchins» made of tiny polystyrene balls, with zinc oxide nanowire «spines» are created using a simple electrochemical process.

The European Nanotechnology Landscape Report is an ObservatoryNANO Work Package 3 deliverable which is a compilation of efforts by the entire consortium. Particular thanks goes to the following partners:

Author Contributions

Introduction

- Eleanor O'Rourke, Institute of Nanotechnology, eleanor.orourke@nano.org.uk

The European Nanotechnology Innovation Landscape

- Brian C. Winans, Bax & Willems Consulting Venturing, b.winans@bwcv.es
- Laura Kauhanen, Spinverse, Laura.Kauhanen@spinverse.com

Intelligent, Connected and Safe World

- Pirjo Pasanen, Spinverse, Pirjo.Pasanen@spinverse.com

Sustainable Food and Environment

- Eleanor O'Rourke, Institute of Nanotechnology, eleanor.orourke@nano.org.uk

New Energy Economy

- Brian C. Winans, Bax & Willems Consulting Venturing, b.winans@bwcv.es

Ageing Population

- Matthias Werner, NMTC, werner@nmtc.de

Improved Resource Efficiency

- Leif Brand, VDI Technologiezentrum GmbH, brand@vdi.de

Conclusion

- Brian C. Winans, Bax & Willems Consulting Venturing, b.winans@bwcv.es

Data Contributions

Funding

- Tom Crawley, Spinverse, tom.crawley@spinverse.com
- Laura Kauhanen, Spinverse, Laura.Kauhanen@spinverse.com

Patents

- Leif Brand, VDI Technologiezentrum GmbH, brand@vdi.de

Publications

- Ad Notten, UNU-MERIT, notten@merit.unu.edu

Title Page Image Contribution

- Nicole C. Müller, Empa, nicole.mueller@empa.ch

Compilation

- Brian C. Winans, Bax & Willems Consulting Venturing, b.winans@bwcv.es

Lastly, thanks to all ObservatoryNANO partners that reviewed the document and provided their feedback.

DISCLAIMER

This report intends to provide a compilation of publicly available information about the relevant topic. The content of this report has been prepared as a result of the desk research made via existing literature and publicly available web pages, as well as with expert interviews and company surveys. The information herein is believed by the authors to be reliable and has been obtained from sources believed to be reliable. Colleagues have reviewed this report for accuracy.

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The European Nanotechnology Landscape Report offers an overview of the nanotechnology landscape in Europe targeted at policy makers on all levels (local, regional, national and European). It furthermore examines how nanotechnology developments, and the solutions they enable, can help address some of the Grand Challenges that Europe is facing today such as:

An ageing population

New energy economy

Sustainable food & environment

Intelligent, safe & connected world

Improved resource efficiency of industrial production

Even though nanotechnology offers some unique characteristics that can be exploited into many functionalities, one cannot state that nano-enabled developments are necessarily the best science or technology to address each particular problem. This publication refrains from taking a position on this issue; it merely identifies nanotechnologies and their potential contribution to solve some of societies' most challenging problems.

While considering nanotechnology as a solution, many aspects must be taken into account; societal and environmental impacts, and ethical and health risk analysis are required for an intelligent matching of societal demands and nanotechnological capabilities.

Many of the nanotechnology applications identified in this report are not 100% mature or proven at the time of publication. As a result, for those nano-enabled solutions that are foreseen for the future, no guarantees can be given that they will become reality in the expected timeframe. Factors such as the urgency of the global challenge, the likelihood of achieving the nano-enabled solution, and the time-line for its likely achievement are all adding uncertainty to the future outlook and must be taken into account.

The European Nanotechnology Landscape Report also builds upon policy-supporting primary data collected by the ObservatoryNano consortium. European nanotechnology companies' patent, publication and funding data is analyzed to provide a clearer picture of the European landscape. More than 100 European companies involved in nanotechnology have also been surveyed to examine what factors are of major concern to them, and how they perceive policy instruments influence their performance in a global business world. Given the total number of nanotechnology companies in Europe, the 100 respondents offer a statistically significant reflection of businesses opinions and realities; even so one should not consider the census results as absolute truths but rather as strong indications of perceptions of informed and highly involved individuals.

Table of Contents

Introduction

Europe faces a number of 'Grand Challenges', outlined in the Lund Declaration 2009[1] , such as global warming, tightening supplies of energy, water and food, ageing societies, public health, pandemics and security. Nanotechnologies offer the potential to help address a number of these challenges leading to an eco-efficient European economy, which competes effectively with other world regions.

In order to achieve these goals policy makers must ensure that European research is world leading. However, the innovation pathway from basic research, through development, to commercialisation must also be highly effective. With this need in mind the FP7 ObservatoryNANO project has undertaken to provide policy makers at all levels, from local governments up to the European Commission (EC) and European Parliament (EP), with an overview of the nanotechnology landscape in Europe. This has involved monitoring of new technology developments and their market impacts through desk research and extensive expert engagement together with a company survey to identify and gather information on European nanotechnology business activity. The survey has built upon the patent, publication, and funding analysis that has been ongoing since the project's inception in 2008. It already includes direct input from over one hundred nanotechnology businesses across Europe, as well as basic data on over 1500 nanotech companies identified by the ObservatoryNANO through objective criteria.

The first part of this report looks at the European Nanotechnology Innovation Landscape. The methodology utilised to identify nanotechnologies companies will be outlined before the results are presented. An analysis of EU innovation tools is presented that illustrates which innovation stimulation instruments are available to policy makers, and what a balanced portfolio of such instruments might look like, from a nanotechnology specific science-to-market perspective.

The second part of the report will take five of the Grand Challenges identified and provide a snapshot of the wide-ranging y development are outlined. Further, the obstacles being faced in the development of the relevant technologies are evaluated including EHS and ELSA issues, Regulations & Standards, and also economic and technological barriers. Finally two case studies of specific developments and their impacts, market potential, and barriers to success are highlighted.

[1] http://www.se2009.eu/polopoly_fs/1.8460!menu/standard/file/lund_declaration_final_version_9_july.pdf

Organisations involved in the manufacture, supply or use of any material have a duty to understand any risks that it may pose to the health of their workforce, customers and the environment, and to put in place such measures that are needed to manage these risks. This requires them to address any evident gaps in knowledge in order to gain a better understanding of the risks associated with their materials, whether to show compliance with regulation, pre-empt regulatory changes, and (particularly where no regulation exists) demonstrate responsibility[2] . ELSA, EHS, and Regulations & Standards issues are obviously very important considerations when addressing the future development of nanotechnologies within Europe. Aspects relevant to each of the grand challenges featured above are outlined within this report but considerably more in-depth analysis has been conducted within the ObservatoryNANO consortium. This information together with all other output; including annual factsheets, Briefings, and more in-depth technical reports; can be found on the ObservatoryNANO website at **www.observatorynano.eu.**

[2] SAFENANO, 2011: http://www.safenano.org/KnowledgeBase/Guidance.aspx

The European Nanotechnology Innovation Landscape

Introduction

Through research and primary data collection ObservatoryNANO has strived to better quantify the European nanotechnology landscape. In order to identify European nanotechnology companies, three criteria were selected;

- FP7 funding
- publications
- patents.

To obtain additional in-depth information, a selection of these companies was approached to complete an online survey.

The first group of companies was determined as those that had received funding from "Framework Programme 7: Nanosciences, nanotechnologies, materials & new production technologies" (FP7 NMP); 478 different companies were identified as having received FP7 NMP funding. Those companies that published nanotechnology-related articles between 1998 and 2009 fell into the next group with 278 different companies identified as being involved in publications highlighted using a set of defined keywords.

Those companies that filed European nanotechnology patents between 2000 and 2010 were the last group that was identified with 1,126 different companies filing patents during this time. Many companies featured in more than one of these groupings and therefore the data set was cleaned to obtain a total of 1,540 unique listings. In the next stage, additional research to obtain basic information, such as location and sector of activity, was completed for the identified companies. **Figure 1** displays the number of companies located within the EU27 and associated states.

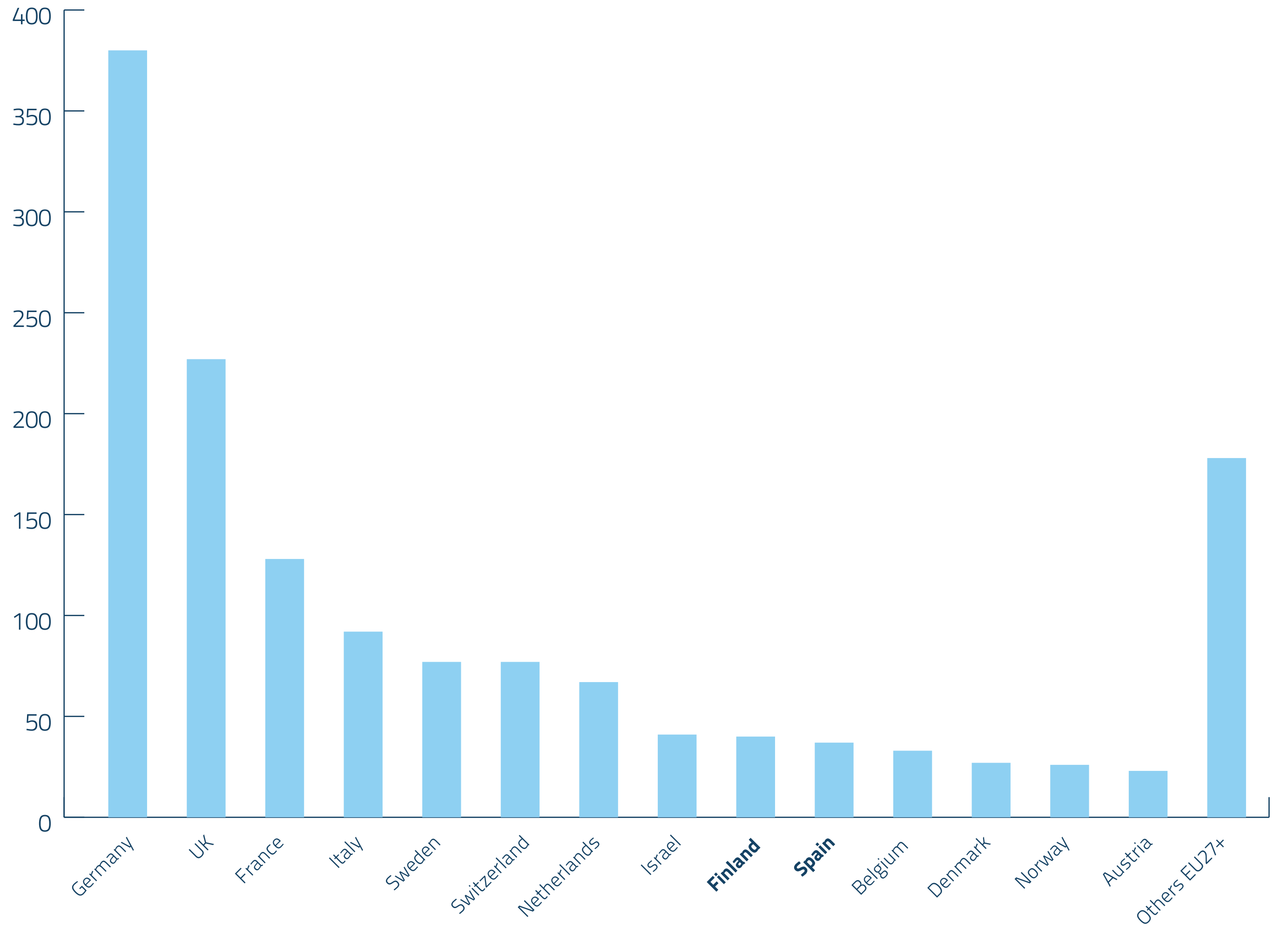
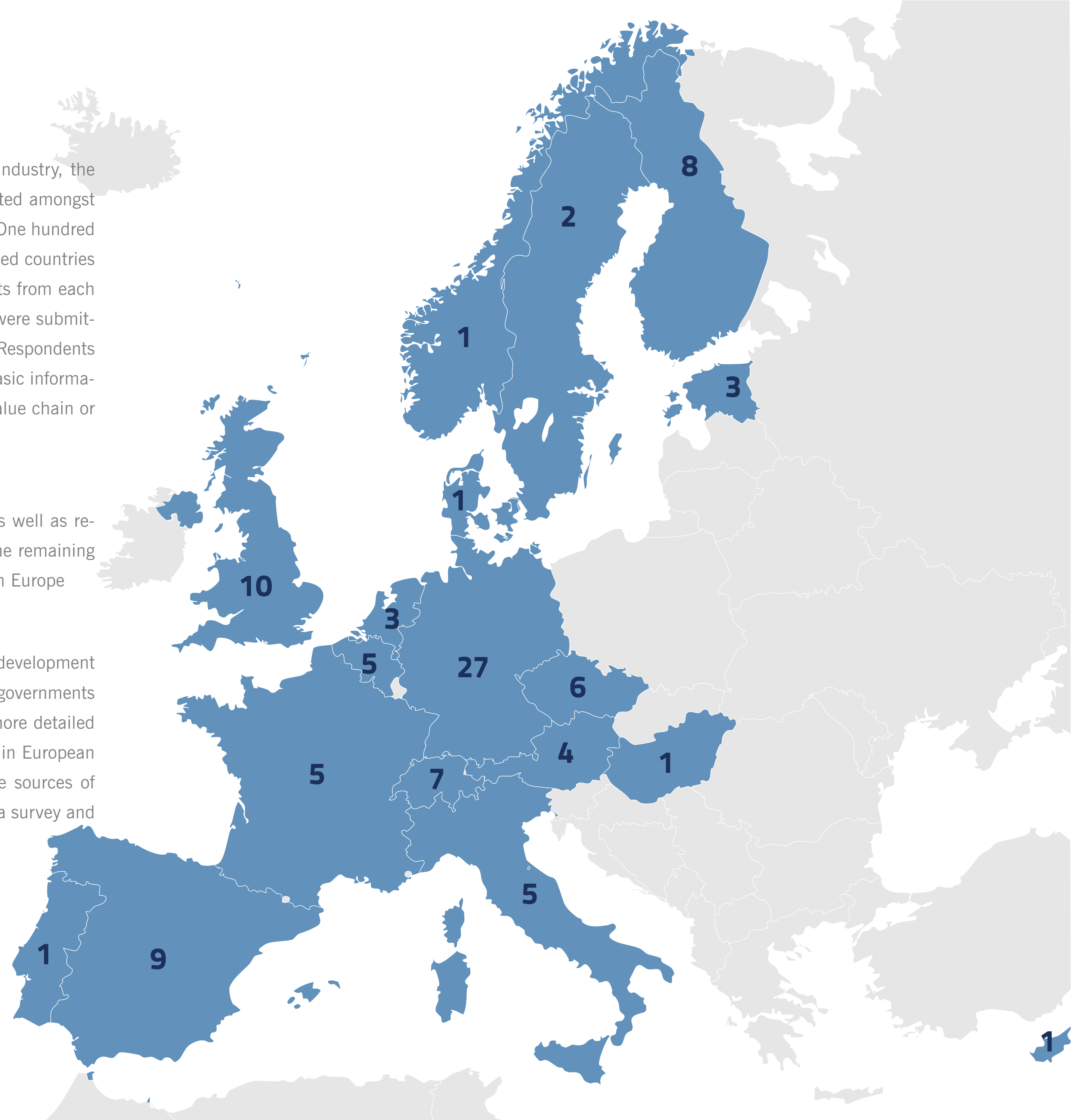


Figure 1: Nanotechnology companies identified in EU + member states

In order to better understand the EU nanotechnology industry, the ObservatoryNANO developed a survey which was distributed amongst some of the 1,540 nanotechnology companies identified. One hundred different companies answered the online survey. The shaded countries on the map in **Figure 2** indicate the number of respondents from each EU member and associated countries. Company surveys were submitted from companies in 17 different EU member states. Respondents answered various questions ranging from the company's basic information such as size or location to its place in the nanotech value chain or its views on government support.

Data analysis from the aforementioned investigation, as well as research surrounding EU public funding is summarized in the remaining portion of this chapter. Public funding of nanotechnology in Europe

By 2011, billions of euros have been committed to the development of nanotechnology by public funding agencies, national governments and multinational organisations. This section contains a more detailed look at the activities of a number of funding organisations in European countries based on desk research using publicly available sources of information and input and feedback sought from experts via survey and discussions.



Several programmes oriented specifically to nanotechnology are also implemented, in addition to nanosciences related themes under bigger programmes, national strategies for nanotechnology, research clusters, foundations and centres dedicated to this field. Included are: Finland's two FinNano programmes, that ended in 2010; Norway's Nanomat programme, which started in 2002 and will finish in 2016; The Austrian Nano Initiative commenced in 2004; the Netherlands' NanoNed programme, completed in 2010; and the on-going NWO-nano and NanoNextNL initiatives. The total value of these nanotechnology programs is over €700 million. Furthermore, France's five-year Nano2012 public/private strategic R&D program, led by STMicroelectronics, has been allocated a €2.3 billion R&D budget, making it one of France's biggest industrial projects. French national and local government are providing substantial support for the project, contributing some €457 million.

Germany has the highest public sector investment in nanotechnology of any European country. Its level of spending is second only to the European Commission. The German Ministry of Education and Research (BMBF) claims that over half of all European nanotechnology companies are based in Germany[3]. Germany's nanotechnology development is guided by the Nano Initiative Action Plan 2010. Several other countries have also published their strategies for nanotechnology including Sweden (National strategies for nanotechnology (2010)), United Kingdom (Nanoscale Technologies Strategy 2009-12) and Poland (Strategy for the reinforcement of Polish research and development in the field of nanosciences and nanotechnologies (2009)).

Figure 3 shows public funding figures for selected organisations. The figures for the amount of funding should primarily consist of grants awarded to the field, but some numbers may also include loans making the results less comparable. It should be noted that the estimates for the funding of nanotechnology differ within organisations caused by the uncertainty of determining which projects fell within this definition. Some respondents do not give any estimates for the nanotechnology funding due to the lack of special nanotechnology programmes within the organization, while others include only the portion of their programme oriented specifically to nanotechnology, disregarding other possible nano-oriented project funds falling outside of the specified programme.

Figure 4 displays a sampling of selected scientific funding organizations and how they distribute funding between companies and research institutes. The chart shows overall scientific funding versus that being directed specifically to nanotechnology.

Looking globally, the direction of public funding for nanotechnology

Figure 2: Survey respondents mapped to their associated countries

[3] http://www.bmbf.de/en/11945.php

Funding Figures

Key

* = figures are rough estimates
** = figures cover Natural Science and Engineering discipline

Annual overall funding for science & technology (million eur)

Annual funding specifically for nanotechnology (million eur)

Country	Organisation	2009		2010		2011 (estimate)		2012 (estimate)	
Finland	Tekes	482 +97 in loans	22	478+155 in loans	25,4				
Finland	Academy of Finland	302	12	361	15	315	13		
Sweden	VINNOVA	237,5	7	242,6	7	247,7	7,5	253	7,5
Sweden	Swedish Research Council	149,4**		149,2**					
Sweden	Swedish Foundation for Strategic Research	49,8	15	55,2	17	60	18	60	18
Norway	Research Council of Norway	650	0,14	650	0,14	650	0,15	650	0,15
Latvia	Latvian Council of Science	5,3	0,2	4,8	0,4	4,7	0,4	4,7	0,4
Latvia	Latvian Academy of Sciences	0,29							
Lithuania	Research Council of Lithuania	1,5		14,2		15,7		15	
Germany	German Research Foundation	2.200	80	2 300*	80*	2 400*	80*	2 500*	80*
Germany	Federal Ministry of Education and Research	5 600*	165	5 450*		5 800*			
Germany	Leibniz Association	1 300*	25,1	1 300*		1 300*		1 300*	
Germany	Helmholtz Association	3 000*	40	3 000*		3 000*		3 000*	
Germany	Max Planck Society	1 300*	17,3	1 300*		1 300*		1 300*	
Germany	Fraunhofer Society	1 700*	16	1 700*		1 700*		1 700*	
Netherlands	Foundation for Fundamental Research on Matter	95	22,5	95	22,5	95	22,5	95	22,5
Netherlands	Technology Foundation	78							
Netherlands	NanoNextNL - national research programme	62,5	62,5	62,5	62,5	62,5	62,5	62,5	62,5
France	Nanosciences Foundation	3,5	3,5	3,3	3,3	1,8	1,8	1,6	1,6
France	National Center for Scientific Research	3 200*		3 100*		3 200*			
France	National Research Agency	820*							
Switzerland	Federal Office for Professional Education and Technology	70	14	70	14	70	14	70	14
Austria	Austrian Science Fund	148	5						
Hungary	National Innovation Office	222	7	183	6	191	6	27	1
UK	The Higher Education Funding Council for England	1.180		1.200					
UK	Scottish Funding Council	118		121		120		120	
UK	Invest NI			38					
UK	Biotechnology and Biological Sciences Research Council			499	11				
Ireland	Higher Education Authority	152	11	102	6	96	4		
Ireland	the Irish Research Council for Science, Engineering and Technology	25	2,5	25	2,5	23	2	23	2
Ireland	Science Foundation Ireland	171		162*		161*			

Figure 3: Yearly overall Science & Technology funding and funding specifically for nanotechnology

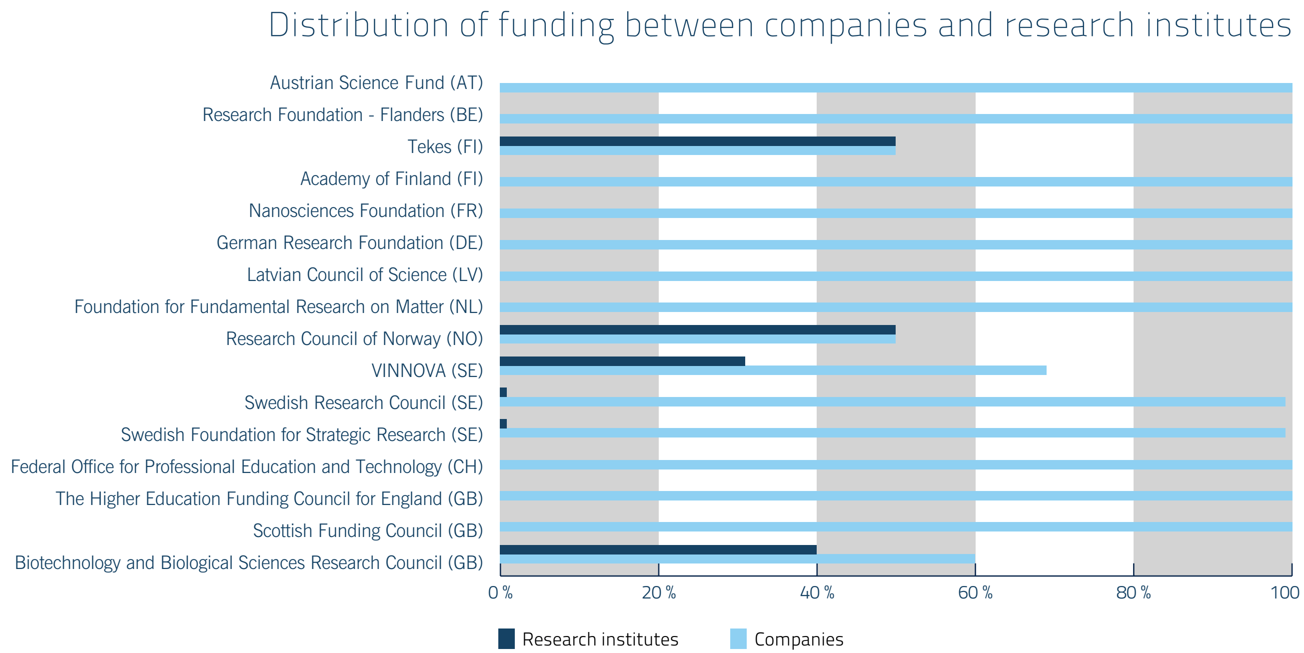


Figure 4: Selected organizations' distribution of funding between companies and research institutes

is unclear. Some argue that specific nanotech funding will decline while application-specific funding will grow. This could potentially make future analysis of nanotech funding even more challenging. However, it is clear that significant new funding is coming from countries which have yet to elaborate a nanotechnology strategy. Countries that have had longer funding commitments are continuing to increase their investment, albeit at slower growth rates; US nanotech funding increased by 2.4% to US$ 1.5 billion in 2009.

Analysis of EU Innovation Instruments

In addition to these figures we also performed a more in-depth analysis of innovation policy instruments available to the nanotech community in two example member states: Spain and Finland. The policy instruments considered in these two mapping exercises are shown in general terms in **Figure 5**.

This mapping exercise resulted in the two specific maps of innovation policy instruments for Spain **(Figure 6)** and Finland **(Figure 7)**.

This mapping exercise showed that both countries have quite a rich portfolio of instruments in place, even though the investment per capita in Finland is substantially higher than in Spain. In absolute figures, Spain actually leads in volume of investment, but not in output. Strong differences are observed when comparing the origin of patent applications in each country; whereas in Spain more than 90% are applied for by public entities, in Finland more than 80% are applied for by commercial, for-profit organisations.

In both countries, instruments that stimulate the latter stages of science-to-market processes, as well as instruments that leverage public procurement, are underdeveloped, whereas funding for earlier stage R&D is covered by many instruments on regional, national as well as European levels. Tentative conclusions to be drawn from this initial analysis would be that nanotech innovation policy makers may want to consider putting more emphasis on later stages of the pathways to larger scale market adoption, and that they could probably leverage the purchasing power of public entities with needs that nanotech-enabled solutions can address.

Nanotechnology innovation policies

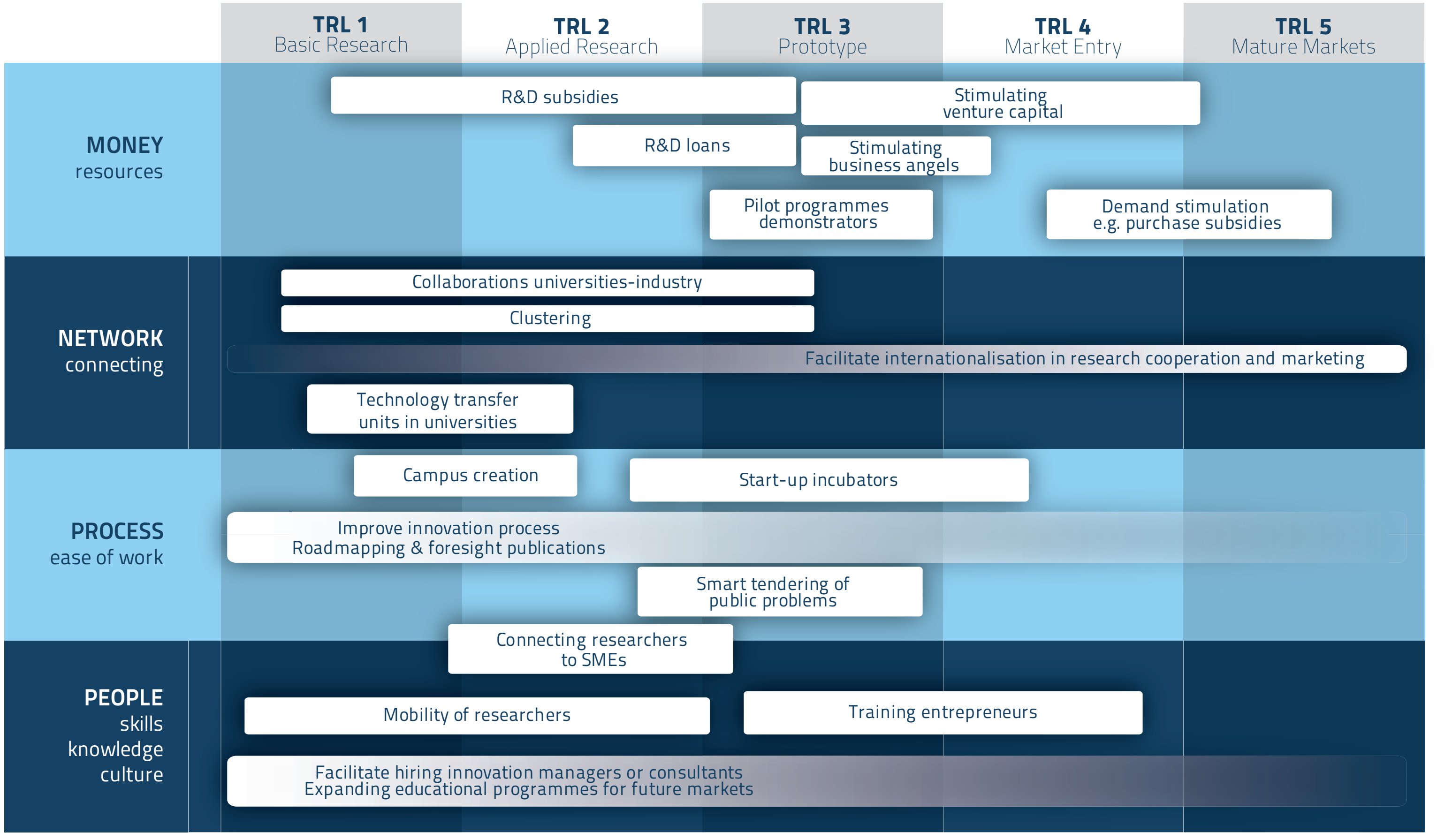


Figure 5: Nanotech innovation policy instrument map across technology readiness level and development area

Nanotechnology innovation policy instruments-SPAIN

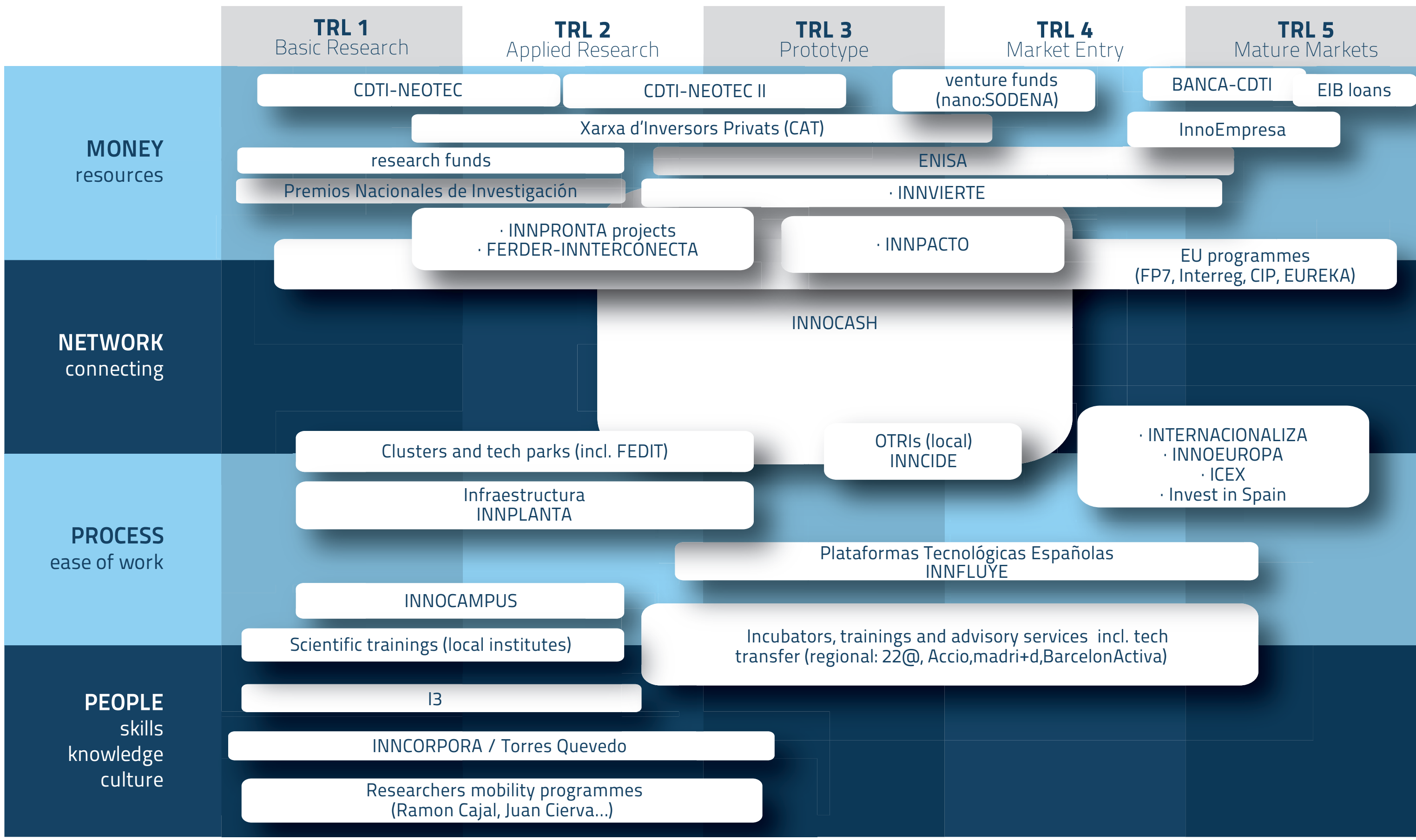


Figure 6: Nanotech innovation policy instrument map for Spain

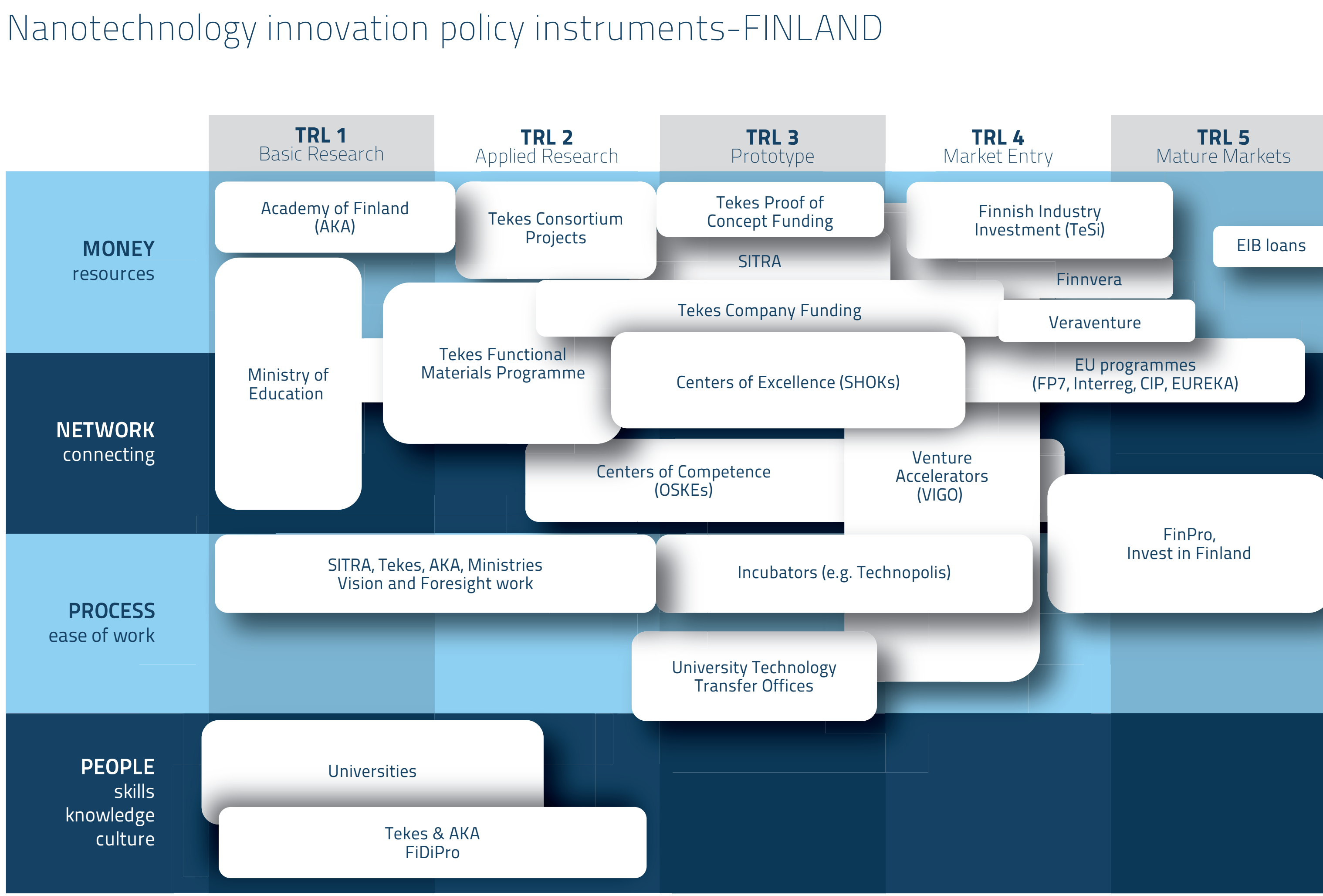
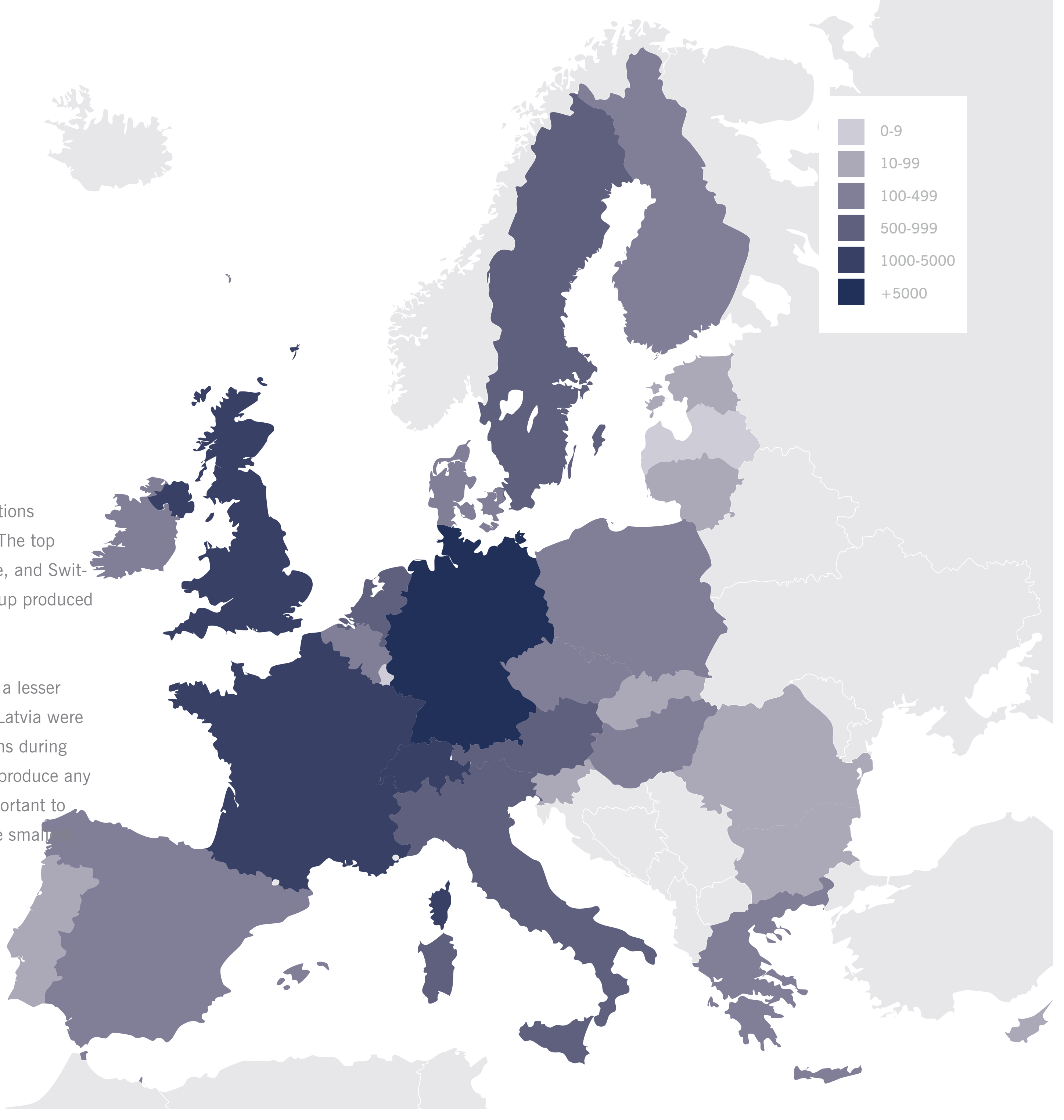


Figure 7: Nanotech innovation policy instrument map for mml

Publications across countries

Figure 8 displays a heat map of the number of publications produced by each EU country between 1998 and 2009. The top publication-producing countries were Germany, UK, France, and Switzerland, each producing over 1000 publications. This group produced two-thirds of the publications during this time period.

The Eastern European countries generally published to a lesser extent than their Western counterparts. Luxembourg and Latvia were at the bottom of the list producing less than 10 publications during this time period. Malta was the only country that did not produce any publications related to nanotechnology. However, it is important to remember that these three countries also have some of the smallest populations of EU member states.



Country	Number of Publications	2009 Population[4]	Publications per 100,000 residents
Switzerland	1.031	7.701.856	13,39
Finland	494	5.326.314	9,27
Sweden	816	9.256.347	8,82
Germany	6.449	82.002.356	7,86
Austria	590	8.355.260	7,06
United Kingdom	2.688	61.595.091	4,36
Netherlands	650	16.485.787	3,94
Denmark	191	5.511.451	3,47
Ireland	151	4.450.030	3,39
Belgium	319	10.753.080	2,97
Estonia	39	1.340.415	2,91
France	1.491	64.369.147	2,32
Slovenia	40	2.032.362	1,97
Czech Republic	191	10.467.542	1,82
Hungary	180	10.030.975	1,79
Luxembourg	8	493.500	1,62
Italy	955	60.045.068	1,59
Cyprus	12	796.875	1,51
Greece	161	11.260.402	1,43
Lithuania	35	3.349.872	1,04
Slovakia	56	5.412.254	1,03
Spain	409	45.828.172	0,89
Bulgaria	56	7.606.551	0,74
Poland	280	38.135.876	0,73
Portugal	73	10.627.250	0,69
Romania	71	21.498.616	0,33
Latvia	7	2.261.294	0,31

Figure 8: Publications produced by each EU country between 1998 and 2009

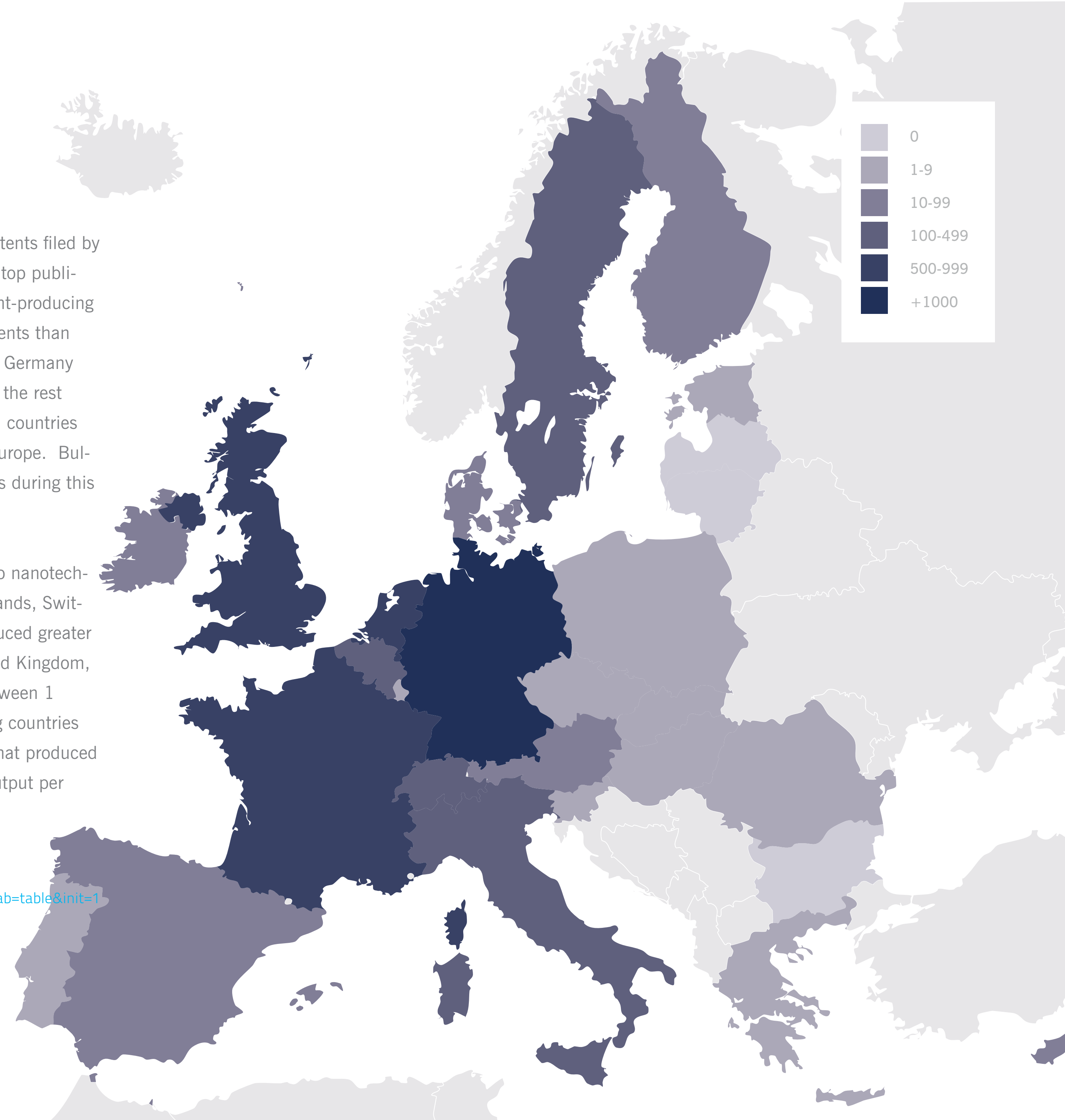
Figure 9: Publications produced per 100,000 residents between 1998 and 2009

When looking at per capita output, Switzerland is the largest producer of nanotechnology publications per capita, followed by Finland, Sweden, Germany and Austria. The countries all produced over 5 publications per 100,000 residents. Spain, Bulgaria, Poland, Portugal, Romania, and Latvia were at the bottom of this list, each producing less than one publication per 100,000 residents. Figure 9 displays the countries that produced publications between 1998 and 2009 and their per capita output per 100,000 residents.

Patents across countries

Figure 10 [4] displays a heat map of the number of patents filed by each EU country between 2000 and 2010. Many of the top publication-producing countries are also the most prolific patent-producing countries. Germany filed many more nanotechnology patents than any other country. In fact, the number of patents filed by Germany (3,730) is almost equal to the number of patents filed by the rest of the EU member states (3,767). The Eastern European countries again generally produced fewer patents than the rest of Europe. Bulgaria, Latvia, Lithuania, and Malta did not file any patents during this period.

Regarding per capita output, Germany remains the top nanotechnology patent-producing country, followed by the Netherlands, Switzerland, Cyprus and Sweden. Each of the countries produced greater than 2 patents per 100,000 residents. France, the United Kingdom, Finland, Denmark, Austria, and Belgium all produced between 1 and 2 patents per 100,000 residents while the remaining countries produced less than 1. **Figure 11** displays the countries that produced patents between 2000 and 2010, and their per capita output per 100,000 residents.



[4] Eurostat, http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tps00001, date accessed 29-sep-11

Country	Number of Patents	2009 Population[4]	Patents per 100,000 residents
Germany	3.730	82.002.356	4,55
Netherlands	720	16.485.787	4,37
Switzerland	314	7.701.856	4,08
Cyprus	20	796.875	2,51
Sweden	224	9.256.347	2,42
France	998	64.369.147	1,55
United Kingdom	942	61.595.091	1,53
Finland	75	5.326.314	1,41
Denmark	70	5.511.451	1,27
Austria	87	8.355.260	1,04
Belgium	110	10.753.080	1,02
Luxembourg	4	493.500	0,81
Ireland	32	4.450.030	0,72
Italy	130	60.045.068	0,22
Estonia	2	1.340.415	0,15
Slovenia	2	2.032.362	0,1
Hungary	7	10.030.975	0,07
Czech Republic	5	10.467.542	0,05
Greece	4	11.260.402	0,04
Spain	14	45.828.172	0,03
Slovakia	1	5.412.254	0,02
Poland	4	38.135.876	0,01
Portugal	1	10.627.250	0,01
Romania	1	21.498.616	0

Figure 10: Patents produced by each EU country between 2000 and 2010

Figure 11: Patents produced per 100,000 residents between 2000 and 2010

Publications/ Patents Comparison by Country

Figure 12 displays a chart comparing the patent and publication data during the same 10-11 year period as previously discussed. Malta is not shown, as it does not appear to have produced any publications or patents during this time. The vast majority of countries produced more publications than patents. During this time period, countries like Romania and Portugal each only filed 1 patent while producing approximately 70 publications. Poland had a similar ratio, producing 4 patents and 280 publications. The Netherlands and Cyprus were the two exceptions to this; each country produced more patents than publications. Figure 10 clearly shows that Germany is a leader when it comes to both nanotechnology patents and publications. During the time period analysed, Germany produced close to 2.5 times the number of publications and almost 4 times the number of patents as the next highest patent and publication-producing country, the United Kingdom. However, it is important to remember, as noted previously, on a per capita basis some countries are equally prolific, if not more so, than Germany.

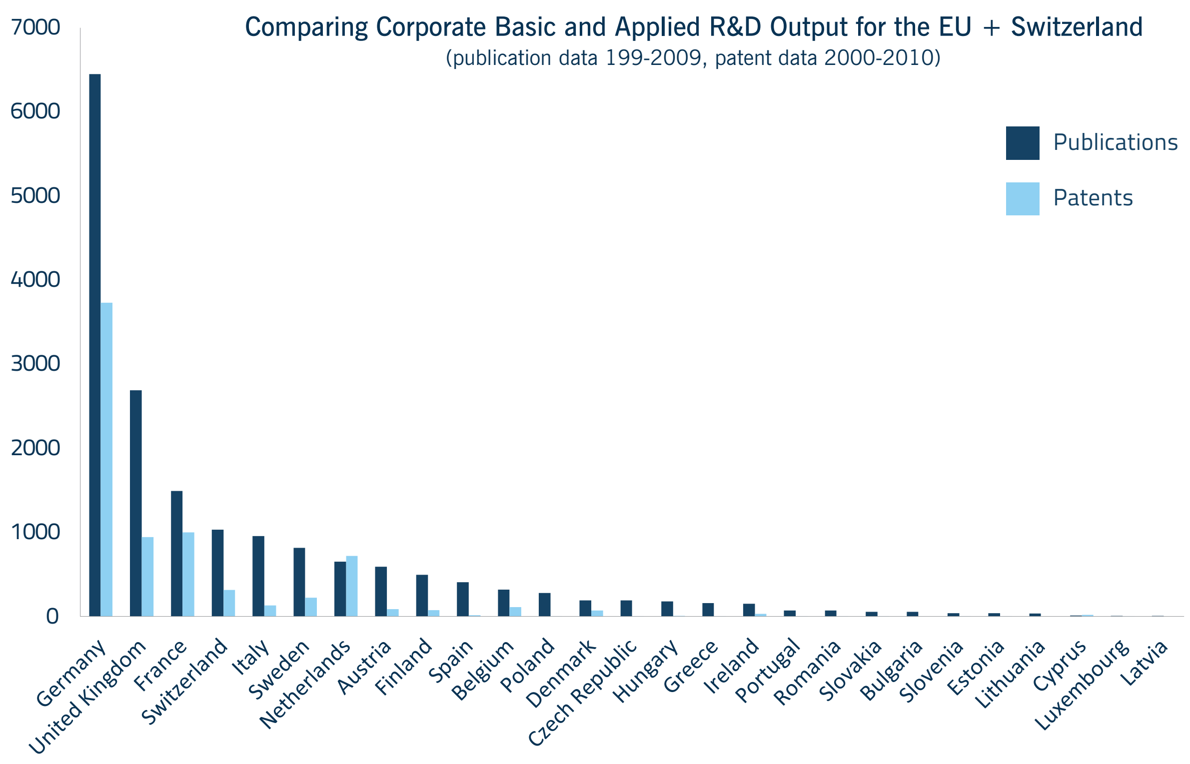


Figure 12: Publication/Patent Comparison by country

Publications/Patents Comparison by Sectors and Grand Challenge

A comparison of EU-wide publication to patent data is displayed in **Figure 13** by sectors within each Grand Challenge.

From 1998 to 2009 the Energy sector was recorded as producing the most publications of any sector at 524 while the Textiles sector produced the least at 60. From 2000 to 2010 the Chemicals and Materials sector produced the greatest number of patents at 4,669 while the Textiles sector produced the least at 90. It is not clear why certain sectors may produce more nanotechnology patents and publications than others. One cannot assume that certain sectors produce more nanotechnology inventions than others. In fact, studies have shown that the number of patentable inventions per dollar of R&D vary less among sectors than the number of patents per dollar of R&D[5]. In other words, companies in certain sectors find patenting and publishing strategically advantageous while companies in other sectors do not find this to be the case. Further research is warranted to understand the true reasons behind the disparity in the numbers.

[5] http://www.lu.se/upload/CIRCLE/INN005/Mansfield_Patents_and_Innovation.pdf

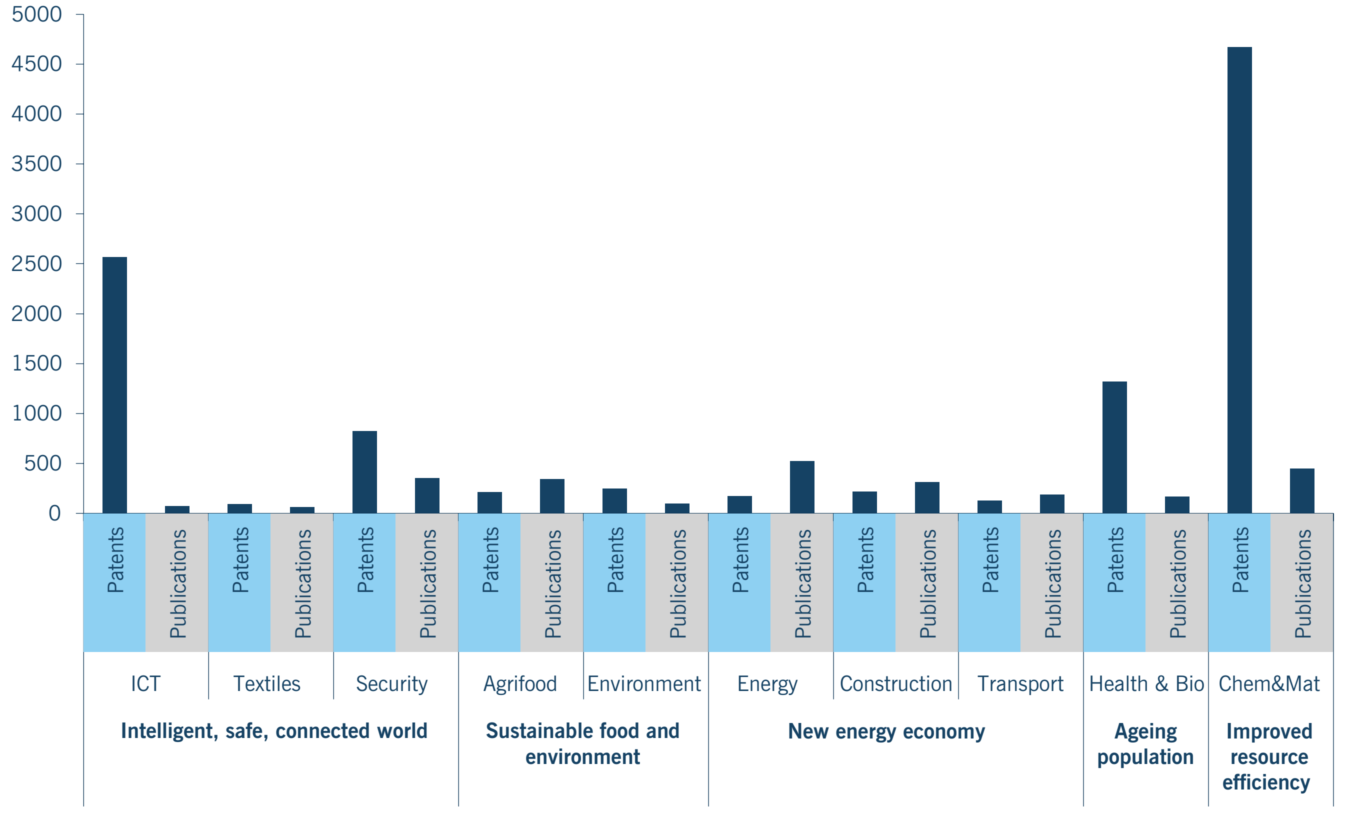


Figure 13: Publication/Patent Comparison by Grand Challenge

The survey of nanotechnology businesses in Europe[6]

The purpose of the data obtained from the survey is to provide European policymakers with a clearer understanding of the nanotechnology industry. Since only 100 of the 1,540 companies answered the survey, by no means can broad generalizations be made for the entire nanotechnology industry within Europe. However, this information does help to provide an interesting picture of a small sample of companies within the industry.

NANOTECH COMPANIES' GENERAL PROFILE: From the survey sampling it was found that a quarter of the companies answered having more than 1,000 employees (28%) while a quarter indicated having less than 10 (24%). Over half of the companies were independently founded (54%). Most did not receive private funding (78%) while most did receive some sort of public funding (71%). The vast majority of respondents only have one principal site for their nanotech related activities (70%). Although companies identified themselves as working with nanotechnology, over half of the respondents indicated that less than a quarter of their products are nano-enabled (58%). In addition 60% indicated that less than a quarter of their company employees work within nanotech related roles.

[6] Note: The percentages mentioned in the following section are based on the total number of respondents that answered each question. In cases where respondents did not answer a question, they were not included. As a result, the percentages mentioned are not always based on all 100 respondents.

NANOTECHNOLOGY AND REVENUE: 67% of respondents indicated that less than a quarter of the company's revenue comes from nano-enabled products or services. Although nanotechnology may not be a company's principal source of revenue, during the recent economic downturn, it has proven to be a stable and lucrative one; 20% of respondents indicated that revenue from their nanotech business remained stable and 61% witnessed growth of some kind. In fact, 27% of respondents experienced revenue growth rates of 20% and above.

NANOTECH MARKETS: When it comes to markets respondents indicate that the transportation, chemistry, and health sectors were their most important in terms of nano-related products. Agrifood and security are the sectors witnessing the least involvement by the nanotech companies surveyed. 66% of respondents sold some or all of nano-related products to the EU with less than 10% of respondents indicated selling to the following regions: India, Central and South America, Middle East & Africa, Russia, and Australia & the Pacific.

ENVIRONMENT, HEALTH & SAFETY: 70% of respondents (who answered) indicated that they make available the toxicity and ecotoxicity of their products and 53% provides best practices and standards on the full life cycle of their products. 74% of respondents indicated they implement best practices for occupational health and safety. 68% of respondents who use nanomaterials indicated that they undertake research specifically related to EHS aspects

THE MARKET IMPACT OF NANOTECHNOLOGY: In general respondents are positive about nanotechnology's impact on market share. 65% of respondents believe that nanotechnology has had some sort of positive effect on market share. Only 3% found nanotechnology to have a negative impact, and it was only marginally negative at that. Respondents are also positive about nanotechnology's impact in helping companies to enter new markets. 80% of respondents believe that nanotechnology has had a positive impact in enabling them to enter new markets while only 1% of them find nanotechnology to be a hindrance. However, there is not a strong indication that nanotechnology enables cost reduction. 63% of respondents are indifferent about nanotechnology's impact on reducing cost. 27% find it to reduce costs while 11% find it to increase costs.

NANOTECHNOLOGY REGULATIONS: Most respondents do not feel nanotechnology regulations have an impact on their companies' success (63%) while 25% indicated that the impact has been negative. Approximately two-thirds of respondents are neither satisfied nor dissatisfied with REACH legislation (61%). They showed equal indifference about existing standards such as ISO (64%). As future standards are created, it may be wise to have more interaction with companies to ensure regulations actually meet their needs.

GOVERNMENT FUNDING FOR NANOTECHNOLOGY: Respondents indicated that government funding for nanotechnology research generally had a positive impact on their business's success. 67% of respondents believed that funding for fundamental research had a positive impact while 79% believed applied research funding was beneficial. Funding towards production scale up and EHS issues were viewed as having neither a positive or negative impact by respondents (with corresponding percentages of 60% and 55%). Approximately half of the respondents (54%) believed funding for demonstrations to have a positive impact on the success of their business while the other half (46%) believed it had no impact.

GOVERNMENT SUPPORT: Figure 14 shows the percentage of respondents and their level of satisfaction with each level of government support. Although less than 15% of respondents indicated dissatisfaction with government support at any level, approximately one-third of them look at support with indifference.

Figure 14 Government support satisfaction

Level of satisfaction	European Union	National Government	Local Government
Very satisfied	16%	19%	12%
Somewhat satisfied	36%	39%	33%
Neither satisfied nor dissatisfied	37%	29%	42%
Somewhat dissatisfied	7%	8%	9%
Very dissatisfied	4%	5%	4%

Figure 15: Degree to which barriers impact companies' commercial success

Level of impact	Technological	Economic	Policy	Society	EHS
Major impact	24%	22%	4%	8%	11%
Moderate impact	42%	27%	21%	17%	24%
Some impact	19%	32%	41%	33%	37%
No impact at all	15%	19%	34%	42%	28%

BARRIERS TO COMMERCIAL SUCCESS: Respondents were asked to what extent did the five barriers listed in **Figure 15** impact their nanotechnology business's commercial success. As can be seen by the chart, companies view technology to be the biggest barrier to their nano-products' commercial success. 85% of companies indicate that technological barriers have some impact. The cost penalty associated with nano-enabled products is the second most impactful barrier at 81%. One third (34%) of respondents do not feel that policy barriers play any impact at all while 42% feel no impact by societal barriers.

One possible policy conclusion to these responses could be to prioritize R&D/innovation activities aimed at driving down the costs of nanotechnology enabled products. However, as mentioned in the introductory paragraph of this section, the information obtained only represents a small percentage of the nanotechnology companies identified within Europe. In order to guarantee a more accurate picture of the nanotechnology industry within Europe, it is recommended that a larger sampling be obtained to provide more insightful analysis.

Intelligent, Connected and Safe World

Introduction

Sustainable solutions to the Grand Challenges of global warming, tightening supplies of energy, water and food, ageing societies, public health, pandemics and security require more efficient methods for obtaining, collecting, organising and disseminating data. For example, nanotechnology can enable more effective environmental and health monitoring methods, better-distributed healthcare and more efficient security systems. Moreover, there is a need for faster and more powerful computing in order to keep track and organise the increasing amount of data produced by the evolving information society. To ensure economical and environmental viability, these systems need to be cost-competitive, have reduced energy consumption, and use natural resources in a sustainable way. Nanotechnology offers an opportunity to solve these challenges.

This chapter will give an overview to three technology areas; information and communication technologies, security technologies and nano-enhanced textile technologies. The chapter introduces the most important nanotechnological developments related to these areas, and discusses their main impacts, obstacles, and risks. Two example cases with high market opportunity are presented in more detail; printed electronics, and nano-enabled protective textiles.

The challenges to be addressed by the nano developments

INTELLIGENT AND CONNECTED WORLD

The development of information technology in the 20th century has been very rapid, and it is likely that the latest innovations in nanotechnology will accelerate the pace in the future years. The next-generation computing and entertainment systems and increasing interaction with devices mean that even more powerful artificial intelligence and communication systems will be incorporated in our everyday lives. The key aspect in technologies enabling a more intelligent world is the **demand for rapidly growing computational capacity** of electronic circuits. The so called Moore's law has for a few decades predicted the development speed in traditional silicon based microelectronics with great accuracy, but as the microchips are getting smaller - down to line-widths of few tens of nanometres - the fundamental limits dictated by physics are getting closer. It has been estimated by ITRS[7] that development of microprocessors will soon slow unless new innovations are made. For some time still, the silicon based CMOS technologies can be scaled down by more advanced production methods like extreme ultraviolet lithography, but after a while alternative semiconductor materials and new ways of realising computing systems will be required. Somewhat surprisingly, one of the most critical aspects in scaling down the size while at the same time increasing the computational power is the heat generated by the circuits: the higher the operation speed and the smaller the size the more difficult it is to keep the temperature of the circuit at acceptable levels.

Sheer computational capacity is, however, not the only motivation anymore, but the focus is shifting towards integrating different features of artificial intelligence into everyday objects, such as clothing and home appliances. The world is moving towards increasingly **ubiquitous information access**.

In fact, the RAND Corporation has estimated in 2006 that globally the biggest challenges in the field of ICT will be developing devices for ubiquitous information access and assuring **sufficient wireless communications capacity** in rural and remote areas[8]. Large-scale adaptation of ubiquitous information access will, however, depend on the availability of cheaper, smaller and more energy efficient and environmentally sustainable solutions for everyday intelligent objects. In addition, it has already become evident that the limited amount of radio spectrum will become a bottleneck for wireless communication systems in the near future; this has already been recognised by the phone operators as the demand for fast mobile broadband access has risen. The optimal use of radio spectrum can be ensured with novel cognitive radio technologies or use of higher radio frequencies, requiring significantly faster electronics circuits. Unfortunately, here the Moore's law will not help since many radio specific component technologies cannot be scaled similarly as the transistors.

SAFE WORLD

Personal and public security and safety have become increasingly important in the modern world. Personal security concerns us all in our everyday lives, at work, and in our free time. Public security solutions are used by the police forces, military and border guards to monitor and protect us from external threats. Public security as a topic is controversial, as it often clashes with personal privacy and other human or civil rights. Trends and advancements in nanotechnology, especially

[7] ITRS Roadmap

[8] RAND Corporation – Global Technology Revolution 2020

concerning security and ICT applications, have raised new concerns regarding privacy[9]. Personal and public safety are generally considered to be positive issues, but advancements in these areas have to be carefully evaluated in order to avoid over-protection and thus complicating or limiting normal activities.

Personal protection for people working in hazardous environments is needed for protection from fire, heat, hazardous substances, as well as other external threats. This need is critical for public workers such as firefighters and police. Current solutions are in many cases very cumbersome to use, or inefficient.

More efficient **security systems** are called for by governments and politicians in border security and in protection against terrorism and organised crime.

Anti-counterfeiting technologies for detection of counterfeited drugs, for example, are an increasingly important area related to personal security. Counterfeited drugs can be hazardous, and currently the methods for detecting those are not efficient enough due to difficulty of use and high cost.

Secure communication and privacy protection methods continue to be an integral part of the information society. The security of currently used cryptographic methods is compromised by the development of even more efficient computers, in particular future emergence of quantum computers, capable of deciphering the currently use codes.

[9] Malsch & Fruelund-Andersen, 2011, Ethical and Societal aspects of Nanotechnology Enabled ICT and Security Technologies, ObservatoryNano http://www.observatorynano.eu/project/document/3525/

The nano-enabled solutions

Figure 1 outlines some ways that nanotechnology developments can help to solve the problems presented above.

NANOELECTRONICS ENABLE BOTH INCREMENTAL ADVANCES IN INFORMATION PROCESSING AND COMPLETELY NOVEL, INTELLIGENT SOLUTIONS

There are five rather distinct sections among information and communications technologies that enable both incremental advances and completely novel, intelligent solutions: 1) data processing, 2) data storage, 3) data transportation, 4) data display and 5) data collection technologies. Nanotechnology impacts all.

Data processing technologies will continue to scale for a while according to Moore's law with the help of nano-enabled manufacturing methods. As the limits of scaling become closer, radically new solutions based on new nanomaterials and nanoelectronic components are required. New computing systems based on nanoelements can increase the speed of electronics beyond silicon-based technologies, and reduce the power consumption significantly. Very low power operation is crucial not only for saving energy and reducing the heating of circuits with high data processing capability, but also for allowing for autonomous intelligent devices, either battery operated or capable of harvesting their own energy.

Information processing technologies are assessed in more detail in the ObservatoryNANO "Integrated Circuits" report (2010)[10]. A new paradigm in data storage technologies for future include so-called Universal Memory[11], capable of integrating the best features of current memory technologies by combining both working memory and persistent storage, and thus radically affecting how all future computing systems will operate in the future.

Data communications in the future benefits from high speed and low power electronics, and new nanomaterials, which can be used to enhance the properties especially for optical communications systems, that can be used for device-to-device (optical cables) or chip-to-chip communications[12]. Ultra-high speed electronics components with operating frequencies at the terahertz can be used to develop new radio communication systems operating at frequencies which are currently not used, thus alleviating the need for more radio spectrum. New nanomaterials can also be used for building miniaturized radio spectrum sensors, which could be integrated into all mobile devices, and used to ensure flexible use of the radio spectrum.

Nanotechnology also enables very interesting display technologies, for example bendable displays and e-paper, as well as assisting the display industry to replace scarce and problematic natural resources such as Indium-Tin-Oxide (ITO) with cheaper and more environmentally sustainable artificial nanomaterials, e.g. carbon nanotubes or graphene[13].

NOVEL SENSOR TECHNOLOGY GIVES POSSIBILITIES FOR EXTENSIVE DATA COLLECTION AND MONITORING

Advances in sensor technology require tight co-operation between many different fields of science. For instance sensors for explosives detection are based on advanced chemistry and nanotechnological innovations, but at the same time require (wireless) data transportation capabilities enabled by nanoelectronics and autonomous power supply and storage, of efficient energy harvesting systems[14]. Sensors are currently used extensively in security systems, in manufacturing, and in healthcare, but they are rapidly also emerging in consumer solutions.

[10] ObservatoryNANO "Integrated Circuits" report , 2010

[11] ObservatoryNano Briefing on Universal Memory, 2010

[12] ObservatoryNano Focus Report on Optical Interconnects, 2010

[13] ObservatoryNano Briefing on Nanotechnology for Flat Panel Displays, 2011

[14] ObservatoryNano Briefing on Thermoelectricity for Energy Harvesting, 2011

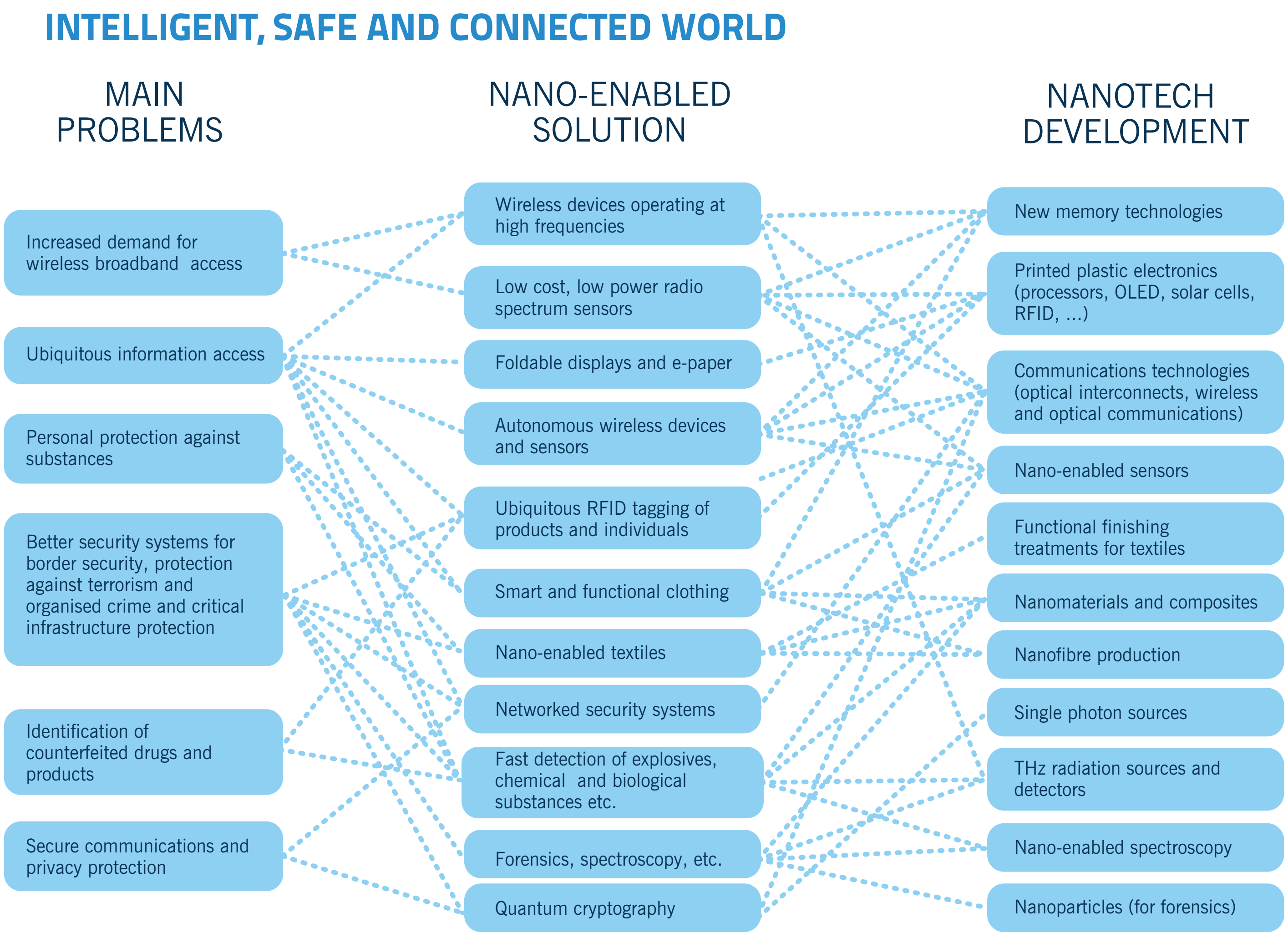


Figure 1: Matrix showing the problems to be addressed, the potential nano-enabled solutions, and relevant nanotechnology developments.

For instance, almost all new smart phones contain multi-axis acceleration sensors and light sensors. The critical issue for widespread use of novel sensors is to ensure low power operation, small size and low cost. In these, nanotechnological advances such as printable electronics[15] are needed.

NANOTECHNOLOGY MEANS IMPROVED PHYSICAL PROPERTIES IN TEXTILES

Nanotechnology can enhance the properties of traditional textiles as well as bring new kinds of composites to offer solutions that are both lightweight and extremely durable. The most important applications of technical textiles are in[16]; transportation (21.2%), protective uses (20.2%), construction (15.3%), furniture (9.0%) and medical (8.1%) leather and footwear (4.0%), electronics (1.6%) and sports (1.3%). There are a number of features offered by nanoenhanced textiles[17], including protective properties such as resistance against toxic agents (e.g. chemicals and gases), microbes and bacteria, heat, fire and impact. Transportation, medical and sports textiles require somewhat different properties, such as water repellence, self-cleaning surfaces, moisture management properties, abrasion resistance or even healing, drug or fragrance release properties. Construction applications, as well as some transportation applications, require high tensile strength offered by nanotechnology, and in electrical applications the electrical conductivity is of great importance.

Integration of textiles and electronics can naturally be achieved even without nanotechnology, but nanotechnology enables solutions with smaller energy consumption, lighter weight and increased durability, reliability and comfort.

NANOTECHNOLOGY ENABLES MORE EFFICIENT AND HIGHLY NETWORKED SECURITY SYSTEMS

In the area of security technologies, nanotechnology enables and improves various kinds of novel sensors, for example for detection of explosives. Together, the nano-enabled textiles, RFID products, functionalised nanocoatings and nanoenhanced imaging and non-invasive detection methods will significantly improve security and anti-counterfeiting[18] technologies.

On the other hand, developments in information and communication sector mean that the ubiquitous information access will enable building highly efficient security systems that automatically monitor and give warnings on external threats: the sensors (for chemicals, gases, audio,

[15] ObservatoryNano Focus Report on Printed Electronics, 2010; and Global Printed Electronics Market-Materials, Manufacturing Technologies, Applications and Trends (2010-2015), marketsandmarkets.com

[16] European Technology Platform for the Future of Textiles and Clothing, 2006

[17] ObservatoryNano Briefing on Nano-enabled Protective Textiles

[18] ObservatoryNano Briefing on Anti-Counterfeiting Applications

video etc.) will be incorporated into autonomous networked security systems[19]. With the increasing computational capacities, the networked security systems in airports would, for example, be able e.g. to detect dangerous baggage left alone with an automatic security system utilizing cameras.

Anti-counterfeiting technologies can be improved significantly with the help of nanotechnological innovations. For example, new surface enhanced Raman scattering methods can be used for fast detection and identification of various substances, and the development of smaller and more affordable terahertz frequency electromagnetic radiation sources and detectors will increase their use in airport security scanning and in detection of counterfeited drugs.

Quantum cryptography, which is enabled by the development of better optical communication devices, such as better lasers, optical cables and reliable single photon sources, will make it possible to build superior cryptographic communication systems that cannot be broken unknowingly[20]. This will become of crucial importance if the current cryptographic methods are rendered obsolete by the development of efficient quantum computers, capable of deciphering the codes used today.

[19] ObservatoryNano Briefing on Nanosensors for Explosives Detection

[20] ObservatoryNano Briefing on Nanotechnologies for Secure Communications

HIGHEST TECHNOLOGICAL IMPACT FOR FUTURE INTELLIGENT, SAFE AND CONNECTED WORLD IS IN INTEGRATION OF PREVIOUSLY SEPARATE AREAS OF TECHNOLOGY

In the short term nanotechnology will increase performance of individual components in terms of data processing capability, energy consumption, or wear resistance for example. In the longer term, however, the key impact of nanotechnology is that it enables higher degrees of integration of different components into novel solutions, such as wearable computers enabled by the integration of textiles and electronics.

Increased level of integration of electronics with plastics and textiles means that it will become possible to build wearable computers and to integrate RFID tagging into any kind of commercial product. Advances in nanotechnology in electronics, materials and chemistry may lead into new kinds of sensors that can operate autonomously without an external source of power.

Perhaps the single most important technology for the intelligent, safe and connected world grand challenge is printed electronics that ties together all the above-mentioned technologies with very simple and economic manufacturing.

IMPACTS ON SOCIETY

Implementing nanotechnology to information and communication technologies, security technologies and textile technologies will in the short term produce new products with enhanced properties. Public and private safety will increase as more efficient safety systems and solutions are introduced. New capabilities of security technology will further amplify the discussion about the relation of security and privacy.

More efficient devices and systems may also increase the productivity of individual workers or decrease the need for workforce, and thus bring the threat of increasing unemployment. However, the emergence of new technology shakes the markets and that opens possibilities for existing and new companies.

In the long term, as electronics become smaller, even imperceptible, and they are integrated virtually everywhere, the level of automation and intelligent systems around individuals will increase. Dependence on these systems increases as well, as they become invisible and part of daily routines. Individuals can be connected to information networks all the time and their every move can be monitored by several automated systems. The questions regarding privacy and the use of the information gathered by the sensors will be crucial, and need to be carefully evaluated and the need for regulation assessed.

Primary Data Summary

In the ICT and security sectors the companies feel that nanotechnology has helped them enter new markets and increase their market share more than the other surveyed companies on average. Security and ICT companies also managed to cut costs with nanotechnology more than the average nanotech company. Textiles companies did not note as many benefits from nanotechnology in comparison to other sectors.

Percentage-wise ICT companies have done more toxicity related research than an average nanotech company while toxicity related risks are typically higher for other sectors. The ICT, security and textiles sectors were above the average in regards to taking into account nanotechnology's lifecycle issues.

Obstacles

The largest obstacles preventing higher market penetration for nanotechnologies related to intelligent, safe and connected world can be summarised in four key categories:

- **Technological immaturity both in technological features and production;**
- **High price;**
- **Low market demand for nano-enabled products; and**
- **Environmental, health and safety and societal aspects.**

Technological immaturity is a clear obstacle for most novel information and communication technologies; for example technologies such as universal memory, nano-enabled flat panel displays and printed electronics. Manufacturing technologies and the capabilities of these technologies are currently much worse than the traditional mature market technologies, and it will still take at least 3 to 5 years for the technologies to enter markets and become really competitive with current commercial solutions. The same challenges apply in many textile and security technologies, where full scale utilisation of nanotechnology requires several years of experience from technology and production scale-up for the technologies to become competitive.

The largest obstacle hindering nanotechnology use in the industry is often the high price of nanotechnology enabled products, which means that even superior features are not strong enough grounds to invest in nanotechnology rather than in traditional technology with competitive price and well tested features. The high price is often due to the technological immaturity which can render production scale-up very difficult. This leads to practical disadvantages such as low yield, which means lower production efficiency and thus higher price. This is a particular challenge for new nano-enabled solutions in the ICT area. Especially in the case of electronics and microprocessors new technology adaptation is expected to be slow even when the technological maturity is sufficient and production cost are comparable. The extremely heavy investments, concentrated manufacturing with only a few large players and rapidly progressing technological development according to Moore's law mean that new technologies will not be able to compete with silicon CMOS technologies for a long time to come.

Moreover, there remain environment, health and safety concerns in relation to the use of nanotechnologies which require further investigation, especially for products where nanomaterials may come to direct contact with humans, such as textiles. For example, concerns exist about the potential release of nanomaterials from protective clothing, due to abrasion or wear and tear and subsequent human or environmental exposureError: No se encuentra la fuente de referencia. Thus, there is a need to further understand any potential risks, and to put into place such measures required to manage them. Key to this is demonstration of responsible development, including compliance with guidance and regulation as it emerges, pre-emption regulatory changes, and (where there exists reasonable cause for concern) use of a precautionary approach. This will in turn help to improve public awareness and acceptance of nanotechnologies that are in direct contact with users.

Societal issues, barriers and obstacles in information and communication as well as security technologies are mostly related to research ethics, privacy and dual use aspects.Error: No se encuentra la fuente de referencia These issues, in general, have not been explored sufficiently. Thus there is danger of technological advancement drifting into questionable directions and public opinion turning against nanotechnology in general, if the potential undesirable scenarios are not addressed. Advances in information collection and processing mean that various organisations will have a possibility to track people's daily life, which is a threat to the privacy of individuals. In the textiles sector, most societal issues are related to product life cycle issues and in the potential toxicity and ecotoxicity of the textile products.

Technological barriers are seen to have the most impact on commercial success of nano-enabled products for ICT, security and textiles sectors. For textiles, EHS issues and societal barriers have a stronger impact than with an average nanotech company.

Case 1: Printed electronics

THE PROBLEM

Printed electronics, also called plastic electronics, is one of the most important technology trends in electronics manufacturing. As the name implies, the technology involves printing of electronics and electrical circuits on flexible media, such as polymer film or even paper. This means that it is possible to integrate electronics into plastics packaging or clothing for example. Due to the roll-to-roll production method printed electronics circuits will have very low cost.

NANO-ENABLED SOLUTION

Nanotechnology in printed electronics means using nanotechnology-enhanced functional electronic or optical inks to print the active or passive devices. Examples of printed electronics components include electrodes comprising printed metal particle ink, carbon ink or conductive polymers, or diodes and transistors comprising of printed organic semiconductor and dielectric layer(s). Using nanoscale particles in the inks improves the performance and reliability of the circuits, and can help to lower the production costs.

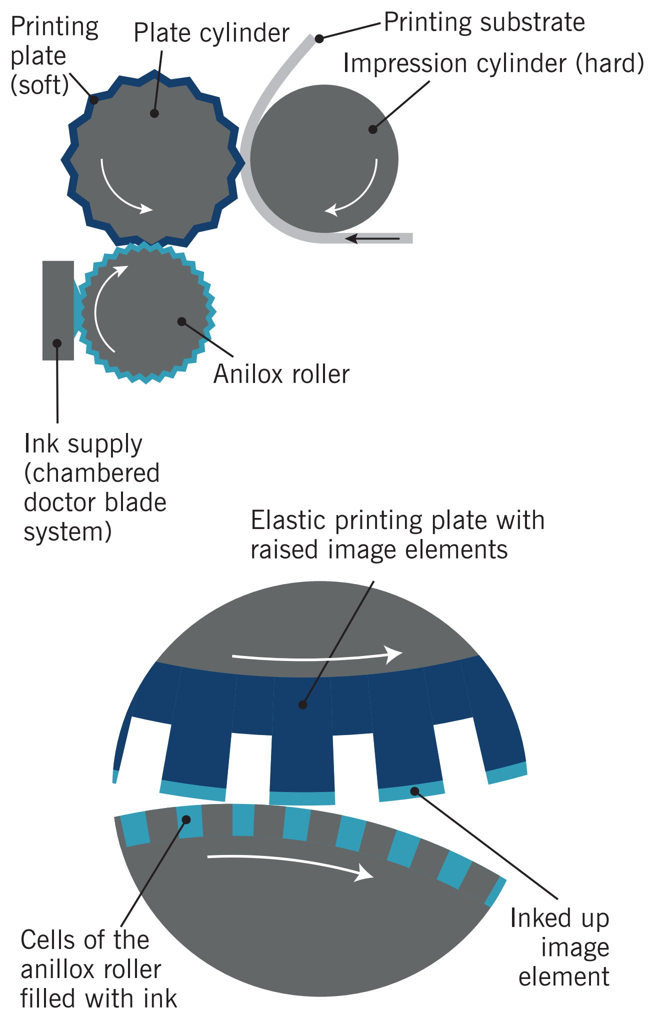


Figure 2: Printed electronics can be done using similar technologies as in traditional printing, but with nanotechnology enabled inks (illustration of Flexography printing).

THE IMPACT

The largest advantage of printed electronics is its huge potential for printing complex functionality (logic circuits, LEDs and lighting, solar cells, radio frequency communication systems) on an inexpensive plastic film that can be easily disposed and recycled in the end of its life cycle. At the current stage of development, printed electronic circuits have only simple functionalities, but as electronics development has shown in the past, technology will rapidly develop and provide more evolved capabilities.

MARKET OPPORTUNITIES AND EUROPEAN ACTIVITY

For the consumers and industry, printed electronics will mean a large number of novel products with very competitive pricing compared to the currently available solutions. Thus it is estimated that the impact of printed electronics will be huge once the remaining technological challenges are solved. Some applications, such as printed RFID labels used for identification, are already being produced, and other applications like printed e-paper and foldable displays, are quickly emerging. The very early market phase of printed electronics means that Europe is in good position to secure a leading position in the field. The field is very technology and capital intensive and requires very little manual work, which means that the cost disadvantage of European labour does not have a big impact on Europe's competitiveness in the field. The global printed electronics market is growing very rapidly and is expected to reach $24 billion in 2015 at an estimated CAGR of 38.4%ix. It is expected that printed electronics will replace to some extent the traditional electronics production, which is currently concentrated in Asia. Therefore, if Europe can become a leader in printed electronics manufacturing the overall impact to employment and economy may be positive.

CHALLENGES

Currently, the largest challenges of printed electronics are related to technological maturity and to the immature materials and inks currently used. Manufacturing technologies also need to develop to provide sufficient yield and performance to be able to compete with traditional technologies. Finally, the customer needs and clear application needs are still partly missing.

Case 2: Nanotechnology enabled protective textiles

THE PROBLEM

Rising health and safety concerns for those exposed to dangerous environments or working in high-risk professions have increased the demand for improved protective apparel and accessories.

NANO-ENABLED SOLUTION

Nanotechnology provides conventional protective textiles with a multitude of new features and properties, often with reduced weight and increased strength. Nanosized particles can be used in finishing stages for better and more durable protective coatings, but the biggest impact in protective textiles will come from novel types of nano-enhanced fibres. For example, electrospun carbon nanotube or polymer nanofibres can be made into textiles which are soft and have good strength to weight ratio, but yet at the same time can act as barrier against micro-organisms or very fine particles. Nanometre-sized clay particles finely dispersed in polymer matrix can be used to enhance the stiffness, tensile strength, thermal stability, gas barrier properties and the flame retardant properties of textiles without compromising the weight and softness of the material.

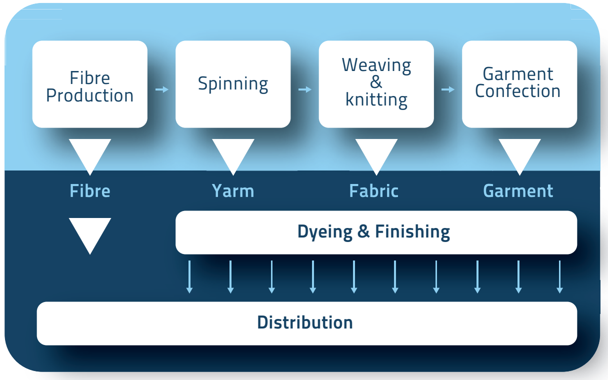


Figure 3: The textiles value chain. Advanced materials and nanotechnology features are created in fibre production and finishing sections.

THE IMPACT

Novel surface treatments and coatings, nanocomposites and nanoscale fibres, and functional nanoparticles offer textile products providing improved levels of protection together with a lower weight, higher comfort, novel or multi-functionalities, or more environmentally friendly processes. The use of dynamic materials integrated in clothing can enable safety products to react to chemicals, biological agents, or changing external conditions. Smart materials combine electronics with textiles allowing for tracking of the wearer, monitoring of physiologic parameters, and energy provision for communication functions. Integrating tracking, monitoring and communication functionalities into clothes might also have negative implications for privacy unless the technology development promotes “privacy by design” from the beginning.

MARKET OPPORTUNITIES AND EUROPEAN ACTIVITY

Huge technological benefits offered by the nano-enabled protective textiles and Europe's strong position in the field mean that Europe has a key role in future in the market. The industry currently accounts for approximately 200 000 jobs in Europe, and it has been selected by the European Commission as one of the areas of the Lead Market Initiative for Europe, aimed at creating an innovation-friendly market framework to re-launch conventional industrial sectors and reduce time to market of new goods and services.

CHALLENGES

The largest challenges related to nano-enabled protective textiles are; the current high cost of manufacturing and relatively low level of demand resulting from a lack of marketing capabilities and slowly changing public procurement procedures. Nano-enabled textiles also need extensive environment, health and safety related standards and regulation because of the potential user exposure to nanoparticles. How to implement "privacy enhancing design" of "smart textiles" incorporating sensors and electronics is also a major challenge for responsible development of these products.

Summary

Nanotechnology is expected to enable huge development in this area, but the largest advantages are to be gained from integration of various technological areas together (for example ICT and textiles => wearable computers)

Most important impacts of nanotechnology are miniaturisation and lower power consumption of data processing and communication devices, but also completely novel features that would not be possible without nanotechnology enabled products

Printed electronics is one of the key technologies for future enabling the integration

The largest obstacles are currently related to 1) immature technologies, 2) high price, 3) low market demand for nano and 4) environmental, health and safety and societal aspects.

Sustainable Food and Environment

Introduction

With a rapidly increasing world population the demand on the world's natural resources and environment has become ever higher. Solutions must be found to protect, and prevent further degradation of, the environment, promoting a sustainable Europe while still providing the resources, such as clean water and adequate food, to ensure a high quality of life for its citizens. Existing technologies have made some progress in dealing with these issues but is not keeping pace with the scale of the problems being faced; however, nanotechnology developments offer great promise in helping to address some of these challenges.

The challenges to be addressed by the nano developments

Achieving a sustainable Europe will, without doubt, be a major challenge. Some of the most pressing issues being faced include:

PROVISION OF CLEAN DRINKING WATER - with increasing demands on water supplies and the likelihood that climate change will increase water stress, particularly in southern regions, access to clean drinking water will become an increasing problem[21]. The EU is also committed, through the Millennium Development Goals[22], to aiding developing nations improve their levels of access to clean drinking water.

ENVIRONMENTAL CONTAMINATION – soil, surface water, sediment, and groundwater contamination is widespread across Europe with nitrate contamination from agriculture being a particular problem[23].

AIR POLLUTION – this remains a major issue for many European cities and is particularly dangerous for vulnerable groups such as children, the elderly, or those with respiratory disorders[24].

[21] http://ec.europa.eu/environment/water/quantity/scarcity_en.htm

[22] http://ec.europa.eu/environment/water/quantity/scarcity_en.htm

[23] http://www.eea.europa.eu/themes/water/water-pollution

[24] http://ec.europa.eu/environment/air/index_en.htm

REDUCING CO_2 EMISSIONS – the EU has ambitious goals for reducing CO_2 emissions in a bid to limit the impact of climate change[25].

REDUCING WASTE – despite efforts in terms of recycling and reuse citizens of the EU remain some of the most wasteful in the world with increasing volumes of packaging waste due to our 'convenience' culture. The Agrifood industry is also a major source of waste including food packaging and organic waste[26].

AGRICULTURAL PRODUCTIVITY AND SUSTAINABILITY – with a high population density, diminishing water supplies, and contamination of the environment from pesticides and fertilisers there is a pressing need for food production to become more productive and less energy intensive.

IMPROVING FOOD QUALITY & SAFETY – the detection of contaminants in the food chain, be it during processing or the manner, in which the product is packaged, is vital for ensuring consumer safety. Longer shelf life (for example influenced by type of packaging) also increases sustainability as less food will be thrown away.

HEALTHIER PROCESSED FOOD – the rise of processed food continues and with an associated increase in obesity levels efforts are being directed into 'functional foods' that provide increased nutritional value with lower levels of salt, fat and sugar without affecting the taste or feel of the product and with improved biocompatibility.

Clearly nanotechnologies, or technology as a whole, cannot address these wide ranging issues alone; however, they can potentially offer solutions in a number of aspects of the challenges being faced.

[25] http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO Briefing No 1 Biodegradable Packaging.pdf ObservatoryNANO Briefing No.1: Biodegradable Food Packaging

[26] http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO Briefing No 1 Biodegradable Packaging.pdf ObservatoryNANO Briefing No.1: Biodegradable Food Packaging

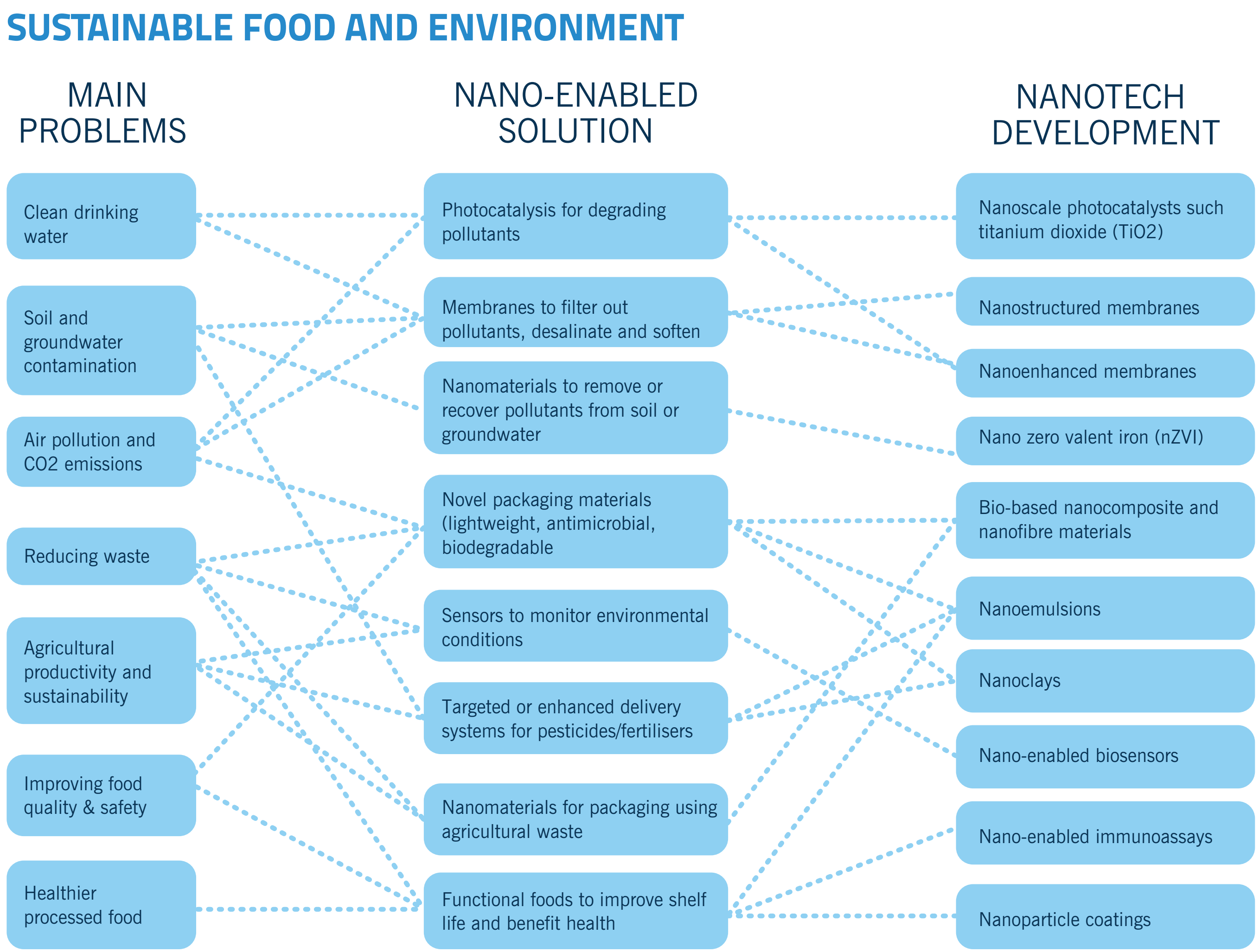


Figure 1: Matrix showing the problems to be addressed, the potential nano-enabled solutions, and relevant nanotechnology developments.

The nano-enabled solutions

As we can see from Figure 1 the challenges outlined in the previous section can be addressed with one or, in most cases, a number of nano-enabled solutions based on different nanotechnology developments. Below are some examples of pathways describing how these nanotechnologies are helping address the challenges:

CLEAN DRINKING WATER

Photocatalysis based on nano€catalysts, the most common of which is nanoscale TiO2, is a very promising method for the treatment of contaminated water; indeed solar photocatalysis has been identified as the main technology breakthrough for water treatment and purification, particularly in developing region[27]. Nanostructured and nano-enhanced membranes are used for filtration, which can effectively remove pollutants, offer desalination potential (important for many increasingly arid coastal regions) and soften drinking water supplies[28]. Furthermore, nanosorbents are being developed to remove different contaminants, such as arsenic, from drinking water sources.

[27] ObservatoryNANO Briefing No. 2: Photocatalysis for Water Treatment Briefing, http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO%20Briefing%20No.2%20Photocatalysts%20for%20Water%20Treatment.pdf

[28] ObservatoryNANO Briefing No.13: Nanostructured Membranes for Water Treatment

ENVIRONMENTAL CONTAMINATION

Due to the increased surface area of nanomaterials they offer more effective remediation potential compared to the larger molecules of conventional treatments. The most promising nanomaterial for addressing soil and groundwater contamination is nanoscale zero valent iron[29]. Other options to remove contaminants from water include nanoscale photocatalysts, nanosorbents and nanomembranes[30]. The reduction of (toxic) wastewater (e.g. from metal or textile industry) is one of the major goals in developing new nano-enabled solutions. Nitrate contamination of soil and groundwater from the agricultural industry is a major problem in Europe[31]; nano-enabled solutions for targeted and more effective delivery of nutrients will hopefully lead to reduced run-off and decreased contamination levels and thus address the problem at its root.

AIR POLLUTION AND CO_2 EMISSIONS

A number of the nano-enabled solutions described in **Figure 1** can be utilised to degrade environmental pollutants and reduce or filter greenhouse gas emissions. Solutions to prevent emissions include:

[29] ObservatoryNANO Environment Focus Report 2010: nZVI

[30] ObservatoryNANO Environment General Sector Report 2009

[31] http://ec.europa.eu/environment/water/water-nitrates/report.html

nanomembranes which can be applied to fossil fuel plants to reduce CO_2 output; reducing waste and recycling through novel packaging will help limit methane emissions from landfill sites; and reduced packaging weight will reduce fuel consumption, and emissions, from food transport. For remediating pollutants already in the environment options include photocatalytic nanocoatings incorporated into building materials, which help to reduce air pollution levels in cities

REDUCING WASTE

Nano-enabled packaging solutions offer great potential for waste reduction utilising materials such as nanocellulose, nanoclays, nanoemulsions, and nanocoatings, which offer greater biodegradability and even the potential for edible packaging. Product shelf lives can also be improved with 'smart packaging' making use of nanobiosensors to allow for more effective monitoring of the food's condition.

AGRICULTURAL PRODUCTIVITY AND SUSTAINABILITY

Nano-enabled sensors will improve the management of nutrient and water control of agricultural land thereby increasing productivity and, together with nanomaterials offering enhanced nutrient uptake, the potential for reduced use of agri-chemicals leading to lessened environmental impact. Scientific know-how for highly configurable and intelligent tools (sensors, algorithms, sprayers, grippers) that are capable of adapting to new tasks and conditions will benefit high value crops like greenhouse vegetables, fruits in orchards, and grapes for premium wines.

IMPROVING FOOD QUALITY AND SAFETY

Nanotechnologies such as nanobiosensors, nano-enabled immunoassays, and nano-enabled antimicrobial food packaging will lead to improved food safety in all aspects of the food chain. Nanoreaction technology is used to develop sensors which combine an expertise of sensitive molecular biological processes with the capability of nanotechnology and thus contribute to improved quality control within liquid process food streams.

HEALTHIER PROCESSED FOOD

Nanoencapsulation methods utilizing nanoemulsions or nanoparticle coatings offer the potential for improving the uptake of the human body to nutrients with processed food and reduce the sensitivity of nutrients to environmental conditions thus improving shelf life and reducing need for refrigeration.

Primary Data Summary

During the initial stage of our analysis of nanotechnology company activity across the EU, extensive patent and publication analysis was conducted building upon work completed in the first years of the project.

In terms of patent applications for both the Agrifood and Environment sectors Germany is clearly dominant with France, the UK, and the Netherlands following somewhat behind.

In terms of publications the numbers are small compared to sectors like Chemistry & Materials or ICT at 343 for Agrifood and only 95 for the Environment sector as defined by the publication analysis process. An interesting finding from the patent and publication values for these sectors are the ratio of patents to publications at 0.61 for the Agrifood sector but 2.59 for the Environment sector; this would suggest that the Environment sector is more successful at commercializing the technology whereas the Agrifood sector is more based within the research and development community.

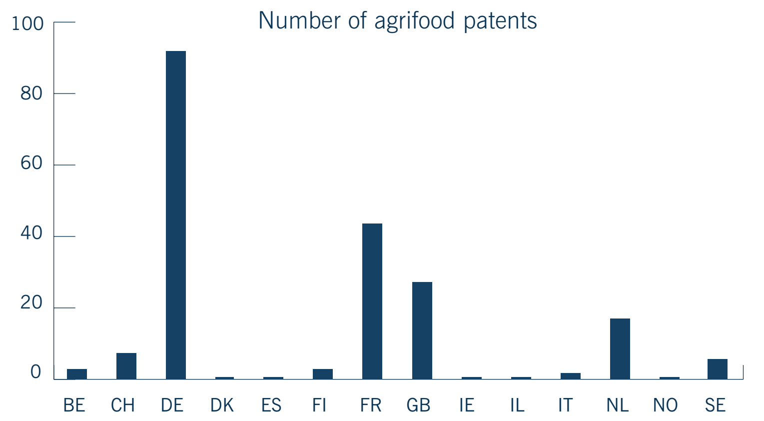


Figure 2 a: Number of patents in the 'Agrifood' sector filed in EU and Associated States (2000-2010)

Obstacles

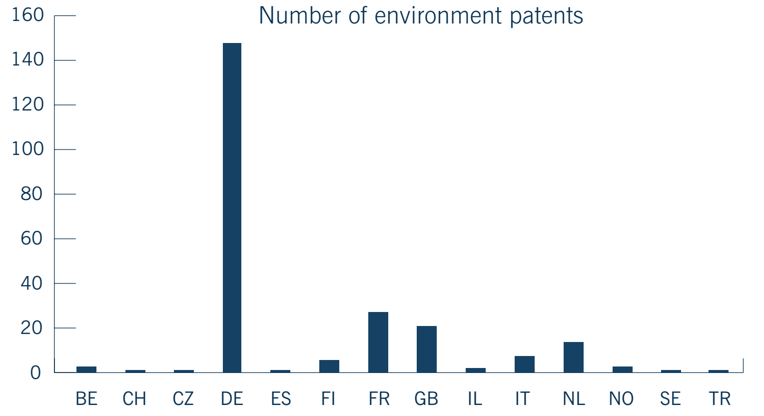


Figure 2b: Number of patents in the 'Environment' sector filed in EU and Associated States (2000-2010)

Nanotechnologies in the sustainable food and environment area face a number of barriers to successful commercialisation and competition with existing technologies despite their numerous benefits, as outlined in the previous sections. These barriers include:

TECHNOLOGICAL BARRIERS

Despite the numerous nano-enabled advances in the Agrifood and Environmental sectors described there still remains technological barriers to be overcome before full-scale commercialization and market dominance over existing technologies can be ensured. Indeed respondents of the ObservatoryNANO company survey (who associated themselves with either or both the Agrifood and Environmental sectors) noted technological barriers having greater impact on commercial success than any other factor. Indeed in both our case studies technological barriers are cited as the most critical to future development of these technologies.

ENVIRONMENT, HEALTH AND SAFETY RISK

Applications of nanotechnology in the environment or within food production, processing or packaging are more sensitive than many others such as electronics. Such concerns and fears for health and safety, and environmental issues must be overcome for successful exploitation of such technologies. During ObservatoryNANO analysis of risk of human and environmental exposure in this area there was, in general, thought to be a low level of risk; however, the following scenarios were highlighted as having highest potential for exposure[32]:

- Water or soil remediation utilising free nanoparticles such as nano-sized zerovalent iron resulting in release into the ecosystem;
- Unintentional release of nanoparticles or nanofibres from any material (e.g. nano-enhanced membranes, nanoparticle coated surfaces (TiO_2) or from other systems containing nanomaterials such as nanosorbents;
- Potential release at disposal stage;
- Potential for nanomaterial residues in agricultural production of meat, milk and crops;
- Application of nano-enhanced food additives (in functional foods or to improve taste or texture) will have, by nature, the highest potential exposure for consumers;
- Potential for release from food packaging (exposure of consumers during handling or when nanomaterial migrates to food;

[32] ObservatoryNANO EHS Analysis: Environment & Agrifood sectors

exposure of the environment when nanomaterials are release in the waste phase);

- Food processing procedures related to quality control;
- Application of nano-emulsions in pesticides;
- Application of nano-enabled equipment coatings for disinfection.

It is important to note that despite the recent investment into environmental, health and safety research there remain substantial gaps in knowledge, which with the precautionary principle currently being endorsed by the European Union[33] may hinder development.

PUBLIC ENGAGEMENT

After the extreme negative response of the public to genetically modified food in the 1990's it is vital to conduct appropriate public engagement throughout the development and commercialisation of new technologies, particularly in the food industry. NGO, Friends of the Earth (FoE), have called for a moratorium on the further commercial release of food products that contain manufactured nanomaterials until nano-specific safety laws are established and the public is involved in decision making[34]. However, they have acknowledged that nano-encapsulation may reduce the number of additives required during food processing.

In terms of environmental applications it will be vital to communicate the potential benefits offered by nano-enabled solutions but also present the potential risks in a balanced and transparent way. The NGO's FoE and European Environmental Bureau (EEB) have raised critical concerns about the expected environmental benefits of nanotechnology. Certain environmental applications of nanotechnology may be more energy hungry and polluting than contribute to sustainability. Environment, Health and Safety (EHS) aspects of these applications of nanotechnology are not taken into account sufficiently according to these groups.

Recent opinion polls and surveys in the EU, UK, the Netherlands[35] and USA indicate that the general public is not totally negative about food and environmental applications of nanotechnology. Lack of awareness and uncertainty about the potential benefits and risks are still dominant. Diverging attitudes towards these and other applications of

[33] http://www.europarl.europa.eu/stoa/archive/ta/nanotechnology/reports/workshop_report_en.pdf

[34] http://www.foeeurope.org/press/2008/Mar11_Nano_food_and_agriculture_report.html

[35] http://www.nanopodium.nl/CieMDN/english/

nanotechnology have been identified, between men and women, young and old, and different religious and political groups. There are doubts about who benefits from these applications; whether consumers or producers. Regulation and labelling and transparency are major concerns that should be addressed adequately in the short term. Failing this, public trust in the potential of nanotechnology to contribute to sustainability could well diminish rapidly. Food packaging technologies are expected to be more readily accepted by consumers than nano-enabled food additives for example.

POLICY, LEGISLATION, REGULATIONS AND STANDARDS

It may be somewhat surprising to note that from the company census responses policy is not seen as a major barrier to the commercial success of food & environment nanotechnologies. However, lack of legislation and specific regulations and standards for nanomaterials has been cited, during our expert engagement activities rather than from the response of census participants, as a significant barrier to commercialisation in the Agrifood and Environmental sectors. An example is the collapse of the Novel Food Regulation review in March 2011 due to issues related to clone derived products rather than nanotechnologies[36]. Without this framework, it is difficult to provide guidelines for regulation and standards for food contact or encapsulation products containing nanomaterials potentially leading to uncertainty and reduced investment attractiveness.

REQUIREMENT FOR PRODUCTION FACILITIES OR NEW INFRASTRUCTURE

A number of the developments described in this chapter would require new production facilities or infrastructure to be implemented. For example nanostructured membrane water filtration plants would require new infrastructure and maintenance experience. Therefore the water industry is unlikely to invest except in the case of new facilities or driven by new standards or regulations or high purification costs (because the water used as feedstock for drinking water production is more polluted).

[36] http://www.europarl.europa.eu/oeil/FindByProcnum.do?lang=2&procnum=COD/2008/0002

Case 1: A nano-enabled solution for clean drinking water

The problem

Most Europeans do not even contemplate the prospect of not having clean drinking water readily available; however, the impacts of global climate change are predicted to substantially increase water stress, particularly in areas of southern Europe[37], in terms of allowing penetration of salt seawater into the aquifers. Population growth leads to more polluted aquifers rendering the water quality unsuitable for drinking without excessive treatment. Additionally, the lack of clean drinking water in developing countries is a major cause of disease and early death.

[37] http://ec.europa.eu/environment/water/quantity/scarcity_en.htm

Nano-enabled solutions

Photocatalysis using nano-catalysts such as nanoscale titanium dioxide (nanoscale TiO_2); the basic concept of photocatalysis is very simple with a catalyst harnessing the (UV€) radiation from sunlight, or an artificial source and uses the energy to break down different substances.

Nanostructured and nanoenhanced membranes are filtration technologies for the removal of a variety of substances.

The impact

Nano photocatalytic removal of pollutants from drinking water is a cheap and effective treatment. Nanostructured and nanoenhanced membranes also offer improvement in water quality, recycling of wastewater, and potential for desalination in coastal arid regions (such as southern Spain); additionally a number of pollutants can be removed in a single filtration step. Nanomembranes may also offer the potential for removal of nanoparticles from water.

Market opportunities and European activity

The worldwide turnover of nanotechnological applications in water and wastewater treatment reached €1.1 billion in 2007 and was predicted to increase to €4.6 billion in 201514. Increasing stringent legislation and standards for water quality are driving the technological developments within the industry. Pilot solar photocatalytic systems for drinking water disinfection in developing countries are underway and show great potential.Error: No se encuentra la fuente de referencia Germany is one of the leaders in the field of nanotechnologies for water treatment; however, there is stiff competition from the USA, China and Japan.

Challenges

There remains a number of technological challenges to be overcome: the optimum setup system for nano-photocatalytic systems; nanomembrane fouling; and low accuracy modeling of membrane performance on a large scale. Additionally a conservative water industry will remain reluctant to integrate new systems unless driven by legislation, higher quality standards, and costs. Health and safety concerns may surround the use of nano-TiO_2, as toxicity studies have proved inconclusive. Also functionalised nanomaterials within nanoenhanced membranes could present EHS issues[38]. (Nanostructured membranes contain no free nanoparticles.)

Figure 3: RayWOx solar receiver by Hirschmann for solar photocatalytic water purification.

[38] ObservatoryNANO Briefing No.16: Nanoenhanced Membranes for Water Treatment

Case 2: Sustainable Food Packaging

The problem

Food packaging waste is a serious, and increasing, problem worldwide as a result of an ever-increasing demand for convenience food, and individual wrapping of fresh produce (such as fruit). Existing plastic packaging is not designed to be easily or safely disposed of, or recycled, and therefore presents a problem when entering the waste stream.

The nano-enabled solution

Natural polymers, such as sugars and proteins, can be combined with nanoclays and bio€based nanomaterials to create potentially non€ toxic, biodegradable and biocompatible materials – which some have dubbed as "green nanocomposites".

The impact

By using these naturally occurring polymers the materials may be degraded (composted) or even eaten; this would substantially reduce the waste issue presented by food packaging, and also utilize agricultural waste. Nanotechnology developments also provide added value such as increased strength, water and gas impermeability, and additional functionalities such as antimicrobial effects or biosensors, enabling increased shelf-life and reduced food spoiling.

Market opportunities and European activity

The potential market is large; the global market for biodegradable polymers exceeds €135 million and although the number of nano-enabled products is currently small it has increased ten-fold over the past three years. Europe is a leader in the research and development in this field but the number of companies producing products remains low; however, some European regions can be identified as a hub for nano-enabled packaging with active research and development as well as burgeoning production capacity[39].

[39] ObsNANO Agrifood Briefing No.1 Biodegradable Food Packaging http://www.observatorynano.eu/project/filesystem/files/ObservatoryNANO%20Briefing%20No%201%20Biodegradable%20Packaging.pdf

Barriers to success

There are a number of barriers to address before successful commercialisation of bio-based nanocomposites, these are outlined in the graphic below. A major barrier is likely to be EHS issues related to the use of nanomaterials in food packaging and the perceived risk by the consumer, and to an extent the packaging industry, despite the natural basis of these materials. Provision of accurate risk information is key to alleviating such concerns. Additionally respondents to our company survey have suggested that technological challenges remain to be overcome but are very satisfied with funding at EU, national and local levels.

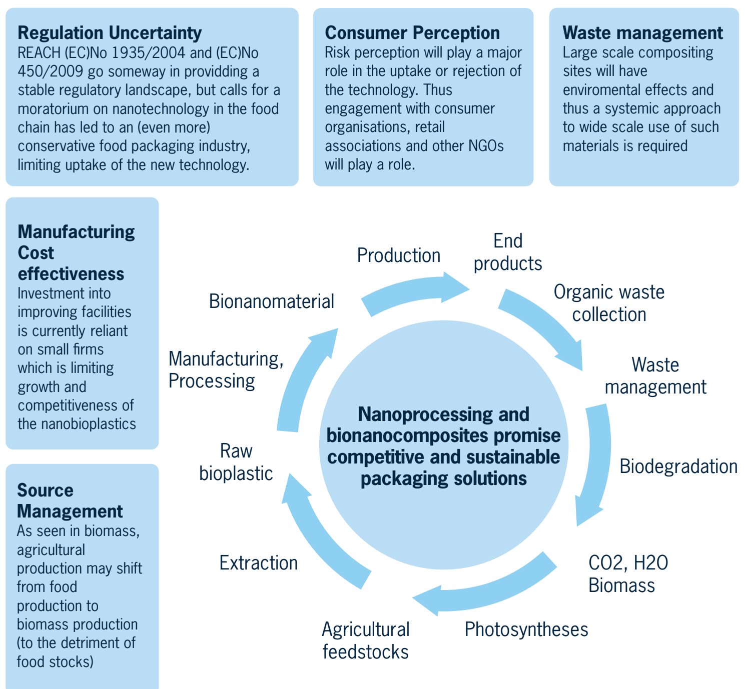


Figure 4: Barriers that pose a challenge to sustainable nano-enabled packaging.

Summary

Nano-enabled solutions hold great promise in addressing some of the challenges being faced in ensuring an environmentally sustainable Europe while providing citizens with adequate access to clean water and food supplies.

Technological challenges remain a key barrier to be overcome before widespread commercialization can be realized, especially given the competition with existing technologies for a number of applications.

Environmental, health and safety concerns must be adequately addressed through continued research to fill knowledge gaps, especially where there is a high potential for exposure to nanomaterials for humans or the environment.

Effective public engagement and provision of (risk) information at all points of technology development will help with public perception and acceptance.

Focus is required on extending application and exploitation of validated food data such as nutrition studies and implementation of standards and best practice. This also forms the basis of long-term sustainability.

New Energy Economy

Introduction

The demands for energy are ever increasing while the world's limited natural resources are being exhausted. Not only is the world struggling to meet its energy demands, but much of the current energy consumption is also wreaking havoc on the environment. The energy crisis, however, is not limited to the environment. Europe imports much of its oil from a small number of non-EU countries making foreign oil dependence a serious threat and unpredictable energy price oscillations a danger to the economy. While consumer and industry energy demands continue to increase, not enough is being done to ensure energy is being used as efficiently as possible. Europe must search for new, sustainable, and clean energy options. Nanotechnology developments offer some unique solutions to enable Europe to enter the New Energy Economy.

The challenges to be addressed by the nano developments

On the 11th and 12th of December 2008 the European Council met and adopted a package that embraces its role in promoting a New Energy Economy. The 27 member states all agreed to enforce the 20-20-20 targets listed below. By 2020 these countries must fulfil the following requirements[40]:

- **20% reduction in the emissions of greenhouse gases**
- **20% increase in EU energy efficiency in the EU**
- **20% usage of renewable energy in total EU energy consumption**

To meet these challenging goals, four critical issues have been identified as areas in which strides must be made:

- IMPROVING ENERGY EFFICIENCY – As society advances and populations grow, there is an ever-increasing need for energy. Almost all new developments and innovations require some form of it. In order to utilise the limited amount of energy available to meet increasing demands, it is critical that society finds ways to use energy as efficiently as possible.
- REDUCING ENVIRONMENTAL IMPACT CAUSED BY PROD-

[40] http://www.europarl.europa.eu/sides/getDoc.do?language=en&type=IM-PRESS&reference=20081208BKG44004; accessed 9-may-11

UCT USE – Since the dawn of mankind society has polluted while giving very little regard to the potential damage of those actions. Only recently has concern been raised about the harm that is being done. To reduce society's impact on the environment, products must be developed which are more environmentally friendly. These products must emit less CO2 and other greenhouse gases and/or consume fewer natural resources.

- REDUCING ENVIRONMENTAL IMPACT CAUSED BY PRODUCT CREATION – Just as products created should not pollute, the efforts used in creating them should be equally environmentally friendly. The fewer natural resources used and CO2 created to make a product, the better. New Energy Economy companies must not only make environmentally friendly products, but implement environmentally friendly production processes as well.
- REDUCING OIL DEPENDENCY – Although this was not specifically outlined as a 20-20-20 target, it is critical that this topic be addressed. By reducing oil dependency, countries will find cleaner alternative sources of energy, which will likely both reduce greenhouse gas emissions and increase the amount of renewable energy consumed. Since half of the crude oil is imported from only two countries, Europe would be in a very risky position if its trading relationship were to sour[41]. Reducing oil dependency proves to be not only environmentally sound, but a wise idea to maintain a sustainable European economy and society.

[41] http://www.energy.eu; accessed 28-apr-11

Nanotechnology developments offer solutions that could help to address all four of the aforementioned issues.

The nano-enabled solutions

The issues discussed in the previous section are addressed by several different nano-enabled solutions that are based on different nanotechnology developments highlighted in Figure 1. Although some of these nano-developments could apply to multiple sectors, for the sake of brevity, their solutions are examined only once and strictly within the context of the transportation and construction industries. The following paragraphs explain how the nano-solutions can overcome the Grand Challenge problems within each of the two industries:

Automotive and Transportation

The following developments in electric vehicle batteries have the potential to improve energy efficiency and reduce both environmental impact and oil dependency: enhanced electrolytes, nano-wires and coatings, and mesoporous separator membranes. Nano-coatings and lubricants, along with improved mechanical nano-layer properties within conventional engines all enable friction reduction. Lastly anti-scratch coatings on lightweight polycarbonate (PC) glass, nano-structured light metals, nano-steel replacements along with nano-structured spray

NEW ENERGY ECONOMY

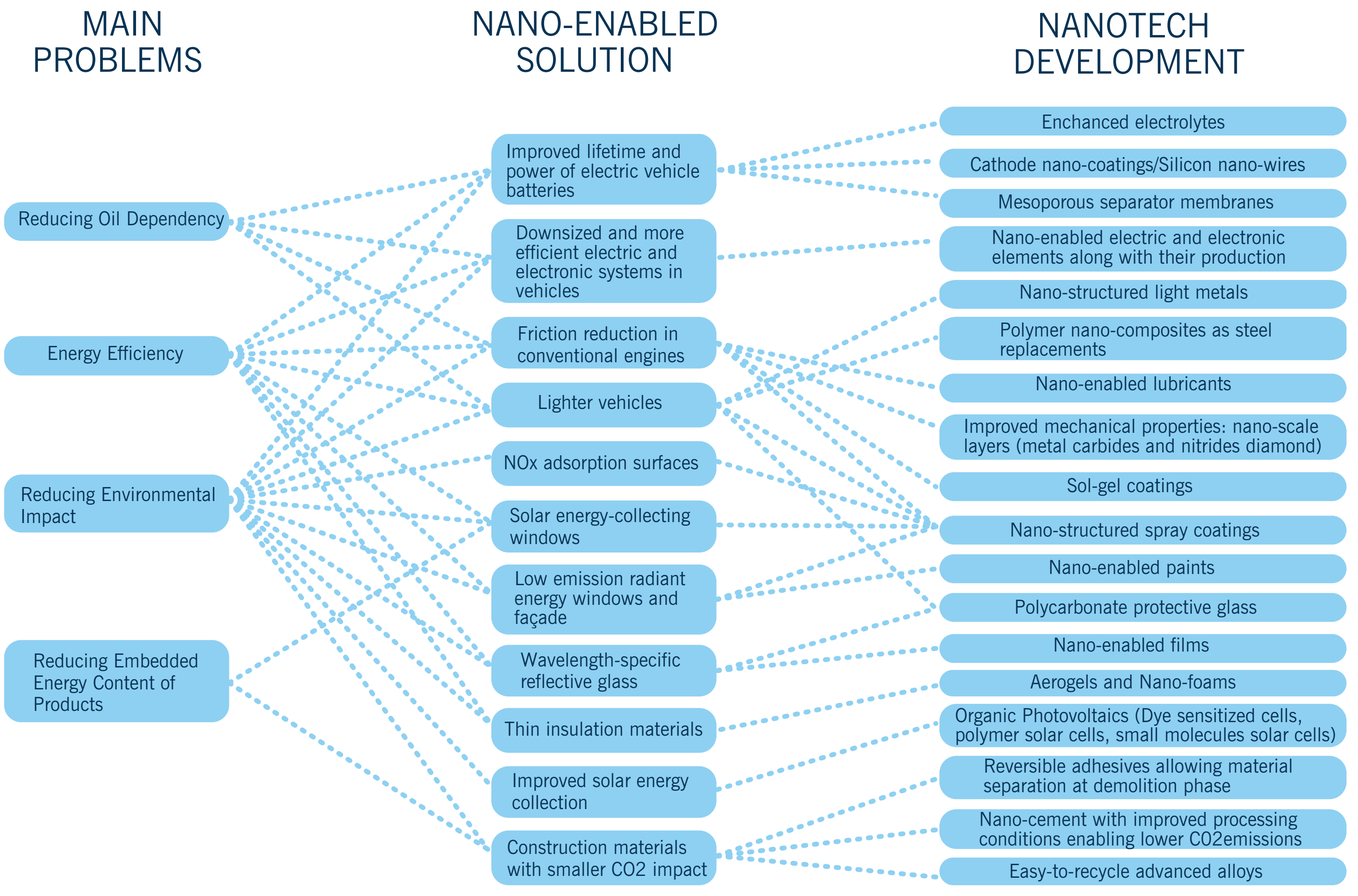


Figure 1: Matrix showing the problems to be addressed, the potential nano-enabled solutions, and relevant nanotechnology developments.

coatings all help to produce lighter vehicles. This is an important issue to the automotive industry as estimates show that a 10% weight reduction in vehicles will lead to a 6€8% improvement in fuel usage and thus a 20 Kg of CO2 per kilogram of weight reduction over the vehicle lifetime. Replacement of glass with PC windows alone can reduce car weight by up to 20 kg![42]

Construction

The next four nanotech developments can perhaps be considered as most relevant regarding energy efficiency improvement in buildings. Aerogels and nano-foams are much thinner than traditional insulation, while just as effective at maintaining temperatures. Nano-enabled films are used to create reflective glass that keeps the sun's heat radiation out in the summer and retains heat inside in winter, without significantly reducing sunlight entry into the building. Nano-enabled paints and nano-structured spray coatings reduce the amount of radiant energy released allowing buildings to better retain heat. The previously mentioned coatings are also used in solar energy-collecting windows. In addition to being energy efficient and environmentally friendly, these windows also create energy for use within the building. Nanotechnology-enabled photovoltaics, on the other hand, could simply reduce a building's dependence on externally produced energy whereas organic photovoltaics offer a potentially low-cost manufacturing process.[43]

On average about 20% of the overall energy consumption during a building's lifecycle comes from embodied energy in construction materials. However as buildings become more energy-efficient, this percentage will logically increase and more focus will be placed upon it.[44] Construction materials and their production processes are being adapted to address this embedded energy problem, leveraging in some cases nanotechnologies. Reversible nano-adhesives allow for easy material separation at demolition. Nano-cement is under development producing far lower CO2 emissions than regular cement. Lastly nanotechnology enables easy-to-recycle metal alloys, preventing unnecessary waste. While NOx adsorption surfaces do not limit CO2 impact, they actually absorb greenhouse gases that are also hazardous to urban citizen's health (excessive NOx concentrations in cities contribute to increased occurrences of respiratory diseases. They do not just reduce their environmental impact; their use actually can reduce serious respiratory

[42] ObservatoryNANO Briefing No.6 Nano-enhanced automotive plastic glazing

[43] ObservatoryNANO Report: Energy - Nanotechnology in Photovoltaic

[44] Chapter on Energy Efficient Materials for Buildings For the Roadmapping Exercise on Materials for the European Strategic Energy Technology Plan; Version 03 24-march-2011 written by: Marlies Van Holm, (MVH), Project architect / Energy Adviser, Flemish Institute for Technological Research; Luís Simões da Silva, (LSS), Professor, Universidade de Coimbra, Portugal; Gian Marco Revel, (GMR), Professor, Università Politecnica delle Marche, Dipartimento di Meccanica, Ancona, Italy (Rapporteur); Michael Sansom, (MS), Steel Construction Institute, Ascot, United Kingdom; Heli Koukkari, (HK), Research Co-coordinator at VTT, Finland; Hans Eek, (HE), Architect, Passivhuscentrum, Alingsås, Sweden (Rapporteur). accessed 10 may 2011

illness in cities[45]!

Primary Data Summary[75]:

From 1998 to 2009, a total of 1,023 nanotechnology publications were identified as being related to the New energy economy grand challenge. A total of 313 nanotech publications were written for the construction industry by 179 different author affiliations. Authors producing 10 or more publications were IBM (17) and Unilever (11). During the same period of time 524 nanotech publications were written for the energy industry by 230 different author affiliations. There were many more authors producing 10 or more publications within this industry. They include the following: IBM (56), Konarka (24), STMicroelect (19), NTT (15), Alcatel Lucent (13), Bayer (12), Rossendorf Inc (12), Accelrys (12), and THALES Research & Technology (11). Lastly there were 186 nanotech publications written for the transport industry. They were written by 107 different author affiliations with Micro Mat Ltd (17) and IBM (11) producing 10 or more publications.

During the period of time from 2000 to 2010, 213 nanotechnology patents were filed for the construction industry, 171 for the energy industry, and 125 for transport. Evonik/Degussa (15), Bayer (11), Merck (10), and the former Rhone Poulenc Chimie (10) produced 10 or more patents within the construction industry. BASF (13), Arkema France (11), Siemens AG (11), and Thales SA (10) all produced 10 or more patents within the energy industry. For the transportation industry Evonik/Degussa and Michelin were the only companies identified to have been issued 10 ore more patents between 2000 and 2010, each issued 11.

It is interesting to note that the quantity of patents that were filed for the transport industry was not only lower, but there were also fewer countries that received transport patent applications. As is the case

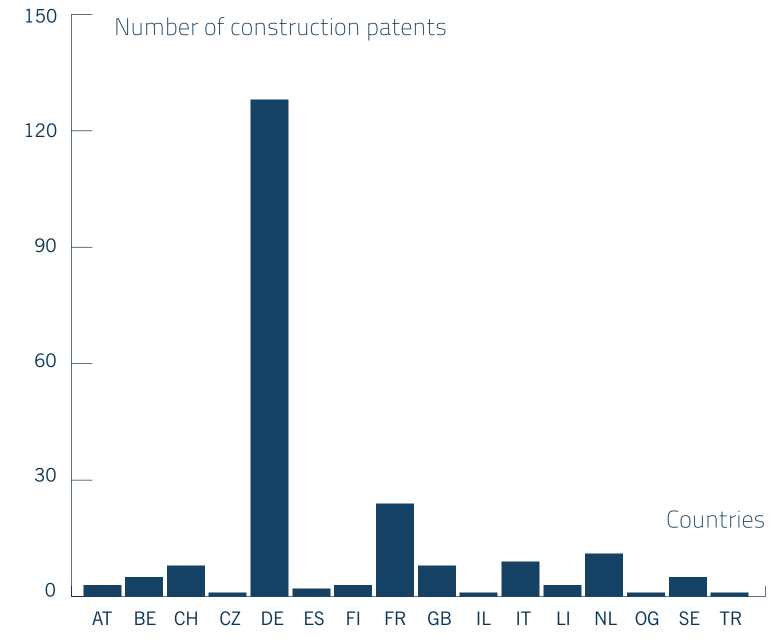


Figure 2 a: Number of patents in the 'Construction' sector filed in EU and Associated States (2000-2010)

[45] ObservatoryNANO Report: Aerospace, Automotive & Transport - Coatings, Adhesives & Sealants

with other sectors, Germany issued far more nanotechnology patents than any other country (having produced 265 of the patents that fall within this Grand Challenge). France is the next highest patent producing nation (with 86 total patents)

Obstacles

Nanotechnology companies that are addressing the New Energy Economy Grand Challenge are not without obstacles to their success. The following topics highlight some of the issues faced by companies within this Grand Challenge:

ECONOMIC BARRIERS

For all nanotechnology applications overcoming costs is a critical factor, as new technologies are often initially more costly. For example, batteries are expected to account for a high proportion of the cost of electric vehicles. If these costs are not reduced, electric vehicles are unlikely to replace the less environmentally friendly internal combustion engine[46]. Producers of Dye Sensitized Solar Cells face economic challenges as well, as increasing their products' lifetime currently means an increase in cost[47].

[46] ObservatoryNANO Report: Energy - Nanotechnologies for Batteries

[47] ObservatoryNANO Briefing No.12 Organic Photovoltaics

TECHNOLOGICAL BARRIERS

The technological barrier poses an even bigger threat. This is hardly a surprise as nanotechnology is a new science that is still developing. For example, hybrid aerogels could possibly be the insulation of the future, as they are much stronger than the current ones being produced. However, due to current technology, they are 5 to 10 years away from

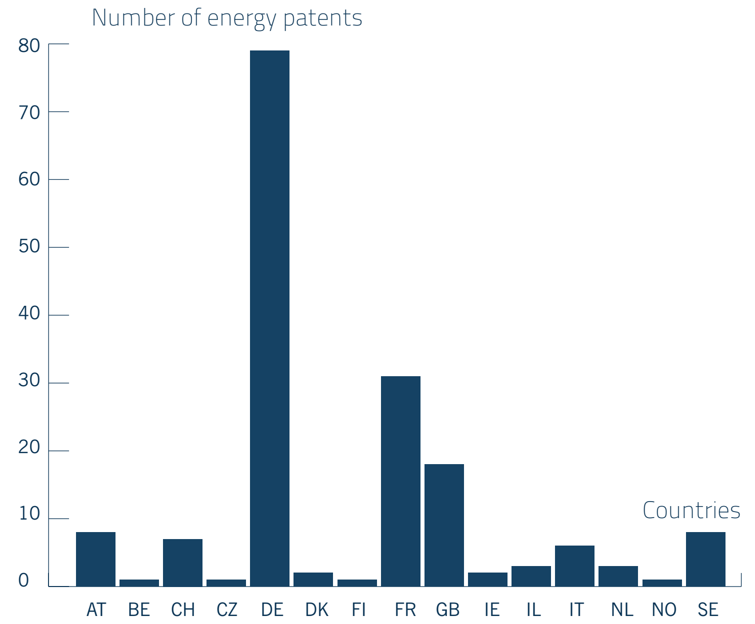


Figure 2b: Number of patents in the 'Energy' sector filed in EU and Associated States (2000-2010)

being introduced into the mainstream marketplaceError: No se encuentra la fuente de referencia. Similar situations can be seen with other nano-developments.

ENVIRONMENT HEALTH AND SAFETY (EHS)

Although EHS does not appear to be a very big barrier to commercial success, this is not to say that these companies have no EHS obstacles to overcome. As previously mentioned, electric batteries in extreme cases could generate fire or explosion. Obstacles such as this are likely the reason why companies generally partake in some sort of research related to EHS issues and have occupation health and safety best practices in place regarding the safe development of nanotechnologies. Although the cases may be extreme and rare, companies do not want to take any chances when it comes to EHS.

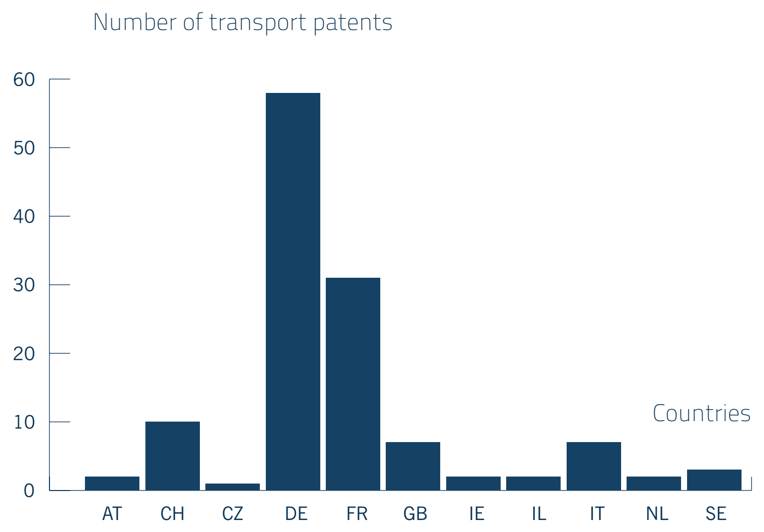


Figure 2c: Number of patents in the 'Transport' sector filed in EU and Associated States (2000-2010)

PUBLIC PERCEPTION

Although nanotechnology has received a lot of negative publicity as of late, those companies working within the New Energy Economy sectors have not felt the impact. It is quite possible that the public is less fearful (or less aware) of these products having a nano component. For example, an individual is likely to be much less afraid of nano-enabled insulation than of cosmetics, foods, or other items that have much closer contact with people.

Even though there is currently not much public concern regarding energy applications of nanotechnology, the public may be more sceptical about the real environmental benefits offered by nanotechnology than companies and other technology promoters think. In a recent public consultation on nanotechnology in the Netherlands, 51.9% of 2319 respondents thought that we will use more energy when this becomes cleaner and cheaper. 25.8% did not think so and 22.3% answered 'maybe'[48]. In a recent report, Friends of the Earth is very critical of the promise of environmental benefits of nanotechnology for energy appli-

[48] http://www.nanometing.nl/resultaten/resultaten-nano-en-de-natuur/ accessed 10 may 2011

cations. Energy applications of nanotechnology may in reality over their full life cycle cost more energy and contribute to pollution than contribute to sustainability. Environment, Health and Safety aspects of these applications of nanotechnology are not taken into account sufficiently according to them[49]. Another NGO European Environmental Bureau appears to be a bit less sceptical but still highlights the fact that the promise of nanotechnology for sustainable energy and manufacturing are slow to materialize and pleads for more research in EHS and life cycle assessment[50].

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[49] FoE, "Nanotechnology, climate and energy: over-heated promises and hot air?" Friends of the Earth Australia, England Wales and Northern Ireland, Europe and USA, 2010, http://www.foe.org/nano-climate. accessed 10 may 2011

[50] EEB, "Challenges and opportunities to green nanotechnologies," Nanotechnologies in the 21st century, issue 1, 2009, http://www.eeb.org/index.cfm/activities/industry-health/nanotechnology/ accessed 10 may 2011

Case 1: Nano-Enabled Insulation Materials[51]

The problem

Heating, ventilation and air conditioning (HVAC) represents some 10% of EU's energy consumption and green€house gas emissions. Since buildings have average lifetimes of greater than 60 years, creative solutions must be developed to address the existing buildings enabling them to be upgraded (retro€itted) in terms of their thermal performance.

Nano-enabled solution

Aerogels and nano-foams can achieve equivalent results to traditional wall insulation materials but with substantially lower thickness and CO2 consumption in their creation, making them very attractive for building retrofitting. Low emissivity glass coatings reduce heat transfer through the glass. In winter radiant heat generated indoors is reflected back inside, while in summer, infrared heat radiation from the sun is reflected away. Window films reduce heat transfer as well, serving as a filter to ultraviolet and infrared light.

The impact

By implementing the various nano-enabled insulation products available, a substantial impact should be seen within a 10€20 year timeframe, reducing existing buildings' HVAC consumption by approxi-

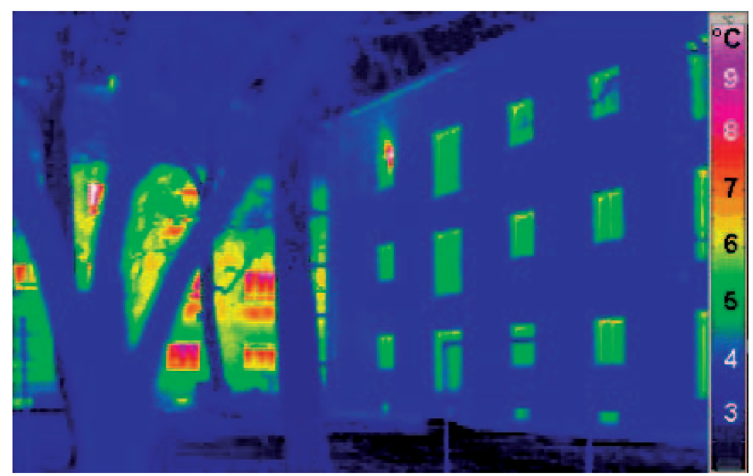


Figure 3: Thermogram of a Passivhaus building (right) with a traditional building (background) – Source: Passivhaus Institut

[51] ObservatoryNANO Briefing No.3 Nano-Enabled Insulation Materials

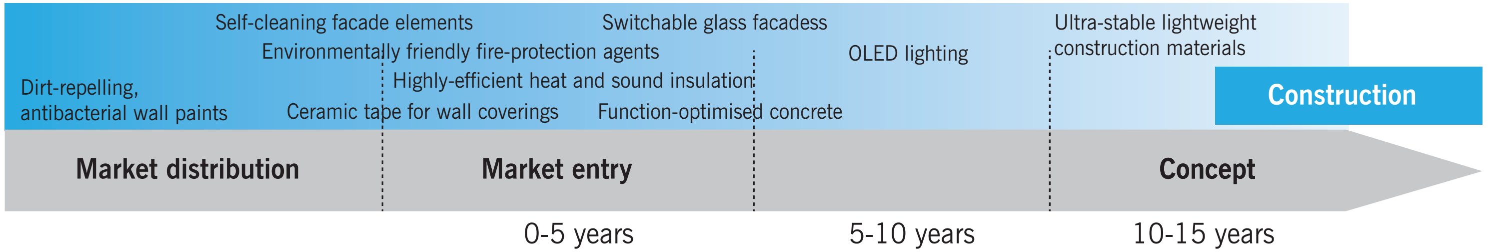


Figure 4: Examples of nano-enabled solutions and degree to maturity in the construction sector [52]

mately 75 kWh/m2. If these nano-enabled insulation methods were instituted for the entire building stock of Europe, this would render a savings of 1.5 million Gigawatt Hours[52].

Barriers to their success:

In order to begin offering nano-enabled technology, both insulation and window manufacturers will need to update and/or add new machinery. In addition, skilled workers will need to be hired and new handling and safety measures implemented. Current aerogels are brittle and expensive with poor humidity resistance. Hybrid and organic aerogels must be developed at much lower costs than presentably obtainable and be produced in larger volumes. The durability of window coatings must also be improved to guarantee full lifetime functionality. It is also important to note builders and investors often have no incentive to invest in higher cost energy-saving insulation. To change this, policy makers could address the financing of this enhanced insulation or introduce a significant cost penalty for not performing any refurbishment.

[52] Cost-Effective Climate Protection in the EU Building Stock, ECOFYS, February 2005 and Cost-Effective Climate Protection in the EU Building Stock, ECOFYS, March 2005

[53] Gómez-Uranga, Mikel, Goio Etxebarria and Jon Barrutia. The Dynamics of Regional Clusters of Nanotechnologies: Evidences from German länder and two Spanish Autonomous Communities. University of the Basque Country, January 18, 2011.

Case 2: Nanotechnology and electric vehicles[54]

The problem

Transport is responsible for 23-26% of all greenhouse gas emissions and also uses around 70-75% of all European oil consumption. In fact, in 2008 EU-27 countries purchased 53.8% of their total energy consumed, while 49% of their crude oil imports came from Russia and Norway alone. The current transport situation must be improved to reduce its carbon footprint and dependency on foreign energy.

[54] ObservatoryNANO Report: Aerospace, Automotive & Transport - Batteries for Electric Vehicles

Nano-enabled solution

As previously mentioned, enhanced electrolytes, cathode nano-coatings/silicon nano-wires and mesoporous separator membranes are all things that could improve energy efficiency and reduce both environmental impact and oil dependency. Motors with permanent magnets made of nanotech enhanced new alloys could reduce motor costs while using less rare-earth metals. Nano oxides, carbon nano fibres, carbon nanotubes, and lamellar nanomaterials all can help reduce rolling resistance in tires that in turn reduces energy consumption. Nanostructured light metals or polymer nanocomposites replace heavier car parts like steel that would reduce the overall weight of the vehicle as well as energy consumption.

The impact

Reducing energy consumed for transport would reduce CO2 emissions and foreign oil dependency while also increasing domestic energy production. In the U.S. it is estimated that a 10% reduction of oil imports and a consequent increase in domestic energy production would add at least $60 billion to the economy. The same could be true in Europe.

Barriers to their success:

The main barrier to large-scale commercialisation of electric vehicles is the battery. Current areas that need to be addressed are cost, technology, production, and access to raw materials. The high cost of raw materials is one of the biggest obstacles to be addressed. It is expected that by 2020 production will be higher. However, large-scale production will require nanotechnology-enabled developments that can be scaled-up, allowing high-volume, low-cost production.

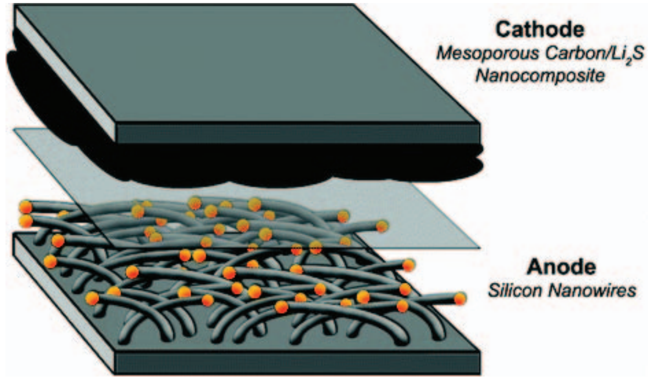


Figure 5: Examples of nano-enabled solution for car batteries [55]

In addition, nanotechnology must provide safety, performance, and durability in electric vehicle batteries. The batteries contain combustible materials such as lithium or electrolyte solvents that in extreme cases of overheating could cause the battery to generate a fire or explosion. Additionally, many lithium-ion cells have lower performance at very low and very high temperatures. Lastly, since lithium-ion batteries are costly, they must be constructed to work for at least 15 years during thousands of cycles (300 000 shallow cycles for hybrid and 7 000 deep cycles for pure electric vehicles) while keeping at least 80% of their initial capacity. Another issue is that automotive plants generally work at over-capacity meaning that there may be slow adaptation to electric vehicle batteries without policy makers providing incentives to manufacturers to make the switch.

[55] http://www.treehugger.com/files/2010/03/lithium-sulfur-battery-breakthrough-more-energy-and-safer.php

Summary

Nano-enabled solutions can address the main issues confronted in the New Energy Economy (Improving energy efficiency, Reducing environmental impact caused by product use, Reducing environmental impact caused by product creation, Reducing oil dependency)

Companies have indicated that economic barriers are critical to their success and especially value public funding that goes towards fundamental research, applied research, and demonstrations.

Technological barriers are of greatest concern to companies as many innovative products are still years away from making it to market.

Public perception and Environment, Health, and Safety issues are of lesser concern to companies, although the majority are involved in EHS-specific research or best practices.

Most companies in our census do not find REACH and existing nanotechnology guidelines to have a negative impact on their commercial success. Possible dialogue with companies may help to ensure future guideline meet companies' needs.

Companies are generally satisfied with the regional, national, and EU support received and believe current policies have had little impact in impeding their success.

Ageing Population

Introduction

The European population is ageing with the number of persons of retirement age increasing whilst the number of economically active persons decreases. In Europe, it is also expected that 50% of babies born today will live to 100 due to improvements in healthcare and living standards. According to a report by the Organisation for Economic Co-operation and Development (OECD), the cost of caring for the elderly could treble by 2050. OECD estimates that 10% of people in OECD countries will be more than 80 years old by 2050, up from 4% in 2010 and less than 1% in 1950, and that OECD member countries are spending 1.5 % of GDP on long term care[56].

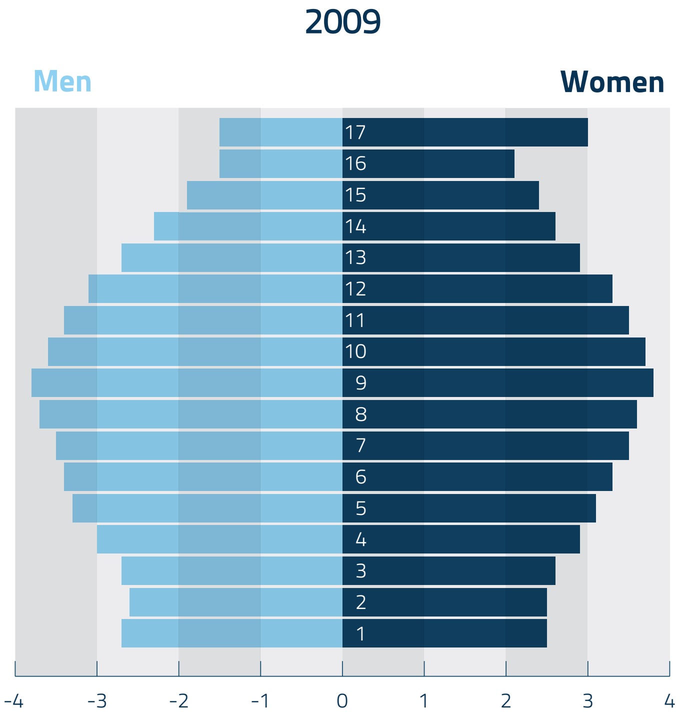
This growth in the ageing proportion of the population is exerting an increasing pressure on social security systems and indeed whole economies. This is largely due to the fact that, as our population ages, there is a consequent increase in the diseases of ageing with their associated cost to healthcare systems. Nanotechnologies can offer new ways and means to counteract this grand challenge by improving the early diagnosis and treatment of disease as well as the quality of life of older citizens.

The challenges to be addressed by the nano developments

Various interacting medical, technological, social and economic factors have resulted in a shift in the age distribution of the European population over recent decades. The dramatic ageing trend in the European population (**Figure 1**) is mainly influenced by the continuing decline in birth rates and extended life expectancy.

[56] http://www.oecd.org/dataoecd/13/8/38343783.pdf

This trend is expected to continue as advances in medicine contribute to the prolongation of EU citizens' life expectancies. Challenges are also compounded with other social issues such as the change in the role of women and changes in lifestyle in the population. Insecurity concerning the employment market and the need for income has influenced birth rates significantly and women may often put off having children for the sake of maintaining their careers.



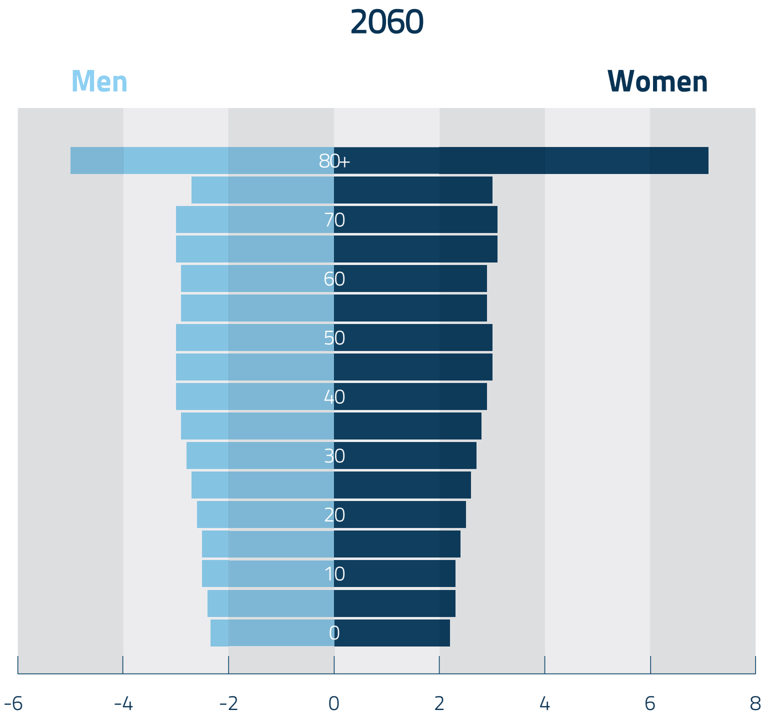


Figure 1: Age pyramids for EU 25 for the years 2009 and 2060 [56]

[57] Eurostat, Population on 1 January by five years age groups and sex, 2011

[58]**Figure 2** shows the major causes of death by age group in the EU in 2003. Increases can be seen in cardiovascular and respiratory diseases as might be expected but there is also a marked increase in “others”. This category includes diseases such as neurodegenerative diseases (e.g. Alzheimer’s Disease and other dementias) which are showing a marked increase in prevalence. In the UK alone over 800,000 people are estimated to be suffering from various forms of dementia including around 465,000 with Alzheimer’s Disease. This figure is expected to increase to over one million sufferers within ten years in the UK with a similar pattern in other European countries. Dementias are also very

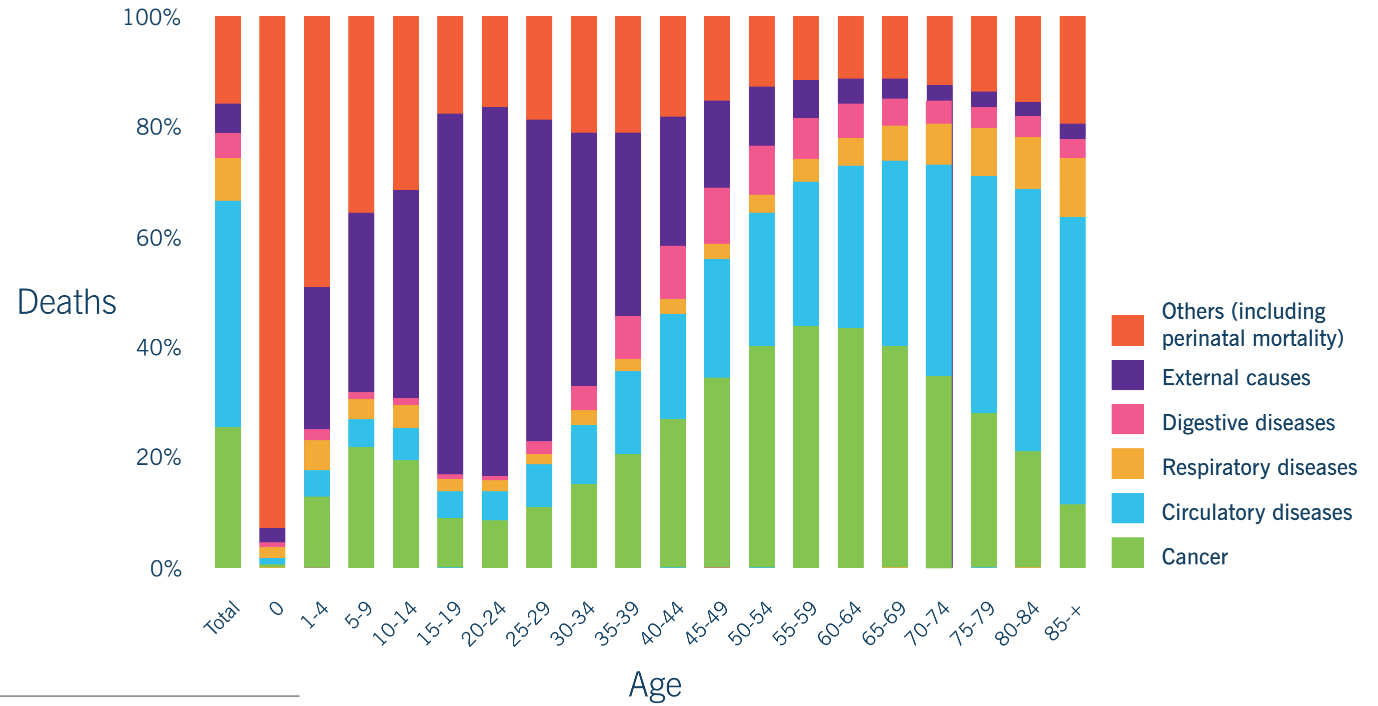


Figure 2: Major causes of death by age group for both sexes [57]

[58] E. Niederlaender, Causes of death in the EU in Statistics in focus, 2006, http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-NK-06-010/EN/KS-NK-06-010-EN.PDF

costly in terms of patient care according to the Alzheimer's Research Trust. It is estimated in the UK that dementia care costs the health and care services more than cancer and strokes combined[59].

Achieving healthy ageing in Europe will definitely be a major challenge. Some of the most pressing issues being faced include:

- Treatment of dementia - Increased incidence of dementias, including the most common form Alzheimer's disease, will provide a huge societal challenge in the European Union in the coming decades. In some European countries, the incidence of dementias is expected to double over the next years.
- Osteo- and rheumatoid arthritis – Degenerative diseases and conditions of the musculoskeletal system are an important challenge in relation to the increased ageing population. Conditions such as osteoarthritis and rheumatoid arthritis can have a profound negative effect on the quality of life of sufferers and can severely limit their mobility and independence.
- Age–related hearing problems – Age related hearing loss is among the most common impairment related to ageing. Approximately 44 million people suffer from hearing loss and 40000 are profoundly deaf in the EU. As the mean age of the population increases, the number of people with hearing or inner ear disorders will also increase.
- Age–related eyesight problems – Around 82% of registered blind or visually impaired persons are over 50 years old, with a significant increase in incidence in those over 804. This incidence includes very severe conditions such as age-related macular degeneration, glaucoma and diabetic retinopathy.
- Treatment of pressure sores and wound healing – Pressure sores are a common and serious problem for people who are in some way immobilised for extended periods (for instance patients in hospitals or in care homes). It is estimated that, in Europe, prevention and treatment of decubitus ulcers costs more than €17 billion per annum.
- Healthcare monitoring of the elderly – the increasing pressure on the health care system for the elderly calls for novel cost effective monitoring solutions, such as biosensing systems that can be networked through internet or telephone systems and used as part of a monitoring or remote care service.
- Implantable Medical devices – Cardiovascular diseases are a major cause of death for people older than 70 years in Europe. The incidence of these diseases rises considerably with increasing age. People aged 85 years and older are more likely to die from

[59] R. Wood, "Defusing the dementia time bomb", Healthcare Manager (issue 1). p.9, 2009

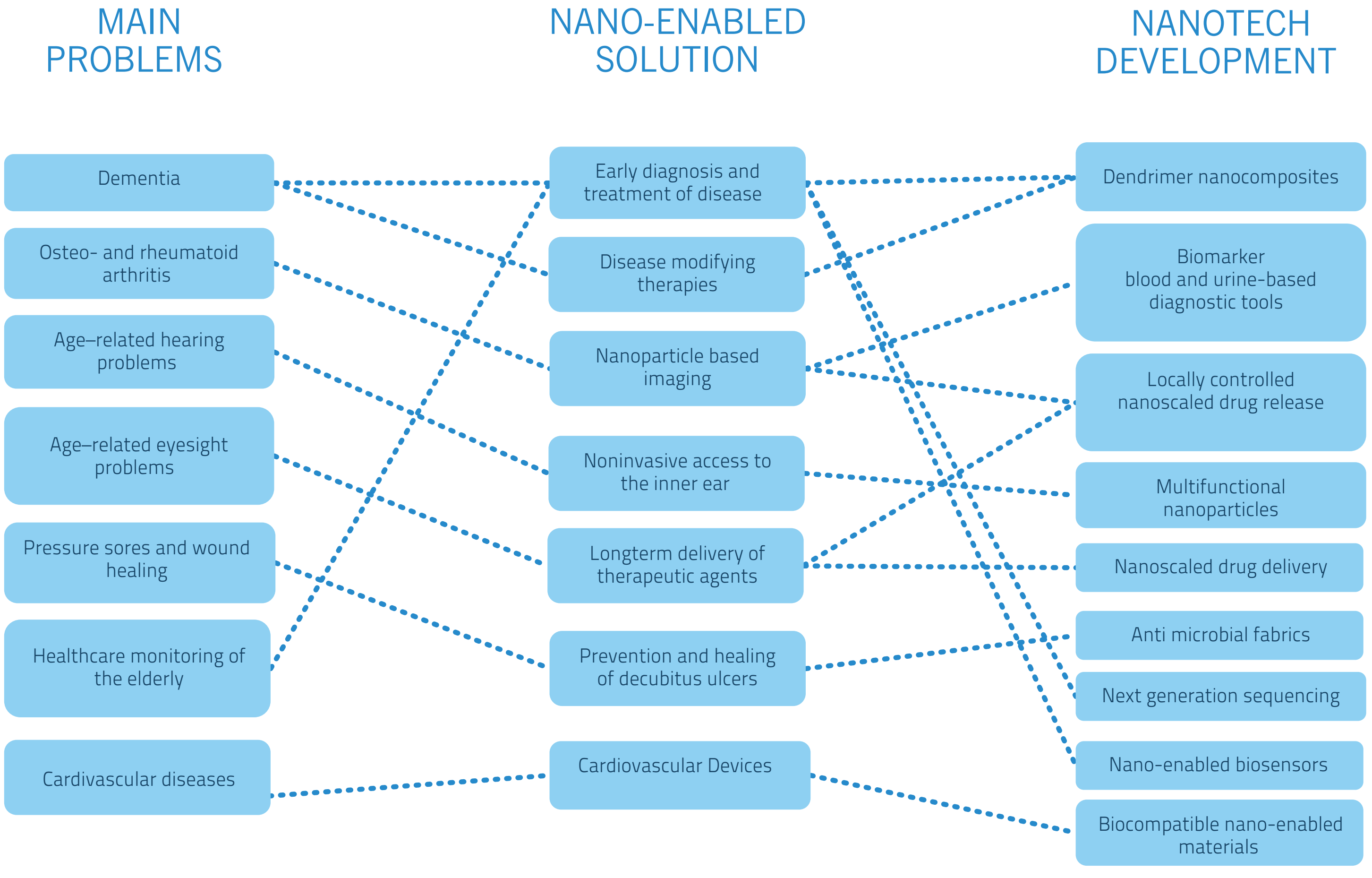


Figure 3: Matrix showing the problems to be addressed, the potential nano-enabled solutions, and relevant nanotechnology developments.

cardiovascular diseases than cancer[60].

Nanotechnologies as a whole cannot address these wide-ranging issues alone. However, they can potentially offer solutions in a number of aspects of the challenges being faced.

The nano-enabled solutions

Nanotechnologies are now being applied in a variety of ways to provide earlier and more accurate diagnosis, improved treatment and better support for some of the medical and care challenges posed by the ageing population. The global value of the nanobiotechnology market in 2010 was $19.3 billion increasing at a compound annual growth rate (CAGR) of 9 % resulting in a calculated forecast at around $29.7 billion in 2015. Major application fields include drug delivery and microbicides accounted for 98.96 % of sales in 2010. This market segment is forecasted to reach $29 billion by 2015 at a CAGR of 8.7 %[61].

Figure 3 summarises the challenges outlined in the previous section, which can be addressed with a number of nano-enabled solutions based on different nanotechnology developments. In the following paragraphs some examples of nano-enabled solutions to these challenges are described:

NANOTECHNOLOGY IN THE DIAGNOSIS AND TREATMENT OF DEMENTIAS

Several lines of evidence suggest that €amyloid (A€) plays a central role in the pathogenesis of Alzheimer's disease and soluble A€oligomers, rather than amyloid fibrils, are now thought to be the major toxic species responsible for disease onset and progression.

Measuring the levels of these oligomers in body fluids represents a possible means for early diagnosis of Alzheimer's disease and/or for monitoring disease progression. The oligomers and their formation process also present an interesting target for the development of novel disease-modifying therapies.

Nanoscale drug delivery may also have an important role to play in delivering therapeutic agents across the blood-brain barrier. This tight biological barrier protects the brain but provides a very effective barrier to many potentially useful neurological drugs. Specialist companies such as Pharmidex, in collaboration with biopharmaceutical multinational Genzyme, are now developing drug delivery systems based on nanostructures that can effectively cross this natural barrier to deliver drugs to the brain.

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[60] Palliative care for older people: better practices, Edited by S. Hall, K. Petkova, A. D. Tsouros, M. Costantini and I. J. Higginson 2011, www.euro.who.int/__data/assets/pdf_file/0017/143153/e95052.pdf

[61] BCC Research, Report: "Nanobiotechnology: Applications und Global market", 2011 http://www.bccresearch.com/report/nanobiotechnology-market-nan050a.html

NANOTECHNOLOGY IN THE DETECTION AND TREATMENT OF OSTEO- AND RHEUMATOID ARTHRITIS

As more and more people live into their 80s, 90s and beyond, maintenance of their mobility and quality of life becomes increasingly important to them. A new approach to establish new diagnostic methods for the easy and early detection of rheumatoid arthritis and osteoarthritis are the use of modified superparamagnetic nanoparticles. This could influence the decision as to which therapy could be the most successful. However, these approaches are in a very early experimental stage and need further investigation.

NANO-SOLUTIONS TO AGE-RELATED HEARING, INNER EAR AND BALANCE PROBLEMS

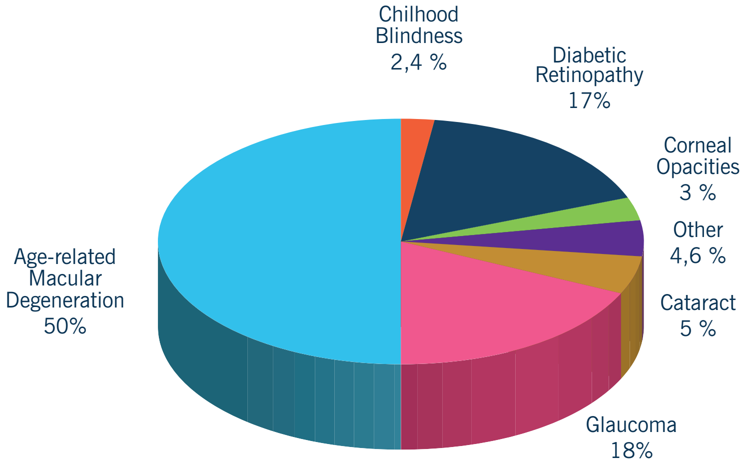


Figure 4: Main causes of blindness in Western countries

In addition to hearing loss, the vestibular part of inner ear also undergoes degenerative changes during ageing and produces a symptom known as presbyequilibrium that may provoke accidental falls or fear of falls. Medical prevention and treatment is limited by the fact that the inner ear is difficult to access as it is buried deep in the temporal bone and isolated from the general circulation by tight barriers.

Using multifunctional nanoparticles, that can be applied using non-invasive methods, that are targetable to selected cell populations, that are biodegradable, that are traceable in-vivo, and that are capable of delivering controlled-release drugs/proteins/growth factors/gene therapy, the inner ear can now be targeted in novel ways and the therapy of inner ear disorders may become possible, including the development of sensory neuroprostheses through tissue engineering strategies.

NANO-SOLUTIONS TO AGE–RELATED EYESIGHT PROBLEMS

Current treatments for age-related macular degeneration are very expensive (around $800 for a single injection intravitreally) and painful for the patient.

Figure 4 shows the main causes of blindness in Western countries. Novel nanotechnology-based approaches may offer new treatments for eye diseases such as macular degeneration. Macular or intraocular implants containing microspheres or nanoscale drug-delivery systems may facilitate long-term delivery of medication within the eye or through periocular or trans-scleral routes. Specially adapted micro needles also offer a further option for pain-free delivery of therapeutic agents. Furthermore, nanotechnology is also currently facilitating the development of novel classes of devices such as retinal implants that may offer longer-term treatments for diseases such as macular degeneration and retinitis pigmentosa. Nanotechnology can also contribute to improve surgical instruments. Nanodiamond based scalpels enhance the surgical control in cataract operations and hence its quality (Figure 5).

NANO-FUNCTIONALISED TEXTILES FOR THE TREATMENT OF PRESSURE SORES AND FOR WOUND HEALING

Because of the increase in the ageing population, it is likely that the problem will grow and that new approaches to prevention and treatment will be needed, particularly with regard to reducing the incidence of, and costs associated with treatment of, the painful, long-term and hard-to-heal ulcers that can occur. A range of different circumstances may lead to the development of decubitus ulcers, such as constant pressure at certain areas of the human body due to immobility, sensitiveness of the skin in these areas, friction, humidity and the susceptibility of the skin towards infection. Other regenerative technologies are also being developed including tissue-engineering techniques for example.

REMOTE BIOSENSING AND HEALTHCARE MONITORING OF THE ELDERLY

Examples include quantum tunnelling composites in pressure sensitive switches incorporated into floor coverings or “smart shoes”, wearable biosensors for physiological monitoring (such as for blood glucose or other metabolic functions), wearable biosensors incorporated into fabrics, using conducting polymers, to sense or monitor movement, breathing, heart function, and blood glucose amongst others. Combined with other networked sensors, for example to monitor utilities usage such as electricity or movement within a building or devices and alarms that an elderly person can interact with, these can provide a very powerful and flexible monitoring system that allows healthcare and social care agencies to provide support and assistance in an efficient and as-needed way. This allows for cost reduction whilst helping to maintain the independence of the elderly person themselves.

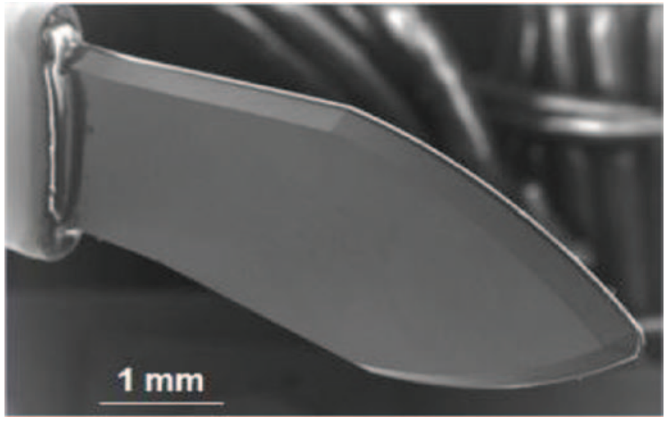


Figure 5: Nanodiamond Scalpel for Cataract Operations ©GFD mbH, Germany

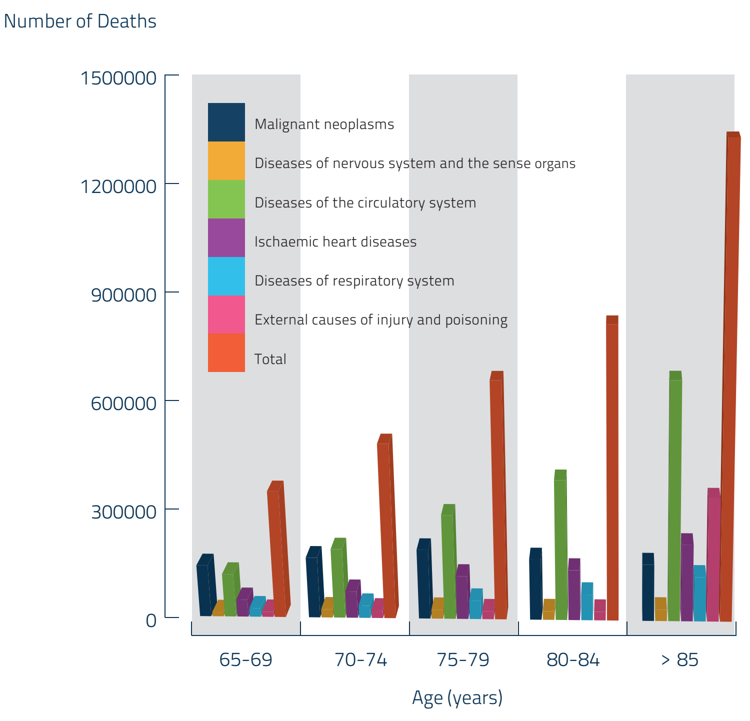


Figure 6: Number of deaths by causes and age group in 27 EU countries

NANO-ENABLED IMPLANTABLE MEDICAL DEVICES FOR ELDERLY PEOPLE

According to **Figure 6**, the ageing population progressively depends on cardiovascular devices. The demand of pacemakers has increased drastically since their introduction because the patients' age has been declining as a consequence of the change in lifestyle over recent decades. Meanwhile these devices are intelligent enough that they can be used preventively by transmitting an impulse in case of heart failure. It is an effective strategy to reduce the heart attack rate. Nowadays the insertion of a pacemaker is a routine procedure, which in general takes about half an hour. Thereby the pacemaker is placed into a pocket near the chest and the electrodes are connected to the heart. The functionality of implantable devices in general will not only depend on the power supply alone and tight integration, but also on the biocompatibility and durability of the materials directly interacting with the organs. Materials composed of ceramic nanoribbons can generate electricity and can convert mechanical energy to electrical energy. When this kind of material is placed against the lungs it can be used to take breathing motions to power pacemakers, which does not require the need for surgical replacements of the batteries which power the device. However, this is currently not state of the art.

Primary Data [75]

The European Commission is funding several projects for the detection and treatment of the above-mentioned diseases using nanotechnologies which are exemplary listed in the following:

- **Treatment of dementia** – The European FP7 Project NAD (Nanoparticles for Therapy and Diagnosis of Alzheimer Disease) is currently engaged with an international consortium of 19 partners on evaluating dendrimer nano-composites for imaging and therapy, nanoliposomes for therapeutic agent delivery and other functionalized nanoparticles for applications in Alzheimer's disease.

- **Osteo- and rheumatoid arthritis** – The European FP7 Project NanoDiaRA (Nanotechnology Based Diagnostic Systems for Rheumatoid Arthritis and Osteoarthritis), comprising 15 partners, is currently engaged in research into developing nanoparticle-based imaging and blood and urine-based diagnostic tools, and biomarkers, for the early detection of both conditions. The research may also offer insights into the development of tissue-targeted approach for locally controlled nanoscale drug release (e.g. in joints alone or intra-articular delivery).

- **Age–related hearing problems** – The purpose of the European FP6 NANOEAR consortium is the development of novel multifunctional nanoparticles (MFNPs). These can be used with selected cell populations, biodegradable, traceable in-vivo, and equipped with controlled drug release. Over 44 million EU citizens with hearing loss and 40000 profoundly deaf could immediately benefit from a MFNP-based drug coated cochlear implant and novel drug carrier system.

- **Treatment of pressure sores and wound healing** – A range of different circumstances may lead to the development of decubitus ulcers. A European Integrated Project entitled Lidwine, involving 18 partners and which concluded in August 2010, has investigated these causative factors with a view to developing novel solutions, including the application of nanotechnology, to develop new products aimed at both preventing and healing decubitus ulcers. One example is the use of polymeric brush coatings which form a nanogel layer to reduce friction by up to 30-40 % between a textile and the patient's skin. Other approaches from the project include the use of sonochemically-coated antimicrobial fabrics incorporating 10-15 nm metal oxide nanoparticles, e.g. ZnO, CuO, MgO, TiO2, novel hybrid silver-silica nanoparticles grafted with a covalent bond tocellulosic textiles, and biosensors for the fast detection of wound infection.

- **Medical Implantable devices** – In the first period after the invention of the pacemaker the number of international applications rose very slowly. Since the 1990s, particularly 1996, when the dual chamber pacemaker entered the market the number of patents enormously increased (Figure 7). The ability of home-monitoring once more leads to an increase in patent numbers.

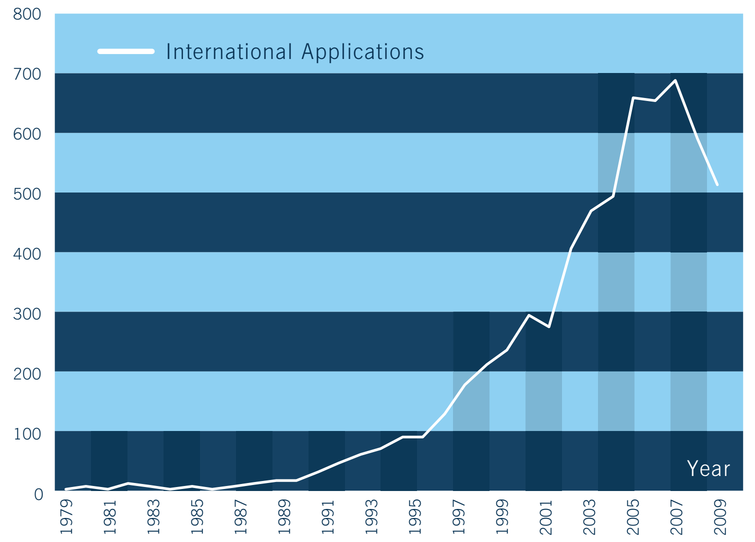


Figure 7: International patent applications for cardiovascular devices VII

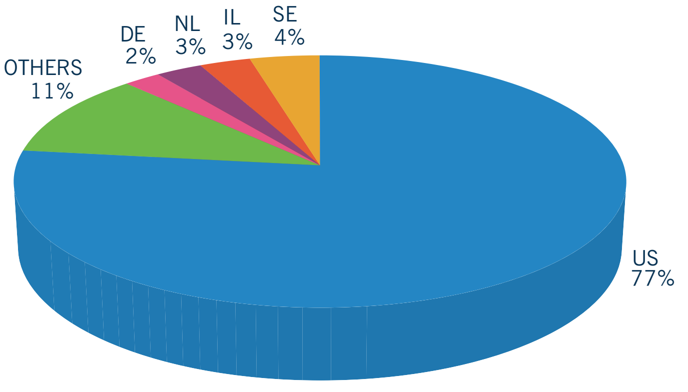


Figure 8: International patent applications for cardiovascular devices in general [61]

Looking at the country distribution of the international applications it can be clearly seen, that the USA are well-positioned. The USA is worldwide leading with nearly 77 % of the international patent applications (see **Figure 8**)[62].

The key players in the global market for pacemakers are Medtronic, producing round about 50% of the total implanted pacemakers around the worldwide followed by St. Jude Medical, Boston Scientific and Biotronik[63]. Medtronic controls more than 250 manufacturing facilities, sales organisations, research and education centres and administration facilities in 120 countries[64].

[62] WIPO, World Intellectual Property Organization, PATENTSCOPE® and NMTC, November, 2010

[63] Diagnostics 2009 – Moving towards personalized medicine, PricewaterhouseCooper(2009)

[64] Medtronic – www.medtronic.de /uber-medtronic/index.htm

Obstacles

PUBLIC ENGAGEMENT

The availability of personal genomic information raises a number of ethical issues. Some parties, such as employers and insurers, may be interested in their employees/clients health status as influenced by their genetic background. This may cause discrimination of the individuals concerned because of certain characteristics of their genome or certain variations within it.

Nanomedicine is a key area of nanotechnology, with a lot of research activity as well as debates about ethical and societal aspects. At least in Europe, three sub domains are the priorities for public and private investment; nanopharmaceuticals, diagnostics and regenerative medicine. Neuronanoscience may in the future become a fourth research priority in Europe. The stakeholder debate focuses mainly on socio-economic issues such as how to improve Europe's competitiveness in nanomedicine or nanobiotechnology in general and on how to make available balanced information for medical professionals and patients. The Nanomed Roundtable made the following recommendations to the European Commission and national governments. The deliberation of ethical and societal issues should be complemented with consideration of the feasibility of particular nanomedicine developments. This should be done by assessment of the visions driving nanotechnological developments as well as analyses of relevant cultural, societal and commercial trends. Current issues discussed in ethical and social science literature which should be discussed in broader forums include autonomy and privacy issues related to personalised medicine and access to nanomedicine for deprived populations. In general, there are six areas of relevant ethical issues, including risk assessment in medical research, diagnosis and therapy, questions of personal and human identity, enhancement by possible nanotechnological implants, distribution of risks and potential benefits, which groups are included in clinical trials, and the potential need for rethinking the traditional model of the patient-physician relationship. Philosophers see the need to engage with embedded notions of health, disease, molecular medicine etc and with the normativity of these concepts[65].

POLICY, LEGISLATION, REGULATIONS AND STANDARDS

The ethical concerns call for a clear legal framework regarding access to sequence data; however, even the best and most comprehensive laws will not completely eliminate the possible dual use of data. For implantable devices strict EMC-standards (electromagnetic compatibility) need to be obeyed. Some of the expected impacts may also have knock€ on effects and consequences that are, as yet, not quantified including the unclear boundary with future genomic therapies.

[65] http://www.observatorynano.eu/project/catalogue/4NB/

ENVIRONMENT HEALTH AND SAFETY (EHS)

Almost 30% of the respondents indicated that EHS has moderate or high impact on commercial success. This seems relatively low, for a product category where many of the applications present a high exposure potential for patients. Especially when nanomaterials are used in an unbound state, they potentially spread through the body. The percentage may be influenced by the types of respondents; when a relatively high number of them develop products from which the exposure potential to nanomaterials is low; this could explain the low perceived impact of EHS. Another factor which probably has great influence on this, is the fact that manufacturers of medical products are used to dealing with many different types of risks. Risks related to nanotechnology aspects are often just another set of risks to them, albeit with more uncertainties than for some other types of risks. All medical products are extensively tested and evaluated for the balance between risks and benefits. The additional EHS concerns related to nanotechnology may then not be perceived of having a high impact.

Case 1: Nano-based implantable medical devices

The Problem

Cardiovascular diseases are the primary cause for death in Europe accounting for around 50% of the deaths. For that reason, more than 4.35 million people die each year in the 52 member states of the European region of the World Health Organization and over 1.9 million in the member states of the European Union. The risk of heart attacks and stroke rises by about 50%, if an individual's weight exceeds the norm by 20% or more[66].

[66] Hexal Herzkreislauf – Risikofaktoren:http://www.herz.hexal.de/risikofaktoren/uebergewicht/

Nano enabled Solution

Nanotechnologies offer enhancements that can be utilised in medical and implantable devices to offer superior functionality whilst reducing the size of the device and ensuring biocompability Examples include active devices such as cochlea and retina implants as well as pacemakers. These implants are as efficient and natural as organs themselves leading to a large reduction in rejection rates.

The Impact

The increase in the number of cardiovascular diseases especially in younger days pushes the market for cardiovascular devices, in which the pacemaker devices constitute a considerable proportion. Nanotechnologies can assist in miniaturising the devices whilst increasing the biocompatibility and reducing cost.

Market opportunities and European activity

The global market for pacemakers is expected to reach $6.1 billion by 2015, predicting an annual growth rate of 5.4% estimates the market research company GlobalData[67].

[67] Market Research, "Pacemakers Pipeline, Technology and Market Forecasts to 2015", July 2009

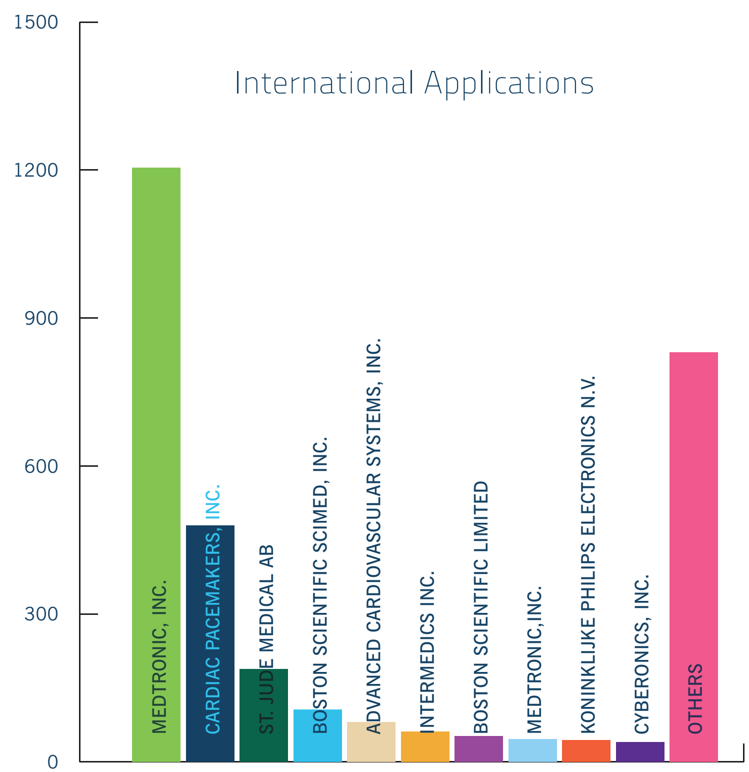


Figure 9: International patent applications for cardiovascular devices

The rise of cardiovascular diseases pushes the market not only in Europe and the USA but also in Asia[68] .

As shown in Figure 11, the key players in this market are Medtronic producing round about 50% of the total implanted pacemakers around the world followed by St. Jude Medical, Boston Scientific and Biotronik[60] (see **Figure 9**). Medtronic controls more than 250 manufacturing facilities, sales organizations, research and education centres and administration facilities in 120 countries[62].

Challenges

With an ageing population the need for optimal medical devices is increased. At the same time several challenges need to be overcome to improve the quality of life associated with the increased demand for implantable medical devices. Nanotechnology can help to increase the number of possible solutions for healthier ageing.

[68] Asian Hospital and Healthcare Management, "Medical Device Market", J. Lau, Industry Analyst Frost & Sullivan: http://www.asianhhm.com/equipment_devices/medical_device_market.htm

Case 2: Detection and Treatment of Alzheimer's Disease

The problem

Degenerative diseases such as Alzheimer's and other dementias are estimated to be more costly, over a longer period of time, to healthcare systems than cancers and strokes combined since dementia is one of the most common diseases amongst the elderly. The percentage of over 65s in the EU is expected to rise from 15.4 % to 22.4 % by 2025 in correlation with the spreading of the Alzheimer's disease[69]. The German Robert Koch Institute reports that the annual treatment cost per person add up to €43000, which demonstrates the need for preventive and more effective treatment[70].

[69] http://ec.europa.eu/research/star/index_en.cfm?p=18

[70] http://www.helmholtz-muenchen.de/fileadmin/FLUGS/PDF/Themen/Krankheitsbilder/Alzheimer.pdf

The nano-enabled solution

Figure 10[71] shows an overview of the treatment methods for Alzheimer's disease and the associated nanotechnological developments.

The impact

Early detection of Alzheimer's disease is crucial since neurodegenerative process caused by dementia start before the diseases symptoms become apparent. Detection at an early stage can slow down the degenerative process and nanotechnologies seem to be crucial for neurological therapy with a potent drug since they can enable the penetration of the blood brain barrier and directed drug delivery.

Market opportunities and European activity

The World Alzheimer Report stated that dementia costs would amount to more than 1% of the world's gross domestic product in 2010 at $604 billion[72]. To put this massive sum into context, if dementia

[71] Nazem, A., Mansoori, A., Nanotechnology Solutions for Alzheimer's Disease: Advances in Research Tools, Diagnostic Methods and Therapeutic Agents, Journal of Alzheimer's Disease 13 (2008) 199-223

[72] http://todaynewsline.com/world-alzheimer-report-2010-1-of-global-gdp-at-us604-billion/224138/

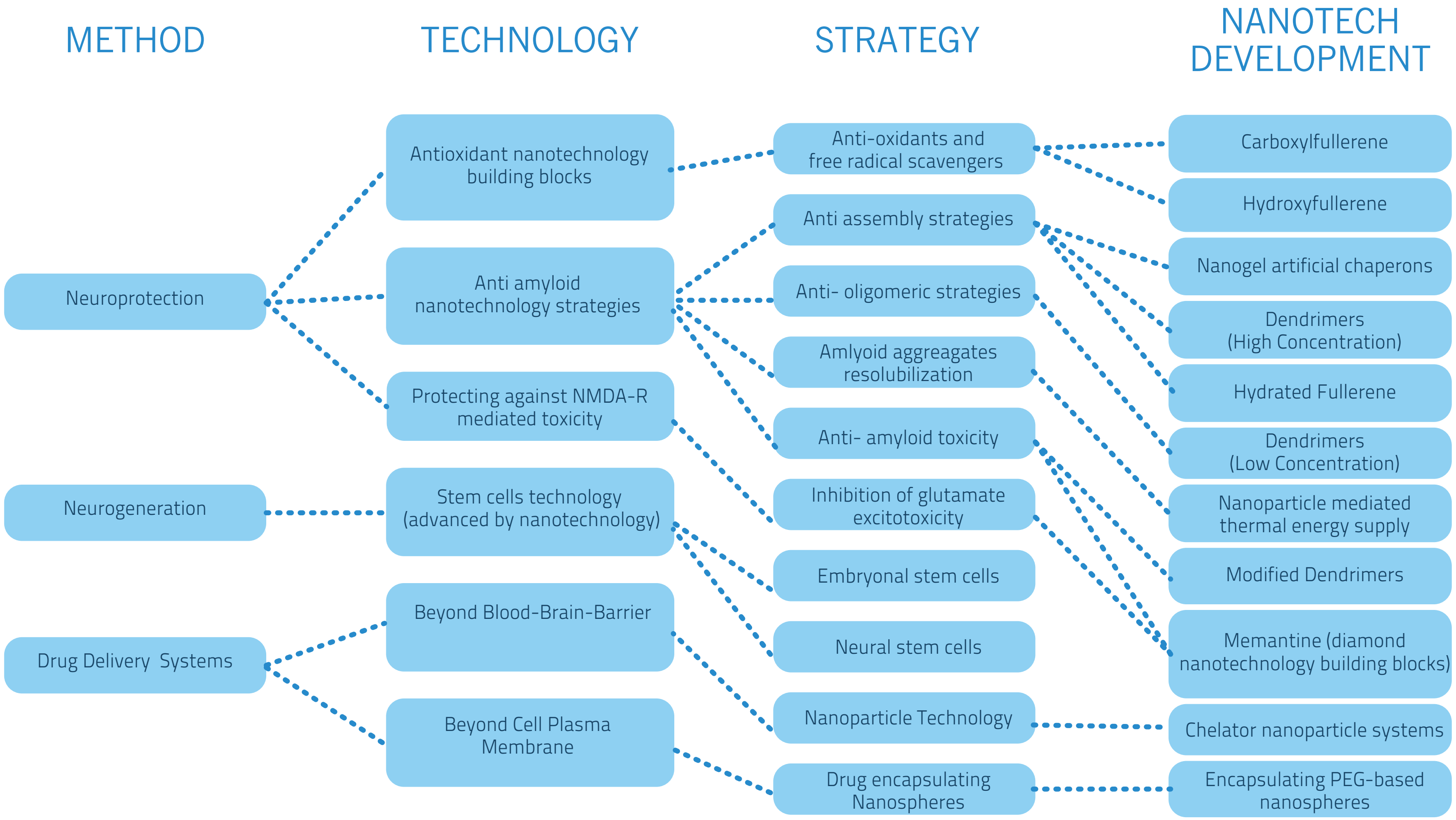


Figure 10: Summary of nanotechnology applications in the treatment of Alzheimer's disease [70]

were a country it would be the world's 18th largest economy. In some European countries, the incidence of dementias is expected to double over the next 40 years.

Challenges

Effective drugs and methods for central nervous system regeneration are the key to making Alzheimer's disease a curable disease. The non-toxicity of nanobased substances has to be verified. Another aspect as for all medical issues is the patient's data privacy, the potential misuse of data being one major risk factor for the population.

Summary

A declining birth rate and increasing longevity are expected to lead to a higher percentage of people over 65 in the EU by 70% by 2050. Those over 80 years are expected to increase by 170% leading to an increasing demand on healthcare provision partnered with a decrease in the working population. This could lead to a requirement for health-care spending to increase by 1 to 2% of GDP by 2050 amounting for about 25% increase in healthcare spending as a share of GDP. The main challenge is to support healthy ageing throughout life. Nanotechnologies can assist to prevent health problems and disabilities from an early age by enabling prediagnosis. Enhanced healthcare services and prevention of chronic diseases could reduce the pressure on the health care system and furthermore novel nano-enabled technologies could potentially contribute to future sustainability by inducing improvements in several sectors such as genetic technologies, medical technologies and information and communication technologies.

The expected demographic change requires the EU to balance the equity and cost efficiency especially the cost benefit regarding the emerging medicine and preventative measures. The EU will also need to deal with prevention and rehabilitation and figure out new concepts for the labour market and pensions. The development of healthy home concepts is an important issue also.

Improved Resource Efficiency

Introduction

Both the rapidly increasing world population and the emerging economic prosperity of numerous formerly underdeveloped countries have caused a growing demand for raw materials, energy resources, rare high-tech commodities and natural resources such as drinking water and agricultural goods. To continue to supply these increasing demands with limited resources efficient resource consumption is one of the grand challenges of our time. Nanomaterials as well as nano-chemistry and procedures of nano-analytical process controls may deliver valuable contributions.

The challenges to be addressed by the nano developments

Chemistry as well as nanomaterials both have a cross sectoral applicability and are of fundamental importance for numerous applications in nanotechnology ranging from electronics and ICT via energy and environment up to health, engineering and security related subjects to mention just a few. A selection of relevant issues is listed as follows:

- **Fossil fuel consumption** – A reduced consumption of fossil fuels and, thus, the emission of CO2 and other exhausts is mostly related to weight reduction. That holds true for transport and mobility applications; however, this is also true for all applications with moving components involved such as in engineering for example. Hence, lightweight construction is one of the major goals to meet the needs of upcoming resource shortages.
- **Multi-functionality** – Multi-functional materials simultaneously expressing more than one outstanding materials property, may open up novel and more efficient applications. A number of new materials, for example, do not only show considerable strengths but are also conductive. Electrical conductivity, moreover, is also a prerequisite of “smart materials”, being equipped with electronic logic such as sensors, antennae amongst others.
- **Resource efficient displays** – Modern flat panel displays and touch screens continue to experience an increasing consumer

demand. However, they depend on rare high-tech materials such as indium. The search for alternatives is becoming increasingly critical, particularly for the European highly developed industrial societies with no appropriate resources on their own territories[73].

- **Energy storage** – The demand for efficient energy storage will continue to increase dramatically both on large and small scale. The fast growing and widespread use of powerful handheld electronics has shown up the limits of mobile, battery based power supply. On the large-scale renewable energies will further increase and their low baseload capacity will enhance the demand for appropriate large-scale storage technologies.

- **Chemical reactions and processes**, particularly on an industrial scale are a backbone for a vast amount of consumer and industry products, components and other applications. Efficient catalysts, for example, are of key importance; they are not only accelerators but quite frequently even enablers of large scale chemical process engineering.

- **Water and air contamination** represent increasing threats to many people. They frequently follow societal and economic prosperity, particularly in emerging countries. Efficient purification techniques, thus, play an increasingly important role. For example, they cover filter technologies as well as techniques based on chemical decomposition.

- **Failure analysis and process control** – Efficient processes require similarly efficient analytical techniques for process control. Both appropriate quality control and failure analysis play a major role and are an increasingly important prerequisite for numerous processes and products.

Nanotechnology may open up totally new approaches or improvements in a variety of chemical and materials related applications. It is often appropriate to achieve higher efficiencies with respect to resource consumption. As this wide area is hardly to be presented in detail within the scope of this overview, the following representation will focus on a selection of promising applications.

[73] European Commission; COM(2011) 25; Communication "Tackling the challenge in commodity markets and on raw materials"

IMPROVED RESOURCE EFFICIENCY

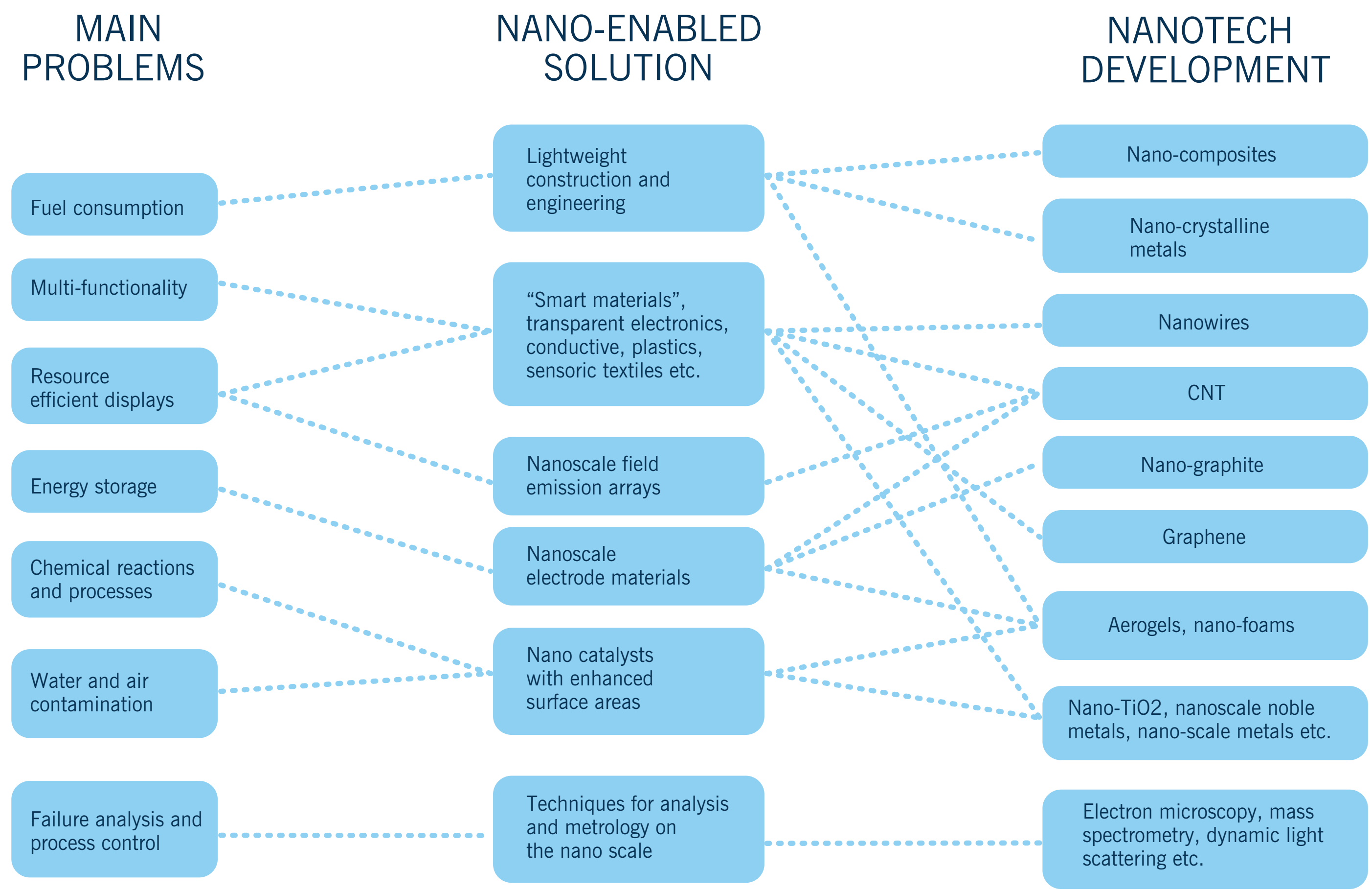


Figure 1: Matrix showing the problems to be addressed, the potential nano-enabled solutions, and relevant nanotechnology developments.

The nano-enabled solutions

The following section addresses a selection of nano-enabled solutions to the challenges listed above.

FOSSIL FUEL CONSUMPTION

Within modern engineering lightweight construction is one of the main means to achieve a more efficient utilisation of fossil fuels. This item is mainly addressed by novel composite materials where nanomaterials may have a considerable contribution. Whereas the utilisation of graphene as the filler additive to polymeric material matrices is rather new, CNT-based composites have meanwhile found their way to first markets. The bulk composite material is characterised by an outstanding mechanical strength at low weight, already comparable to carbon fibre reinforced composites (CFC). Other approaches make use of nano-crystalline metals or nano-metal matrix composites (nano-MMC)[74].

MULTI-FUNCTIONALITY AND "SMART MATERIALS"

Nano-enabled materials offer new possibilities in combining multiple properties such as mechanical strength and chemical, thermal and electrical properties. Numerous components utilised, for example in automotive and aerospace, require a good conductivity to avoid electrostatic charging. Fuel lines in vehicle engines or plastic body components of cars or aircrafts may serve as examples. Both conductivity and mechanical strength may be optimised by the utilisation of composites containing CNTs, graphenes or nanoscale graphite. Compared to conventional fillers they require much lower amounts of additives to achieve the desired properties. Incorporated CNT-based meshes for active heating or material integrated are further applications that are currently being tested on a prototype level.

RESOURCE EFFICIENT DISPLAYS

Most modern flat panel displays and touch screens rely on the utilization of scarce resources such as indium or indium-tin-oxide (ITO) respectively. Recent developments towards flexible and transparent electronics on the basis of CNT thin films are promising in view of a future substitution of ITO, and even graphene is investigated for that purpose.

CNT-based field emission displays on the other hand have been an approach to minimise energy consumption in the flat screen sector. They are characterised by excellent image quality and colour brilliance at low power consumption and, thus, have been assessed as promising for a considerable time. However, they suffer from a strong commercial competition to the well-established LCD technology as well as to novel organic displays (OLED). Besides, the

[74] ObservatoryNANO; General Sector Report, Chemistry & Materials, 2008; (http://www.observatorynano.eu/project/catalogue/2/)

display sector is of only minor relevance for Europe.

ENERGY STORAGE

Nanomaterials are of considerable importance for efficient energy storage. Nano-scale carbon as novel electrode materials meanwhile plays a crucial role in emerging battery and fuel cell technologies. Electrode coatings based on CNT, nano-graphite of carbon foams and aerogels allow for improved storage properties. First commercial applications have been established.

The storage of hydrogen, however, remains more challenging. First promising approaches of hydrogen deposition in CNT-powder could not be confirmed. Further approaches make use of metal-organic-frameworks (MOF), micro- to nano porous crystalline materials.

CHEMICAL REACTIONS

Nano-enabled catalysis is based on nanoscale particles. Chemically these materials are widely identical to conventional bulk catalysts. However, the key criterion is the particles size. The tremendous surface-to-volume ratio of these particles is mainly responsible for the increasing efficiency of nano-catalysts in comparison to macroscopic materials. Metal nanoparticles, for example from gold, platinum or silver, are among the most prominent nano-catalysts. However, nanoscale catalysts may also be manufactured as a combination of substrate materials, such as from carbon and metal catalysts. Nano-catalysts may also be utilised for large-scale chemical production processes.

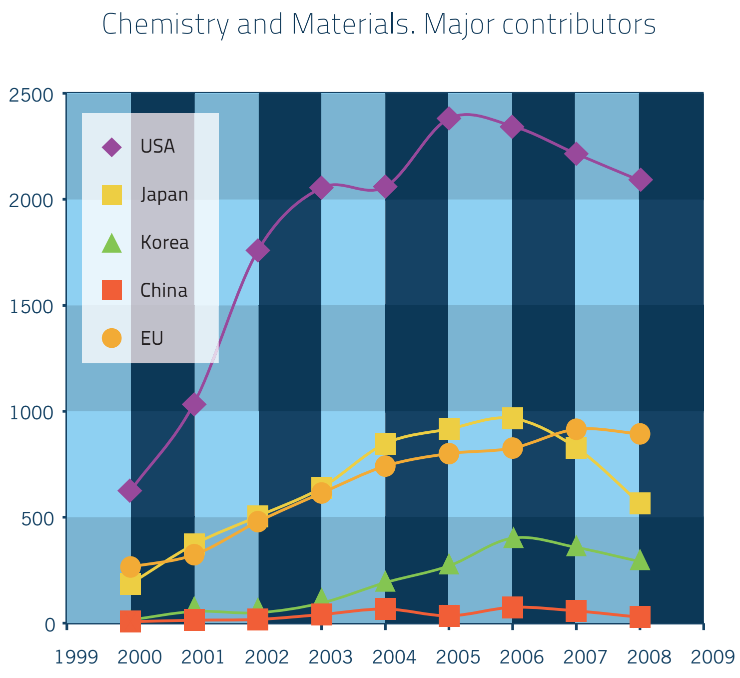
WATER AND AIR CONTAMINATION

Another application of nano-catalysts is the decomposition of organic materials such as pollutants, toxins and microbes. The most prominent catalyst for the latter application; such as purification, detoxification, sterilisation etc.; is TiO_2 which is a photo-catalyst. The catalytic effect is triggered by external illumination with light and the process has been well known for a long time. However, decreasing its dimension to the nano scale has resulted in largely increased efficiencies. Most prominent application examples are “self cleaning surfaces”. However, even air and water purification purposes, as well as destruction of warfare agents and hydrogen production, are widely addressed[75].

[75] ObservatoryNANO Briefing No.2: “Photocatalysis for Water Treatment” and ObservatoryNANO Briefing No.10: “Applications of Photocatalysis”

NANO-ANALYTICS FOR PROCESS CONTROL

The physical dimensions of nanostructures are far below the diffraction limit of visible light, thus preventing nanoparticles from being directly imaged by optical microscopy. Instead, utilisation of X-ray and electron based methods are widely required. Appropriate techniques are established in R&D, and even visualisations down to the single atom level have been realized. With an increasingly widespread application of nano scale structures and materials, appropriate analytical tools for process control are gaining importance. This holds true for both developments in the lab scale and industrial volume production[76].



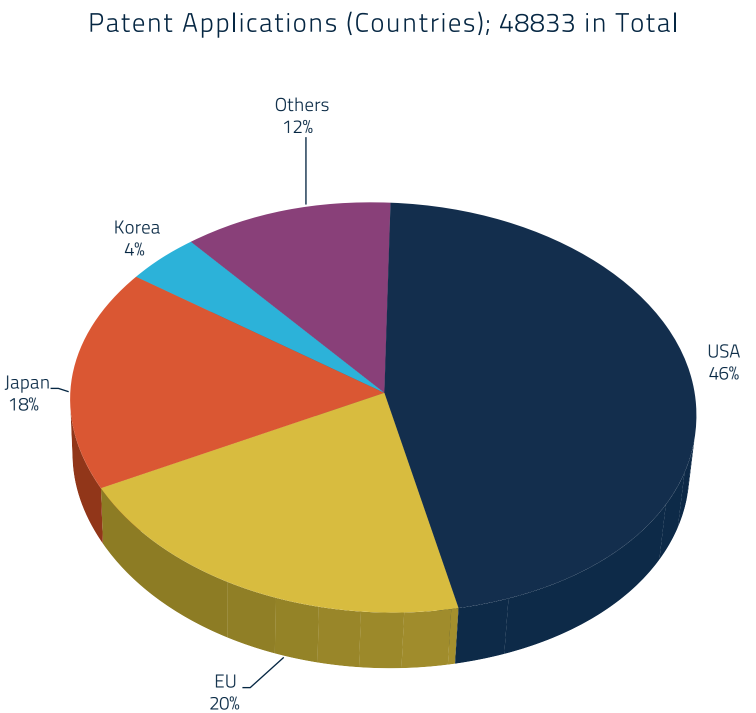


Figure 2: Development of nano-related patent applications in the chemistry and materials sector and comparison of the major contributing countries with the EU since 1972

[76] ObservatoryNANO Briefing No.14: "From Microscope to Nanoscope"

Primary Data Summary[77]

Statistical patent analyses are valuable indicators for innovation in certain areas. Nano-related aspects of resource efficiency may be displayed by an examination of chemistry and material innovations. One may realise a strong increase in the number of patent applications over the first years of the past decade followed by a phase of “saturation”. **Figure 2** indicates a clear leadership of the United States contributing with nearly half of the total amount of applications, followed by the European Union as a whole with about 20%.

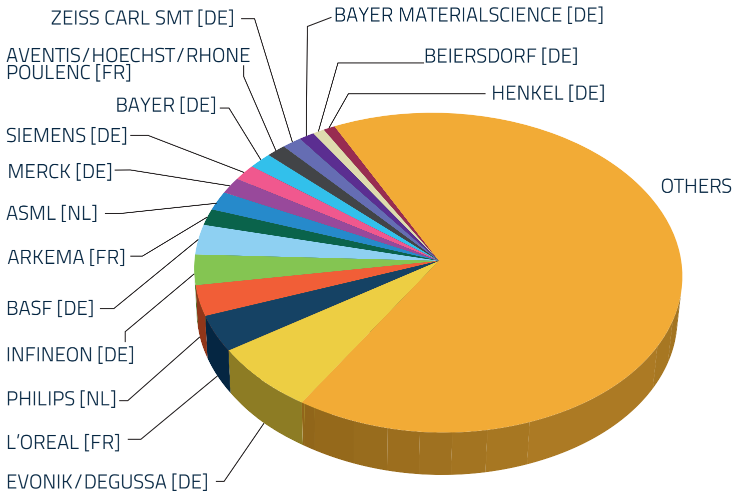


Figure 3: Nano-related patent applications of European companies with respect to chemistry, surface technologies and materials between 2000 and 2010

[77] European Patent Office worldwide statistical database

A more detailed view to patent applications of European companies within the period of 2000 to June 2010 reveals about 800 companies appearing as applicants, and being involved in more than 4600 patent applications in the sector. The 15 largest contributors are displayed in **Figure 3**.

Obstacles

Resource efficiency and its improvement are challenges which will gain considerable importance particularly for Europe. They are of relevance for our society as a whole and thus closely related to mass markets and mass commercialization. Nanotechnologies have the potential to provide valuable contributions to achieve this goal. However, numerous problems are still unsolved and remain an issue.

TECHNOLOGICAL BARRIERS

Numerous issues of improved resource efficiency may be addressed by nanomaterials or methods of nano-chemistry. However, all these scientific fields are far from being mature and still continue to develop. Applications and products have mostly only recently started to diffuse into commercial markets, whereas a multitude of nanotechnological methods still remain in different stages of pre-market research. Technological challenges are at least as manifold as the number of novel research approaches, and therefore, the barriers remain considerable. One of the largest challenges is the upscaling of production processes in combination with appropriate and reliable process control.

ECONOMIC BARRIERS

On the economic side, there are a number of uncertainty factors: one issue is the competitive situation with respect to other either established or emerging technologies. Some examples such as CNT-composites vs. carbon fibre materials or from the display sector have been mentioned above. In the end, it will mainly depend on aspects of global value generation, which technology will finally be successful. However, survey respondents do not overestimate the economic barriers and, thus, assess nano-enabled chemistry-, materials- and analytics as promising.

PUBLIC PERCEPTION / SOCIETAL BARRIERS

Large-scale nano-technological contributions will always depend on a wide societal acceptance, particularly in pluralistic societies. Negative examples of public acceptance may be seen in the public perception of genetically modified food or genetic engineering in general. Thus, aspects of risks for safety, health and environment (see below) are crucial for a wider acceptance of nano-enabled approaches to. Appropriate discussions and early stage public relations based on proper rational facts as well as a comparison of risk and benefit are of considerable importance and a prerequisite for public acceptance.

Public acceptance depends on the trust distinct societal groups have in the promise of nano-enabled solutions. Critical stakeholder groups have already questioned the feasibility of the promise of improved resource efficiency by (nano)technological means. Even if products use less energy and raw materials, this may result in rebound effects of increased total consumption. Moreover, resource use in the whole life cycle has to be taken into account. NGO's like Friends of the Earth[78] have pointed out that the production of nanomaterials may use more energy and raw materials than the production of alternative materials. And what happens to nano-enabled products in waste processing? Will they be fully recyclable or create new waste processing problems?

And how fair will the distribution of benefits and costs due to nano-enabled products be? Social scientists and NGO's[79] have warned that nanomanufacturing may make existing industry obsolete, causing unemployment. They also worry about the socio-economic impact on developing countries which are strongly dependent on commodities markets. Public acceptance crucially depends

[78] "Nanotechnology, climate and energy: over-heated promises and hot air?" Friends of the Earth Australia, England Wales and Northern Ireland, Europe and USA, 2010, http://www.foe.org/nano-climate; EEB, "Challenges and opportunities to green nanotechnologies," Nanotechnologies in the 21st century, issue 1, 2009, http://www.eeb.org/index.cfm/activities/industry-health/nanotechnology/

[79] ReLANS, http://www.estudiosdeldesarrollo.net/~webrelans/inicio.html, Meridian Institute, http://sites.merid.org/nano/?item=%2fnano&user=extranet%5cAnonymous&site=website, ETC group, http://www.etcgroup.org/

on the honesty of the claims of nanotechnology benefits and on convincingly answering critical questions.

Trust in the actors promoting nano-enabled solutions (in particular industry) will depend on adequate and timely responses to calls for transparency (labelling nano-products, registration, sharing information about materials properties and risk assessment) and precaution (worker and consumer safety, environmental impacts and life cycle assessment)[80].

ENVIRONMENT, HEALTH AND SAFETY RISK

EHS aspects are mainly correlated with a large-scale production of nano-scale materials. Aspects of biocompatibility, ecotoxicity and health hazards are of fundamental relevance and have been addressed in numerous research activities during the past decade. The risk results from both toxicity and exposure probability. The situation of ensuring safe processes and handling, thus, varies depending on the specific application.

CNT are one of the nanomaterials about which significant concerns have been raised. Large work programmes are underway to address the issues relating to these materials. As with other nanomaterials, effective control of exposure during production and use is required.

LEGISLATION, REGULATIONS AND STANDARDS

Nanomaterials may expose humans and the environment to new risks. Legislation has to ensure both utilisation of the benefits from novel applications and protection from health, safety and environmental risks. According to an EU communication, legislation can be grouped under chemicals, worker protection, products and environmental protection[81]. In order to properly develop, modify or implement legislation, the scientific knowledge base needs to be improved. A lack of reliable legislation and specific regulations and standards may on a long run represent a significant barrier to commercialisation. However, these policy aspects are obviously not yet fully realised in the business world.

[80] Malsch, Ineke & Hvidtfelt-Nielsen, Kristian, "Individual and Collective Responsibility for Nanotechnology; First Annual Report on Ethical and Social Aspects of Nanotechnology," ObservatoryNano project, online publication, 2009, http://www.observatorynano.eu/project/catalogue/4RC/

[81] "REGULATORY ASPECTS OF NANOMATERIALS"; Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee; [SEC(2008) 2036]

Case 1: CNT-based composite materials

The problem

Numerous developments in modern industrial societies have resulted in increasingly heavy products. Appropriate examples may easily be found in the area of mobility with cars, trucks, trains and even aircraft having gained considerable weight while their absolute numbers have continued to increase. The resulting steady increase in energy consumption raises the need for countermeasures based on an enhanced utilisation of lightweight materials. However, lightweight materials are becoming quite relevant beyond the transport sector as well.

Nano-enabled solution

Carbon nanotubes (CNT) have extraordinary mechanical strength. Huge research efforts have been spent to transfer this strength to bulk materials through the development of composite materials of polymeric resin or even metal alloys and CNT-based fillers. The goal is to achieve an equally dispersed distribution of CNT over the whole bulk material with the nanotubes being firmly embedded. Even low CNT admixtures may remarkably improve the composites´ performance. Potentials may be seen for lightweight materials with improved conductive, tribological and mechanical properties. Metal components, which are currently used because of their conductivity, can be substituted in the future by significantly lighter composites. Other metallic materials with CNT additives are being investigated with respect to improved mechanical strength at simultaneously lower specific weight. Relevance for CNT-reinforced metals is moreover given for high temperature utilisation with respect to their improved heat and creep resistance. In addition, processes of conductivity modification of plastic surfaces may be simplified considerably by CNT resulting in reduced process expenditure.

The impact

Progress in composite fabrication and the increasing industrial volume production of CNT has succeeded in the market entry of stable, lightweight composites for some time. The CNT production has been continuously enhanced and is nearly completely consumed in composite production. However, up to now mainly niche markets are served. Predominantly lifestyle sectors such as sports equipment (tennis and hockey rackets, skis, bicycle frames etc.) have been addressed with some success. The majority of CNT composites is, however, currently addressing electromagnetic shielding and anti-static applications.

Market opportunities and European activities (selection)

Commercialisation of CNT is most advanced in the area of polymer composites. The highest immediate market potential particularly for Europe can be seen in this sector. Despite remaining technical issues and the strong market competition, for example from carbon fibre composites for mechanical reinforcement and conventional carbon black for antistatic applications CNT-based composites may open up additional potentials. However, the actual CNT-production seems to exceed the real current demand.

Meanwhile CNTs are available at a reasonable cost per unit. Prices are currently at 100€/kg today (and lower if bought in bulk rate by the ton). Prices of below 40 €/kg for multi-walled nanotubes are likely to be seen in the medium run[82].

A series of European companies are among the major CNT-producers on a large scale. In 2009 Bayer MaterialScience (DE) established a production plant with a capacity of about 200 tons per year. A production capacity of 3000 tons per year is in the target for the medium term. Arkema (FI) is to build a CNT pilot production plant with a capacity of 400 tons per year[83]. As a novelty, this plant will be the only CNT production site in the world that will use an entirely bio-sourced raw material. Future Carbon (DE) goes one step further, already offering functionalised CNT and CNT dispersions ready for further composite processing[84]. Other companies and institutes, such as Nanocyl, EMPA and Polymaterials AG are increasingly investigating industrial scale processing of functionalized CNT to provide reasonable prices for industrial end-producers[85].

By 2014 the global consumption of nanocomposites should exceed 210,000 metric tons and 1.38 billion US$ at a CAGR of 27.1%. The production amount will still be dominated by clay- and ceramic-based composites with almost 200,000 metric tons. Nanotube-based composites will contribute with much less than 15,000 tons. However, with an assumed market of about one billion US$ in 2014[86] a considerable economic relevance may be expected.

[82] Electronics.ca "Carbon Nanotube Production Dramatic Price Decrease Down to 150kg for Semi Industrial Applications" Feb. 18, 2008

[83] Chemie.de information service; "Arkema to build Carbon Nanotube pilot plant in France" Sep. 21, 2009.

[84] http://www.future-carbon.de/index.php?id=45

[85] http://www.empa.ch/plugin/template/empa/1173/*/---/l=1

[86] A. McWilliams; "Nanocomposites, Nanoparticles, Nanoclays, and Nanotubes"; BCC-Research Report, Jan. 2010

Challenges

For a more widespread success there are both technological and economic challenges remaining. For example, more homogeneous dispersions of CNTs remain an issue, which is addressed by multiple research projects. Besides, CNTs are often contaminated with catalyst residues, and have to be “unravelled” before further processing.

Further challenges are market based. Although CNT production has been dramatically expanded during recent years, commercialisation remains rather expensive for large-scale applications. Moreover, CNT-composites for mechanical enforcement have to compete with other high-tech materials such as carbon fibre composites (CFC). With respect to its antistatic properties, the competition is with carbon black. The latter requires much higher admixtures, however, is much cheaper than CNT, which lets many commercial applications stay with conventional carbon black.

Beyond technological and commercial challenges there are also EHS issues remaining for CNT-based materials. Since the very beginning of upscaled production, CNT have given rise for concerns with respect to bio-compatibility and potential toxicity. Large work programmes are underway to address these issues. Use of CNT and other nanomaterials in composites requires consideration of potential exposure during production and processing and in downstream activities such as cutting and finishing In line with the precautionary principle, appropriate occupational health and safety mechanisms should therefore be in place in order to prevent exposure. Life cycle assessments, including recycling processes, are also required to prevent long-term environmental implications.

Case 2: Nano-analytics for process control

The problem

Both nano scale research and volume fabrication of nanomaterials and nano-scale structures increasingly require appropriate analytical tools for failure analysis and process control. However, conventional optical approaches are excluded due to the diffraction limit of visible light.

The properties of nano-structures to be measured are manifold ranging from chemical composition or aggregation states via surface modifications and functionalisations up to structural or particle shapes to mention just a few[87].

[87] Werner, M., Crossley, A., Johnston, C.; "Characterisation of nano-structured materials"; in Handbook of Surface and Interface Analysis, pp 319, Rivière,J. C., Myhra, S. (Eds.), CRC Press 2010.

The nano-enabled solution

Nano-metrology provides a variety of techniques. The most prominent are microscopic approaches such as electron (EM) and scanning probe microscopy (SPM). However, even super-resolution optical methods have been developed. Other methods are based on spectroscopy and spectrometry, detecting photoelectrons (XPS/UPS), Raman scattering, molecular masses etc. However, even macroscopic analyses such as dynamic light scattering (DLS), centrifugation and such like may provide access to the nano dimension, of ensembles[88].

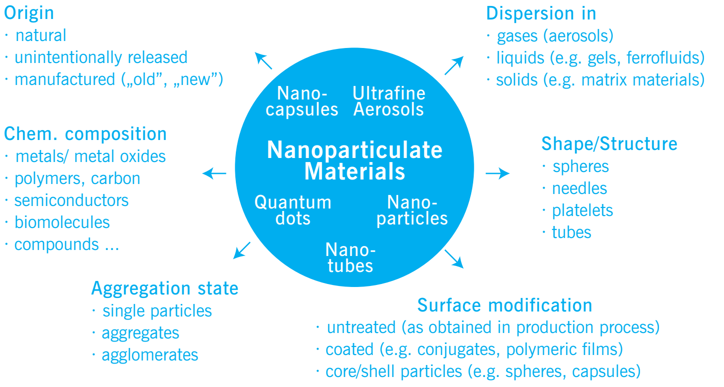


Figure 4: Parameters for the characterization of nanoparticulate materials. (Source: Werner et al.)

[88] Rivière,J. C., Myhra, S. (Eds.); "Handbook of Surface and Interface Analysis", CRC Press 2010.

The impact

Nano-analytical techniques have been continuously optimized, and further improvements as well as the development of novel approaches are ongoing. Nano-analytics is of great importance for both nano-related R&D and an upscaled industrial production, where quality and process control as well as reliable failure analyses are continuously requires

Market opportunities and European activity

Nanoanalytics play a key role for nano-scale structures. They are used in many technical areas including semiconductors, energy, environment, health, agrifood etc. The EC funded "Co-Nanomet programme" [89] identified broad application areas of particular relevance:

- microelectronics
- life sciences, bio-nano-objects
- manufactured nano-objects and nanomaterials.

Life sciences and nanomaterials have been indicated as upcoming markets. Microelectronics in contrast is established and has been the main market driver for decades. In terms of competiveness Europe is in a promising position. However, the US continues to dominate the scene especially with respect to research to market transfers.

Challenges

Concerning nano-analytical techniques there is still optimisation potential particularly for applications in material sciences. The combination of nano-analytics with suitable simulation methods for structural predictions is only partly solved and even databases for the various methods and systems have to be further improved. Furthermore, the handling of sophisticated instrumentation for non-experts remains an important issue.

[89] Leach, R.K. et al.; "Consultation on a European Strategy for Nanometrology". (http://www.euspen.eu/content/Co-nanomet%20protected%20documents/Co-Nanomet%20European%20Nanometroly%20Consultative%20Document%20For%20Circulation.pdf).

Summary

General improvements of resource efficiency are of fundamental importance and are increasingly addressed by R&D as well as industrial production chains.

Europe is not only concerned about increasing resource consumption, but also, as a leading innovation region, has excellent possibilities to take up the appropriate challenges.

Nano-enabled solutions bare a great potential to generate improvements and to contribute to higher efficiencies.

Particularly nanomaterials and nano-chemical processes are of relevance for aspects of resource efficiency. Appropriate analytical methods for research and process control are simultaneously important.

Numerous nano-enabled approaches exist or are being explored; however, a multitude of these remain in pre-market research states.

Numerous technological barriers remain to be overcome before widespread commercialisation, while other technologies are proving economically competitive.

EHS aspects play a crucial role for both economic perspectives and the wider public acceptance. They have to be appropriately addressed by research and public discussion.

A legislative frame of reliable rules and standards is prerequisite for broader commercializations.

Conclusion

As Europe attempts to overcome the previously listed Grand Challenges, nanotechnology offers various developments that may serve to address some of these critical problems. It may, for example, enable more efficient consumption of energy or an improved quality of life to an ageing population. However it is important to remember that nanotechnology does not offer a cure-all that addresses all of the problems of Europe. Nor will developments and offerings that address the Grand Challenges simply appear. Rather, efforts need to be made to ensure these nano-solutions make it to the European citizen.

This report examined the Grand Challenges, the solutions that nanotechnology offers through particular developments. However, it is also important to understand what motivates companies to create such developments. Will EU funding of nanotechnology in general spur such nanotechnology developments to be created or must funding be focussed more on finding solutions to a particular Grand Challenge? Understanding companies' motivation behind creating a particular nanotechnology development is worth researching.

As it has been noted in this paper, companies do not always publicize their research in nanotechnology. In fact, depending on the industry, some companies are fearful of making it known. This factor not only may skew numbers such as the true count of nanotechnology companies, but it can also play an impact in driving (or discouraging) future nanotechnology research. If a company feels nanotechnology research will be punished rather than lauded, it will be more hesitant to pursue such developments. This is just one of many barriers a nanotechnology company may face. While barriers to commercial success have been identified, further investigation could be made to better understand the possible solutions to overcome such barriers.

The report also examined countries' publication/patent ratios. Although this information provides insight into how prolific a country's nanotechnology community is, it does not shed light on the exploitation of these patents. While some countries may make many efforts to fund and support a company's nanotechnology patenting efforts, it could be all in vain if the products behind these patents are never produced. Knowing the degree of successful exploitation of patents is another subject that could be further examined.

While the State of Nanotechnology report has covered many topics ranging from company patent and publication numbers to the barriers they face, it also raises many new questions. While further research may be necessary to better understand the European nanotechnology landscape, this report provides a first analysis of how nanotechnology can address Europe's Grand Challenges.

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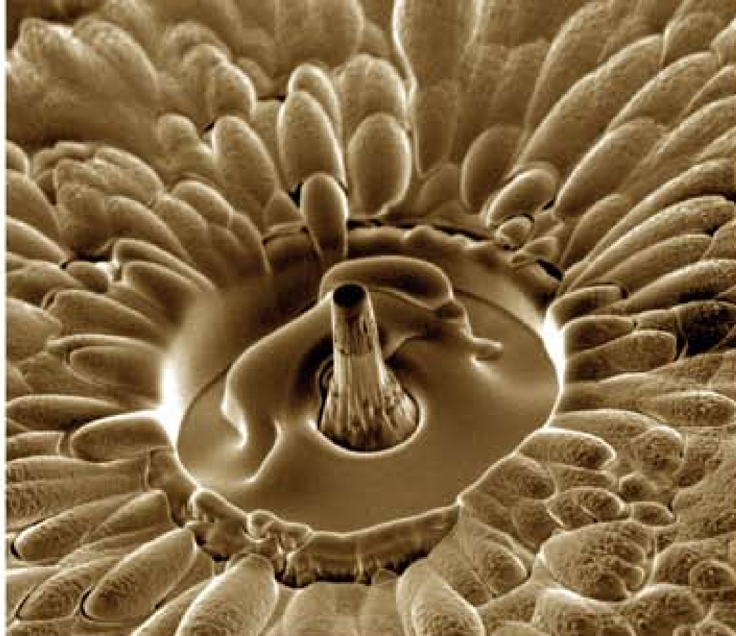
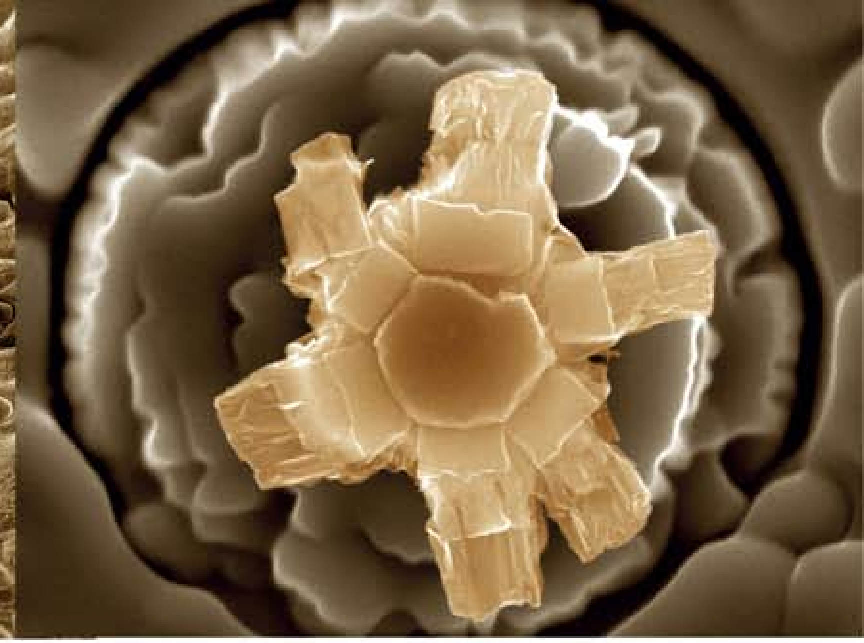
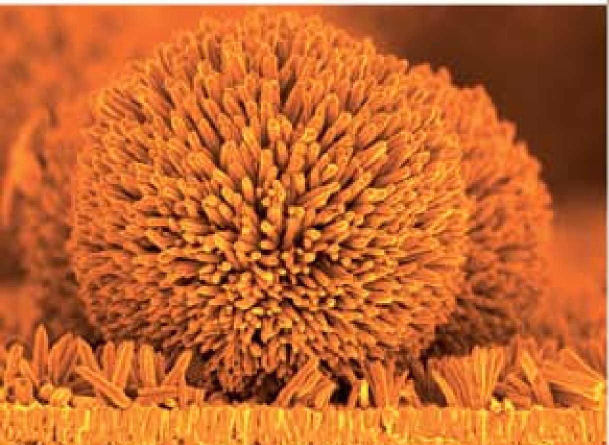
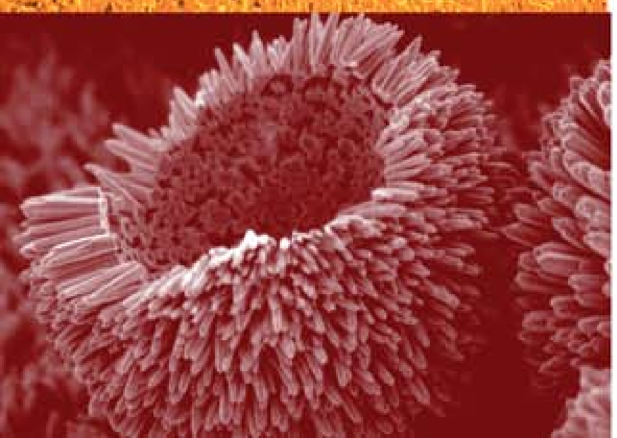
SEVENTH FRAMEWORK
PROGRAMME









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